Supported by

Ministry of Electronics & Information Technology
Government of India

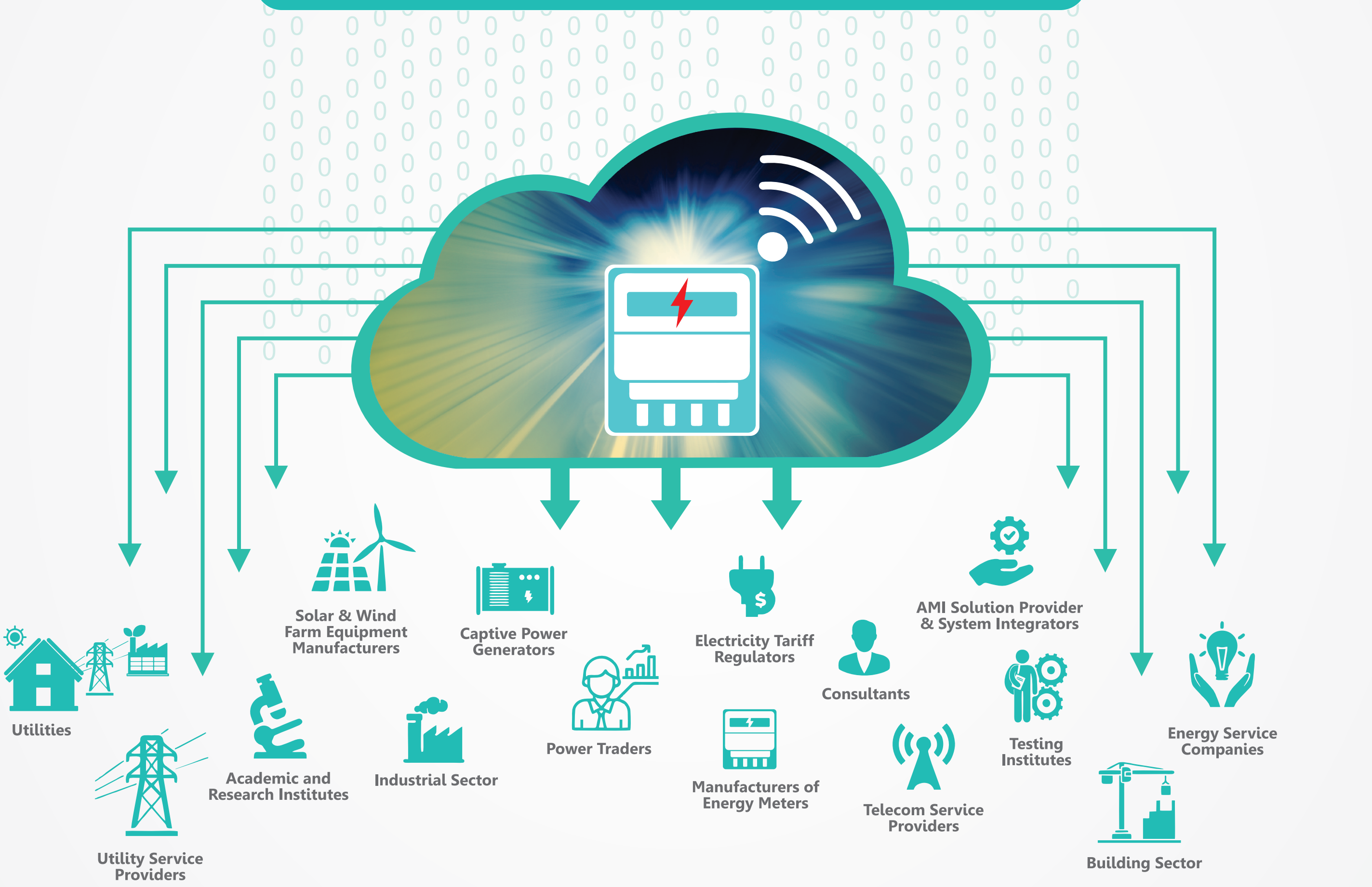
Ministry of Power
Government of India

ieema
your link to electricity

10th Edition

METERING INDIA 2024

21 - 22 November, 2024 | New Delhi



Sustainable & Consumer Centric Utilities Towards NetZero

TECHNICAL PAPERS

Visit: meteringindia.ieema.org

PRINCIPAL SPONSORS

AEW Connecting Future | IoT | AVON | BENTEC

Capital® A Step Ahead | EEPL Eppeltone® | Genus energizing lives | HPL

iskraemeco BY ELSEWEDY ELECTRIC | Kimbāl® Efficient Energy Everywhere | Schneider Electric

SECURE | 30 YEARS MARCHING AHEAD VISIONTEK

ASSOCIATE SPONSORS

AVNET® NXP | RENESAS

SM Innovative Edge | Wirepas

KIT SPONSORS

CYANCONNODE Delivering IoT Excellence | Oakter A CONSUMER BRAND BY RIOT LABZ REAL INTERNET OF THINGS | ZERA

INDEX

PAPER TITLE/ AUTHOR/ ORGANIZATION	PAGE NO.
TECHNICAL SESSION-I: NAVIGATING THE SMART METERING LANDSCAPE: CHALLENGES, INNOVATIONS AND CONSUMER EMPOWERMENT	
Challenges faced during Smart Meter Deployment in Tata Power Mumbai Devanjan Dey | Ruman Maknojia | Rahul Ranadive | Himali Patel Tata Power, Mumbai	4
Overcoming Prepay Phobia to Become Consumer-Centric Utilities While Empowering Consumers Lokesh Devpura | Bhavik Talesra Secure Meters Ltd.	10
Advanced Metering Infrastructure Deployment Challenges Aashish Gaur Genus Power Infrastructures Limited	20
Performance Evaluation and Testing Analysis of Advanced Metering Infrastructure (AMI) System Dinesh J | Shailesh Kapoor | Shivendra Kumar Sinha | Pradish M | Shivakumar V | Amit Jain Central Power Research Institute	27
TECHNICAL SESSION-II: METER DATA: THE FUEL FOR INNOVATION IN DISCOMS	
Smart Metering - A Powerful tool to Enrich Consumer's Experience Rajesh Bansal Consultant	39
Network Optimization, Capex Planning and Demand Response: Use Cases for Meter Data Ashweni Kumar Jain | Niranjan Parkhi Adani Electricity Mumbai Limited	44
Metering Applications Beyond Billing Amit Kumar Sharma | Nikhil Naik Kimbal Technologies	50
Smart Meter Data Analytics: A Case Study from Utility Perspective in MP East DISCOM Dr. Vivek Chandra | Shreyash Shrivastava MP East DISCOM | Esyasoft Technologies	58
Leveraging Meter Data for Consumers and Utilities Vineeth Shetty | Devanjan Dey | Ruman Maknojia | Ajit More Tata Power Mumbai	66

INDEX

PAPER TITLE/ AUTHOR/ ORGANIZATION | PAGE NO.

TECHNICAL SESSION-III: METERING: BEYOND TARIFF METERING

Smart Metering Data Solutions for New Uses Integration 75

Sébastien BRUN
EDF International Networks, France

A Sustainable Electricity Distribution Model for Rural Consumers in India: Synergizing Blockchain Using Smart Meter 80

Aurabind Pal | Raman Garg
REC Ltd.

Solar Energy Disaggregation using Net-Meter Consumption Signals 86

Nisha Agarwal | A K Mayank | Basant Kumar Pandey
Bidgely Technologies Pvt. Ltd.

TECHNICAL SESSION-IV: STRATEGIC APPROACHES FOR EFFICIENT UTILITY OPERATION

Feeder Metering: Why Smart Meters 93

Shreya Shandilya | Dr. Vivek Chandra
MP East Discom

Tariff Regulation and Standards poses Challenges to DISCOMs. 101

Manish Goel | Anil Kumar
Tata Power DDL

Next-Gen Transmission Planning: Integrating Smart Meters in System Studies 106

Sanika Zope
Govt. College of Engineering, Aurangabad

Discrete Approach Over the Power Quality Parameters Monitored by a Utility 114

Dr. Manish Wath
MSEDCL

TECHNICAL SESSION-V: CYBERSECURE DIGITAL TRANSFORMATION OF DISCOMS

Future Strategies for Utilities in the Net-Zero Era 125

Sandeep Beniwal
Genus Power Infrastructures Ltd

Comprehensive Security Framework for AMI Systems: Addressing Regulatory and Compliance Challenges 138

Dr Sumedha Ganjoo | Ankesh Kumar
Secure Meters Ltd.

INDEX

PAPER TITLE/ AUTHOR/ ORGANIZATION	PAGE NO.
Quality Assurance and Testing of Cyber Security Requirementsfor an Advanced Metering Infrastructure Florian Becker | Marcel Schönknecht ZERA GmbH, Germany	150
Architecture & Systems Approach Imperatives for Sustainable Digital Transformation of DISCOMs Mr. N Kishor Narang Narnix Technologies	159
ADDITIONAL PAPERS	
Indigenous Implementation of Advanced Metering Infrastructure Neethu K V | Jiju K | Indhu T | Arun Gopi | Aby Joseph | Davidson C | Sherin John | Mahesh T CDAC, Kerala State Electricity Board Ltd	168
Impact Of Blockchain Technology in Power Sector Value Chain in India Aftab Alam Damodar Valley Corporation	177
User-Centric Load Scheduling for Planning and Execution of Demand Side Management Nisha Agarwal | Basant Pandey Bidgely Technologies	188
Dashboard For Monitoring the Distribution Transformer's Operational Parameters and Utilization Based on AMR Data Veeramuruganandan Paramasivan | Ruman Maknojia Tata Power Co. Ltd.	195
Monitoring The Electric Vehicle Charging and Their Interactions with Solar Energy in Distribution Network Veeramuruganandan Paramasivan | Sujata Guruji Tata Power Co. Ltd.	201
Enhancing Utility Operations and Consumer Experience with Smart Meter Priyanshu Praliya | Mukesh Patel | Ankur Sangwan | Sovik Sharma | Ankit Kumar Tata Power Delhi Distribution Limited	208

INDEX

PAPER TITLE/ AUTHOR/ ORGANIZATION	PAGE NO.
Sustainable And Consumer-Centric Utilities Toward Net Zero: AMI- Empowering Stakeholders Ashish Mundra | Pratiksha Kulkarni Adani Energy Solutions Limited	215
Leveraging Meter Data: For Consumers and Utilities Sonali Gopal Umbre | Manish Thool | Pallikuth Devanand | Gole Milind | Biswas Trusha | Veer Dipak | Rane Vismay Tata Power, Trombay Thermal Power Station	222
Emerging Use Cases in Smart Metering - Discoms' Perspective Saurav Chandel | Subhadip Raychaudhuri | Balagurunathan Tata Power DDL	227
Use Of Smart Energy Meter In Mitigation Of Electrical Accidents And Fire – A Futuristic Approach Dr. Rajesh Arora Delhi Transco Ltd	232

ABOUT IEEMA

Indian Electrical & Electronics Manufacturers' Association (IEEMA) is the apex association of manufacturers of electrical, industrial electronics and allied equipment in India. Founded in 1948, IEEMA has a pan India presence with its corporate office in New Delhi, registered office in Mumbai and regional offices in Kolkata and Bangalore. IEEMA has its State presence in Lucknow, Chandigarh, Jaipur, Srinagar, Guwahati, Raipur, Bhubaneswar, Gujarat and Hyderabad.

IEEMA has a membership base of over 1,000 representing a combined turnover of more than $70 Billion exporting over USD 12 Billion. The members encompass a complete value chain in power generation, transmission and distribution equipment that ranges from public sector enterprises, multinational companies to small, medium and large companies. The industry provides direct and indirect employment to over 2.2 million persons

IEEMA is the trusted voice of the Indian electrical industry and plays a crucial policy advocacy role with the government and its agencies. IEEMA is an integral part of India's energy transition and working closely with policy makers for achieving clean energy goals and net-zero targets. IEEMA promotes initiatives like Atma Nirbhar Bharat, R&D and Innovation expanding global footprints and contributing to grid stability. IEEMA facilitates a robust two-way interaction and valuable exchange between the government and the industry. It sensitises all stakeholders on the future requirements for the development of the power sector in the country. IEEMA also engages proactively in government-industry consultations through its representation on councils and committees constituted by the government and its agencies in policy, strategic and other matters.

IEEMA provides a platform for knowledge sharing, adoption of best practices and networking opportunities for manufacturers, utilities, professionals, international experts and organisations. It organises technical product-specific international seminars, national conferences and workshops. IEEMA works closely with government agencies, utilities, standardisation bodies, research & development organisations and testing institutes to formulate Indian standards for the electro-technical industry and developing energy-efficient products.

IEEMA engages with the startup community through its Electraverse platform, a unique initiative that enables startups in the energy domain to integrate with the core industry. This also enables the startups to strategic funding and future growth opportunities through pilot projects.

IEEMA has been compiling and disseminating detailed statistics of production data for more than three decades which is used extensively by industry and others. IEEMA also evolves and operates equitable and uniform Price Variation Clause (PVC) by circulating applicable monthly raw material prices and indices. Due to its unbiased and systematic approach, IEEMA PVCs have gained recognition and credibility over the last three decades and are a crucial part of almost all tenders of utilities, public sector enterprises and major private players, including projects funded by multilateral development agencies.

IEEMA produces well-researched publications and reports, including the IEEMA Journal - the leading electrical and electronics monthly in the country. IEEMA holds product special conferences and seminars across switchgear, transformers, conductors, etc. IEEMA also conduct world-class exhibitions like ELECRAMA, DistribuELEC, BuildELEC and E3.

ABOUT METERING INDIA

The 10th edition of Metering India organized by the Energy Meter Division brings together experts for discussions on the latest advancements in energy metering. It's a symposium to share knowledge, network, and develop business for a sustainable energy future. This biennial event, organized in collaboration with metering companies and various stakeholders in the electrical ecosystem, for knowledge sharing, networking, and business development. Metering India has a two-decade track record of transforming the Indian energy landscape. Leading experts convene at Metering India to tackle industry challenges and explore new technologies for a more efficient and reliable power grid. Since 2004, more than 4000 delegates representing diversified fraternity of power sector have participated in "Metering India" seminars. Join us for a dynamic exploration of the latest advancements in energy metering.

Empowered by evolving communication technologies, metering has transitioned from its conventional role, to unleashing benefits, from granular analytics and dynamic pricing to demand response, load curtailment, and enhanced revenue protection and upcoming use cases in electricity distribution. This unlocks a spectrum of data-driven revolution positions metering as a cornerstone of a smarter, more sustainable energy future empowering consumers and stakeholders to better manage the transitioning energy needs.

The "Metering India" conference, once focused on traditional themes like revenue management and IT, undergoes a bold transformation. Artificial Intelligence (AI) and Machine Learning (ML) are now center stage, rewriting the script for the energy sector. Smart devices empowered by sophisticated algorithms dismantle the "business as Personalized consumer insights" empower individuals with actionable advice to reduce their carbon footprint. This is just a glimpse of the imaginative potential. Predictive maintenance, cybersecurity fortification, and grid optimization – all stand to benefit from the power of AI and ML

This "Metering India" conference signifies a pivotal moment, by embracing the transformative potential of intelligent systems, where we can create a brighter, efficient, and equitable energy future.

FROM THE DESK OF CHAIRMAN

The metering industry is a crucial component of the energy sector, responsible for accurately measuring and recording the consumption of electricity. With advancements in technology, the industry has evolved significantly, particularly with the advent of smart meters.

The convergence of metering and advanced communication technologies is fueling a data-driven revolution in the energy sector. By harnessing the power of granular data, utilities can implement innovative solutions like demand response and distribution system planning, leading to improved grid efficiency, enhanced revenue protection, and a more sustainable energy landscape.

The objective of the 9th Edition, with the Theme: “Resilient Utilities & Empowered Consumers” of Metering India was to showcase the contribution of Domestic Meter Industry in the transformation of Indian Utilities, establishing Industry as an example of Make in India and emphasizing the readiness of Industry.

Celebrating 10th Editon of Metering India, with the Theme of “Sustainable and Consumer Centric Utilities towards NetZero”, will focus on power of Smart Metering Technology to empower consumers; enhance customer satisfaction and making Utilities sustainable to complement India’s journey towards NetZero. The session comprises of 4 High Level Panel Discussions and 5 Technical Sessions related to Advanced Metering Infrastructure, Sustainable Utilities, Empowering Consumers, smart meter roll outs and challenges, Innovation in Metering and Communication Technology etc.

The industry has risen to the MAKE IN INDIA initiative and is also focusing on exports to the developed world. The future of the metering industry is bright, and the industry is committed to driving innovation, collaboration and progress in the utilities and helping them stay ahead of the curve.

As the world transitions towards a more sustainable and digital future, smart meters will play a pivotal role in shaping the energy landscape. By providing accurate, timely, and actionable data, smart meters are empowering consumers and utilities to make informed decisions and drive energy efficiency.

Warm regards,

Jaideep Mukerjee

Organizing Committee - Metering India 2024

Mr. Jaideep Mukerjee (Secure Meters) Chairman, IEEMA Energy Meter Division	**Mr. Sundeep Tandon** (HPL India) Vice - Chairman, IEEMA Energy Meter Division
Mr. Akeel Khan (Genus Power Infra. Ltd.) Convener	**Mr. Amarjeet Panesar** (Schneider Electric) Co-Convener

S. NO.	MEMBERS	ORGANISATION
1	Mr. Manpreet Singh Johar	Bentec India Limited
2	Mr. Rishi Pratap Goyal	BRPL
3	Mr. Suresh Kumar Pandit	Capital Power
4	Mr. Vipin Kumar Mishra	Capital Power
5	Mr. Vivek Goel	Central Electricity Authority
6	Ms. Mridula Jain	CPRI
7	Mr. Pankaj Chawla	ERDA
8	Mr. Manish C Swamie	HPL India
9	Mr. Ankur Mathur	Iskraemeco India Pvt. Ltd.
10	Mr. Ivyjit Singh	Kimbal Technologies
11	Mr. N Kishor Narang	Narnix Technolabs Pvt. Ltd.
12	Mr. Kamalpreet Wadhawan	PFC
13	Mr. Raman Garg	REC
14	Mr. Amit Kumar	Schneider Electric
15	Mr. Abhinav	Secure Meters
16	Mr. Manoj Kumar Tripathi	EGSM
17	Mr. Anil Kumar Sharma	Tata Power - DDL

ORGANISING SECRETARY

UTTAM KUMAR
M: +91 97175 18502 | E: uttam.kumar@ieema.org

TECHNICAL SESSION I

NAVIGATING THE SMART METERING LANDSCAPE: CHALLENGES, INNOVATIONS AND CONSUMER EMPOWERMENT

CHALLENGES FACED DURING SMART METER DEPLOYMENT IN TATA POWER MUMBAI

Devanjan Dey | Ruman Maknojia | Rahul Ranadive | Himali Patel
Tata Power, Mumbai

ABSTRACT

Tata Power Co Ltd has license to distribute power in the island city of Mumbai and its suburbs. Tata Power Mumbai Distribution is supplying power to 7.63 lakh consumers spread across 485 sq km area. We have rolled out deployment of smart meters in March 2021 and till date we have installed more than 1.25 lakh smart meters with a communication success rate of 97%. We have planned to cover entire consumer base under smart metering within next two years. Always known as a pioneer in deploying cutting edge technologies, Tata Power is the first utility to introduce smart meters to financial capital of India. Our journey of smart metering is filled with many challenges faced during rollout of this prestigious project. Major challenges start with selection of proper communication technology which may vary as per requirement of utility, density of consumer base and availability of communication media. Once, communication technology is finalized, next challenge faced is selection of proper vendor and timely delivery of smart meters. Convincing consumers to replace existing meters with smart meters also is a challenge which needs to be tackled very carefully. Considering the space crunch in Mumbai; next challenge we faced is the availability of space to install these smart meters, as they are significantly larger in size as compared to existing electronic meters. As accurate metering system is vital for a utility, having the necessary testing facilities for smart meter is crucial. We also encountered challenges in testing all features of smart meters using the existing conventional Meter Test Benches at our Meter Testing Laboratory. This technical paper will provide a glimpse of all the challenges faced during the journey and the way we handled those challenges to reach our destination of a successful rollout.

CHALLENGES FACED AND HOW WE ADDRESSED THEM

1. Selection of suitable communication technology:

The choice of communication technology for smart metering plays a crucial role in ensuring reliable and secure data transmission. Some of the communication technologies commonly used in smart metering:

A. Power Line Communication (PLC):

- PLC technology allows smart meters to transmit data over existing power lines, eliminating the need for additional communication infrastructure.
- It is a cost-effective solution and provides reliable communication.
- However, its performance is affected by electrical noise and distance from the sub-station and quality of electrical network.

B. Radio Frequency (RF) Mesh Networks:

- RF mesh networks enable smart meters to communicate wirelessly within a mesh topology.
- These networks are self-healing, meaning if one node fails, the network can reroute data through other nodes.
- RF mesh networks are suitable for dense urban areas where wired connections are challenging.

C. Cellular Networks:

- Cellular technologies 4G and NB-IoT, are gaining popularity in smart metering.
- Advantages include reduced implementation times, lower installation costs, and less complex infrastructure.
- Cellular networks are part of the broader Internet of Things (IoT) spectrum and offer reliable connectivity for smart meters.

In practice, many utilities design systems that combine multiple communication technologies to achieve their goals. The choice depends on factors like cost, reliability, and the specific environment where the meters are deployed. Ultimately, a secure and flexible two-way communication infrastructure is essential for smart metering success.

In our case, we have prior experience of implementing AMR systems on GPRS as well as LPR technology. We have implemented our first AMR system for HT consumers and Distribution Transformers using 2G communication technology in 2012 which was upgraded to 4G later on. We have also implemented LPR based AMR system for 15000 residential consumers in 2014. Both these systems are in service till date. We have also carried out pilot projects to evaluate PLC based communication systems for remote meter reading. After comparing experience gained for above mentioned three different types of communication technologies, we finalized 4G with fallback on 2G to rollout our smart metering infrastructure. We found this better than other technologies due to following advantages:

a. Less capital expenditure.

b. Good network coverage in Mumbai.

c. Option of having multiple network service providers.

d. No need to creating a dedicated team for maintenance of communication network system.

2. Ensure timely delivery of smart meters:

Next major challenge was ensuring timely delivery of meters. This project was started in 2020, when entire nation was just started to fight its way back from COVID-19 outbreak. Many parts of the country were still under partial lockdown. Meter manufacturing industry was struggling to provide timely delivery of meters due to non-availability of semiconductors and other electronic components. To overcome this difficulty, we discussed the scenario with many reputed meter manufacturing companies, jointly finalized our implementation plan and made long term contract for meter procurement. We chalked out smart meter installation plan for entire year and placed purchase order accordingly in advance for meter procurement. This helped us a lot to ensure our supply chain for meters.

3. Creating facility for smart meter testing:

Next major task at hands was to create a facility for testing smart meters. Although we already had a fully automatic laboratory for meter testing, it was not equipped to test smart metering features such as relay connect/disconnect, remote communication and automation in communication for relay testing. Since our existing laboratory was fully functional, we decided not to create an additional facility solely for testing smart meters. Hence, we upgraded our existing laboratory through hardware and software modifications to accommodate new functionalities for Testing Smart Meters as per IS requirements. We created individual communication ports to each meter test position with test bench wiring modification, procured a suitable PC capable of handling 48 communication ports and developed Mass Connect/Disconnect software for Relay testing. After relay testing, the relay test status is also shown in the final Meter Test Report.

Additionally, we extended our NABL scope to include Smart Meter Testing as per IS 16444 requirements at our NABL Accredited Meter Testing & Calibration Laboratory.

Fig- Smart Meter testing laboratory

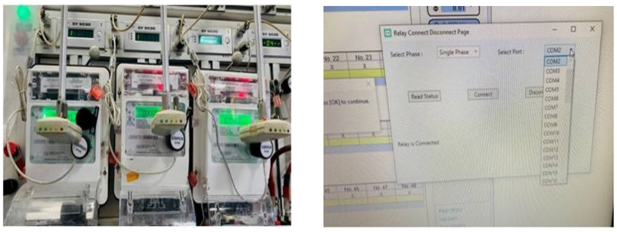


Fig- Hardware & Software modification

4. Convincing consumers for meter replacement:

Once, meter delivery is ensured, next big challenge in hand was to convince consumers for meter replacement. Since electricity meters are considered as cash boxes, consumers were initially hesitated to change their existing meters by smart meters. They were under impression that their electricity bill may significantly increase due to installation of smart meters. Moreover, getting permission from housing societies became even more difficult due to COVID related restrictions. To overcome the mental barrier of consumers, we started arranging consumer awareness sessions in housing societies, where we have explained the benefits associated with smart meters. We also assured them we are not going to charge extra money from consumers for meter replacement and neither there is a chance of increased billing due to smart meters. To overcome the COVID related restrictions, we got all our technicians RTPCR testing conducted on a routine basis. After taking these steps, slowly consumers started to come forward and shown interest in getting their old meters replaced by smart meters. Our consumer app "Know Your Electricity Consumption (KYEC)" started gaining popularity among consumers. Through this app smart meter consumers were getting real-time electricity consumption information and various consumption charts and useful alerts pertaining to their own electricity usage. This initiative made our smart meter project popular among consumers and thus we started gaining their confidence in smart meter rollout project.

Fig- Smart Meter installation ensuring COVID protocols

5. Solving the issue of space crunch:

During the initial days, smart meters were significantly larger in size as compared to conventional non-smart meters. The size difference was so much so that a single phase smart meter used to look as big as a three phase non-smart meter. Now, Mumbai is a city which has grown vertically because of limited space availability. Here, the space available in meter rooms were very limited. Hence, to accommodate bigger size smart meters in these meter rooms were next to impossible. We observed that the size difference is very huge in case of single phase meters. For three phase meters, the size difference is comparatively less. Hence, strategically we decided to start replacement of three phase meters in phase-1 and simultaneously started discussions with multiple meter manufacturers and gave them inputs to manufacture smaller size single phase smart meters. It took our effort of more than one year of regular meeting and follow ups with meter manufacturers to ultimately getting single phase smart meters launched in market which were of smaller size. Till that time, we concentrated on installing majorly three phase smart meters. In few meter rooms, even installation of three phase smart meters was also a challenge. In these cases, we had to change meter board wiring to create additional space for meter installation. We made necessary changes in our meter specifications and included maximum permissible meter dimensions a mandatory parameter of meter specification. Finally, in 2023, we got delivery of 1st batch of smaller size single phase smart meters which could be accommodated in meter rooms.

Fig- Size difference between old and new Smart Meter

6. Issues pertaining to poor signal strength:

At the beginning of the project, we carried out a detailed survey, covering almost all consumer premises to find out better Network Signal Provider & we observed that M/s Vodafone has got a better coverage in Mumbai. However, there are few blind spots within many societies where signal strength is very poor or next to nothing. For example, few of our meter rooms are in basements, where there is no mobile signal at all. We roped in our Network Service Providers (NSP) to resolve this issue. After continuous follow up with NSP, we got signal boosters installed in such locations to enhance signal strength. In some housing societies, we had to meticulously follow up with society representatives and convince them to get permissions for installation of signal boosters in their premises. We have also introduced alternate NSP to improve communication success rate. We also discussed with meter manufacturers to make a provision for connecting external antennae to smart meters, so that same can be extended and placed in a location where signal strength is good. We are now exploring the possibility of deployment of dual SIM smart meters.

CONCLUSION

This project is the first smart metering implementation project in entire Maharashtra. So, the challenges were new to us and solutions were custom made. Moreover, the project was initiated during the COVID times. Despite of all these challenges, we could successfully implement this smart metering infrastructure which has not only benefitted the utility but also our consumers. We have already given many first of its kind services to our esteemed consumers through this smart metering system. Going ahead, we have planned to cover our entire consumer base under smart metering in couple of years.

ieema
your link to electricity

BIO-DATA

DEVANJAN DEY
Tata Power, Mumbai

Date of Birth: 06.02.1977

Qualification: B.E. (Electrical)

Designation: Group Head, Meter Management Group

Present Organization: Tata Power Co. Ltd.

Field of Expertise: Energy Metering

Mobile: +91 92233 36026

Email: devanjan@tatapower.com

BRIEF PROFILE

Graduate in Electrical Engineering from Sardar Patel University, Gujarat. More than twenty years of utility experience in the field of metering. Implemented GPRS, RF and RS485 based AMR systems. Rolled out Smart Metering system for more than 1.25 lakh consumers. Implemented ABT metering systems and energy auditing systems.

HIMALI PATEL
Tata Power, Mumbai

Date of Birth: 19.09.1987

Qualification: B.E. (Electrical)

Designation: Specialist – Meter Testing Lab

Present Organization: Tata Power Co. Ltd.

Field of Expertise: Energy Metering & Meter Testing

Mobile: +91 80970 07910

Email: himali.patel@tatapower.com

BRIEF PROFILE

Graduate in Electrical Engineering from Sardar Patel University, Gujarat. More than fifteen years of utility experience in the field of Metering system, Meter testing, Operation of Meter Test Bench, NABL expertise for Testing & Calibration Lab. Working as Technical Manager at NABL Lab. Having expertise in various metering IS Standards, NABL guidelines, etc. Internal auditor for ISO 17025 & IMS (ISO 9001, ISO 14001, ISO 45001).

BIO-DATA

RAHUL RAMESH RANADIVE
Tata Power, Mumbai

Date of Birth: 04.01.1973

Qualification: B.Tech. (Power Engg), Diploma in Electrical Engg

Designation: Group Head, Meter Testing Laboratory

Present Organization: Tata Power Co. Ltd.

Field of Expertise: Power Distribution

Mobile: +91 72084 08611

Email: rahul.ranadive@tatapower.com

BRIEF PROFILE

Graduate in Power Engineering from BITS Pilani University, More than thirty years of utility experience in the field of Distribution of Power. Worked in various Power utilities like B.E.S.T, Torrent Power and currently working with Tata Power. Actively involved in installation & commissioning of 11KV/ 0.415V consumer sub stations and 33KV /11KV Distribution Sub stations. Handled critical load situations under O&M and worked in all depts. Of Power utility. Currently heading Meter Testing laboratory

RUMAN MAKNOJIA
Tata Power, Mumbai

Date of Birth: 28-07-1978

Qualification: Diploma in Electronics

Designation: Group Head - AMR & Complaint Analysis

Present Organization: Tata Power Co. Ltd.

Field of Expertise: Energy Metering and AMR/AMI Technologies

Mobile: +91 92235 89446

Email: ruman.maknojia@tatapower.com

BRIEF PROFILE

More than 20 years of combined experience in the field of meter manufacturing industry and distribution utility. Headed many projects like meter installation, implementation of smart metering systems, implementation of workflow system for metering.

OVERCOMING PREPAYPHOBIA TO BECOME CONSUMER-CENTRIC UTILITIES WHILE EMPOWERING CONSUMERS

Lokesh Devpura | Bhavik Talesra
Secure Meters Ltd

ABSTRACT

"Ye nahi chalega" was a common statement used by almost every utility when prepayment, along with smart meters, first came into play. Once the industry and utilities learned about its benefits, this quickly changed to *"Ye hi chalega,"* and we witnessed the same in NBPDCL (North Bihar Power Distribution Company Limited) utility. This paper explores the same transformative impact and benefits of the prepayment approach in smart metering systems, helping utility to achieve its sustainable goals while empowering consumers. It highlights the challenges and solutions associated with successfully implementing prepayment systems, focusing on addressing concerns among utilities and consumers and benefits delivery to key stakeholders. It emphasises the role of resilient infrastructure in achieving sustainability goals and outlines effective implementation methodologies while taking an example of utilities like Bihar discom.

By focusing on technological advancements, consumer engagement programs and operational efficiencies, we can leverage what we have learned from NBPDCL utility to create a consumer-friendly ecosystem. The paper also highlights how the prepayment system is convenient for consumers, beneficial for utilities, and sustainable for all the relevant stakeholders. Also, it evaluates the crucial role of smart prepay metering in shaping a sustainable energy future while meeting the needs of every contributor in the power sector.

INTRODUCTION

In India, we are in the midst of a rapid transformation driven by the Ministry of Power for the nationwide adoption of smart prepaid metering solutions, technological advancements, and the evolution of consumers into prosumers. A significant capital investment of approximately ₹1.5 lakh crore is necessary to deploy smart metering systems at that level. The transformation aims to improve service delivery to end consumers and the financial viability of utilities. Although sectors like mobile services and online shopping platforms have successfully transitioned to prepayment and are performing extremely well, there are strong apprehensions from stakeholders when it comes to prepayment in electricity meters. It is crucial to address these concerns about adopting smart meters, with immediate action needed to understand and alleviate this resistance.

Given this substantial investment and its transformative impact on customer experiences, the AMISP (Advanced Metering Infrastructure Service Providers) program must be executed efficiently and monitored rigorously. This will help safeguard investments, ensure seamless consumer experiences, and support future use cases.

To achieve successful roll-outs and to make utilities sustainable and consumer-centric like NBPDCL, it is essential to gather and analyse industry insights on critical success factors, including:

- Ensuring revenue realisation,
- Building trust among all stakeholders,
- Establishing an integrated, adaptable and flexible end-to-end system
- Creating a conducive ecosystem for utilities, consumers and AMISP players,
- Establishing more payment channels for a seamless experience

- Benchmarking service delivery standards

- By evaluating these metrics or similar indicators, industry stakeholders and regulators can identify areas for improvement, integrate best practices, and mitigate the risk of widespread implementation challenges. This will ensure the long-term success of smart prepayment initiatives and help utilities become valuable contributors to the growth of the Indian economy.

APPREHENSIONS OF UTILITY OFFICIALS ON SMART PREPAY METERS:

- Return on Investment (ROI): *"Bahut mahanga system hai, kaise paar padega?"* We have heard it many times. It is now time to ROI, so utilities can find out cash inflows and outflows on their own. They can even calculate the return or payback period on their investment. Now, look at the data of Bihar, as per CM Nitish Kumar, both DISCOMs, NBPDCL and SBPDCL made a profit of ₹215 Crore after a gap of 58 years. For the first time ever, tariff rates have been lowered in Bihar, relieving consumers. So it is critical to evaluate the return on investment in a smart metering program and identify how effectively we can implement this system to enhance consumer convenience and to make the utility self-sustainable.

- **Technological infrastructure:** There are concerns about the readiness and reliability of the technological infrastructure needed to support smart prepay meters. It is required to deploy the end-to-end system to collect huge amounts of data and process effectively to generate an effective dashboard for utilities. We have witnessed the same in NBPDCL, where multiple activities like consumer generation, meter installation, collecting multiple parameters from meters, payment collection, rectification of complaints, user interactive dashboards and utility monitoring system are being handled by our end-to-end system. Utilities require such robust systems for real-time data collection, payment processing and consumer engagement, which may necessitate significant investments and upgrades.]

- **Resource reallocation threat due to operational changes:** Implementing smart prepayment meters entails operational changes for utilities, including adjustments to billing processes, customer service protocols, meter reading practices and moving elsewhere their contractual or permanent manpower or field staff, which were engaged for billing and data collection purposes. There may be a few concerns with the utility regarding its implementation and doubts about their existing manpower, but it needs to be addressed while clarifying that permanent staff of the utility can be utilised for transmission and distribution cells where they contribute to enhancing the overall system efficiency and reducing losses. In North Bihar as well, contractual staff got trained with smart metering system and installation, who were there for billing and collection purposes earlier. They were utilised to replace credit meters with smart prepay meters and address field issues related to smart metering. On-the-job training was provided and equipped them with mobile applications and different tools used in installing smart meters.

- **Data security and privacy:** Utility officials are always concerned about data security and privacy. They are vigilant about protecting against data breaches and unauthorised access to sensitive consumer information collected through smart meters. Public and utility concerns about privacy breaches should be addressed on priority while implementing strict data protection regulations, such as the DPDP (Digital Personal Data Protection) Act and robust cybersecurity protocols. Educating consumers about ease and secure payment mechanisms for recharging smart meters will increase their confidence, and further, it will benefit both consumers and utility officials. So, ensuring the implementation and upkeep of secure data transmission and storage solutions is crucial to mitigate cyber threats effectively. We are striking a balance between leveraging data-driven insights and managing the risks associated with securely handling substantial amounts of consumer data. In North Bihar, various data protection protocols and cybersecurity compliance have been implemented and PIMS (Personal Information Management System) is certified.

- **Fear of losing control:** In the AMISP model, utility officials might worry about giving up control of metering operations and customer service functions to third-party providers. It can be challenging to assess how well AMISPs deliver reliable and high-quality metering services while meeting regulatory standards. To ensure accountability and uninterrupted service, roles and responsibilities can be clearly defined, and strong service level agreements (SLAs) can be set up with AMISPs. Like in the North Bihar AMISP project, the utility has defined performance-linked SLAs for a service provider to perform in the interest of the consumer and the utility. So, it is crucial to define such SLAs and to monitor them properly to ensure value delivery to consumers and benefits delivery to utility.

- **Regulatory compliance:** For smart prepayment meters, standards and compliance are regularly updated to determine who is responsible for what and to speed up procedures. Officials from utilities encounter many challenges in navigating the intricate landscape of regulatory compliance, particularly in smart metering. One major challenge is ensuring compliance with strict data protection and metering regulations, which calls for solid frameworks to preserve customer security and privacy. Legal requirements for data privacy, security measures, and protecting consumer rights are some of the areas of concern. Not following the rules can lead to trouble. Utilities must measure accurately, bill transparently, and protect consumers' data. Adapting to rule changes is a challenge, but it's necessary to stay compliant while encouraging innovation and meeting the market's needs. We also implemented various checks and audits at the system level in the North Bihar project, like multi-level authentication, OTP-based login and role-based access. Also appropriate rights of systems were assigned to utility officials so that they could check what kind of security practices are being followed to protect the data.

APPREHENSIONS OF CONSUMERS ON SMART METERS IN PREPAYMENT MODE

- **Recording of higher energy by smart meters:** Over the decades, end-consumers have moved from using old energy meters to digital meters, and now, the latest trend is smart prepay meters. Many worry that these smart meters might not accurately record their energy usage, making them uneasy about trusting the technology. They are worried that the readings might fluctuate and they might overpay. Also, there is a misconception that these new meters show their real-time energy usage, which could cause arguments about the accuracy of their bills. Therefore, there is a need for clear communication, education about how the smart meter works, and better consumer protection. These actions can build trust among people. In the North Bihar project, installers are explaining the benefits of a mobile app to each consumer immediately after the smart meter is installed at their home. People over there are getting insights on mobile application usage, how they can recharge their meters and know their energy usage, which is not just helping them to adopt digital transformation but building trust towards a smart prepay metering system which is providing the data transparently and inspiring them to save energy for reducing their energy cost.

- **Abrupt disconnection at midnight:** Consumers often worry that if they run out of balance, their meters might cause a blackout at midnight. But this is not true. Utility companies do not disconnect services during non-working hours, weekends, or holidays, to ensure that people are not left without power at inconvenient times like at night. These policies should be promoted and explained among consumers to ease their concerns and build trust among people.

- **Distrust towards companies and utilities:** Consumers often worry that their meters might cause a blackout at midnight if they run out of balance. But this is not true. Utility companies do not disconnect services during non-working hours, weekends, or holidays to ensure that people are not left without power at inconvenient times like at night. These policies should be promoted and explained to consumers to ease their concerns and build trust.

- **Fear of online recharge:** Many end consumers hesitate to use smart prepay meters because they are worried about the online recharge process. They fear technical issues, complicated recharge procedures and the risk of scams or fraud. To address these worries, smart metering service providers and utilities must educate consumers. Further, it is essential to provide secure and user-friendly online recharge platforms and prioritise the protection of consumers' financial transactions and personal information. While creating awareness in North Bihar regarding the online recharge mechanism and its benefits for end consumers, utility has witnessed the record breaking collection of **₹11 Crore in a single day through online recharge**. Also there is need to establish a strong refund mechanism with payment gateways in case of recharge failure and provide transparent information to consumers about their recharge status.

4. HOW TO ADDRESS APPREHENSIONS EFFECTIVELY IN THREE STAGES:

A. Pre-installation phase:

- **Awareness campaigns:** In North Bihar, many comprehensive awareness campaigns were organised, including road shows, nukkad-nataks (street plays), broadcasts, and engagement sessions with schools, panchayats, industries, and utility and administration. We earned the significant trust of consumers and the confidence of utility officials by making them aware of the benefits, functionalities, and safety features of smart prepaid meters. These initiatives can enhance understanding and alleviate concerns. Also, when utility officials are involved in these campaigns, mutual trust and collaboration can be built, encouraging a supportive environment for adopting smart metering technologies.

Fig-1: Broadcasting benefits of smart prepay meter through auto in rural areas

- **Educating the community:** It's important to educate society about smart prepay meters. Such education can be done by broadcasting through newspapers, radio, and TV, distributing pamphlets in the local language, and conducting awareness sessions at multiple places. These awareness sessions and programmes can create a better understanding of smart meters and reduce resistance.

Fig-2: Explaining prepay benefits in school and colleges

- **Local community support:** It's crucial to raise awareness within the local community about smart prepay meters and engage them in discussions with consumers. Community officials have significant influence and can help establish communication with consumers. They can educate the public by conveying the benefits of prepayment, the recharge process, and the accessibility of services.

Fig-3: Conveying the technology and benefits in FCCI and administration

- **Service assurance:** AMIPS players can build trust while establishing communication with end consumers with the help of utility and administration. They can educate consumers and clear their misconceptions about recharge processes, prepayment mode, availability of services, meter life, replacement cost, etc. Clear communication and transparency in the system and policies can reinforce confidence in the smart metering system and technology among the relevant stakeholders.

Fig-4: Installers understanding benefits of smart prepay meter to convey it to end consumers due to door-to-door reach

B. During the installation phase:

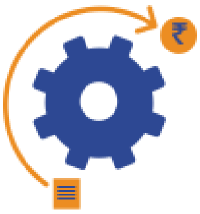
- **Simplified recharge process:** Establishing a simplified recharge process with clear and straightforward procedures can build trust among utility officials and consumers. Utility companies should ensure that the recharge process is user-friendly, with easily accessible platforms and guidance on how to top up meters. Transparent communication about the availability of recharge options and support channels can enhance consumer confidence in the reliability and convenience of smart metering systems. Additionally, educating utility officials about the simplicity and efficiency of these processes can foster internal trust and support for the technology's implementation. Like in the North Bihar project, we conveyed the simplicity of the recharge process to utility and end consumers through effective videos, documents, and door-to-door campaigns, providing them with a recharge experience by setting up the test instance.

- **Quick user guide:** During smart meter installation, it is important to minimise the challenges by ensuring that each meter comes with a guide in Hindi / regional language. This guide must offer clear instructions on how to recharge the meter, manage the account, troubleshoot common issues, etc. By providing and explaining this user-friendly guide to each consumer in North Bihar, they conveniently agreed for a smooth transition and adopt smart meters.

- **Installer-consumer interaction:** In North Bihar, Installers interact with consumers and assist them in installing the mobile app, registering on it, understanding the app and its features, recharging the meter, and locating nearby kiosks (for top-ups) for non-tech-savvy users. This personalised interaction helps the consumer understand their smart meter and its functionalities. All in all, adopting this approach for having a brief interaction will lead to a smooth adoption of smart meter technology.

- **Guest-recharge flexible options:** It is necessary to design a solution not just for the sake of availability but also to fulfil the actual needs of end consumers while keeping their issues in mind. AMISP players should design their end-to-end solution and user interactive touch points in such a way that helps utility and consumers to make their lives easy. A mobile application for North Bihar was designed in a way, where a guest recharge option is implemented in the mobile app on the home page. This guest recharge option is accessible without login, which ensures data privacy and reinforces the concept of "for the people, by the people." Anyone can make a recharge on behalf of anyone from anywhere using this feature. Consumers' concerns regarding online recharge can be addressed effectively. During the installation phase, installers are guiding consumers about the guest recharge option. While adopting this feature and such tools, other AMISP players and utilities can ensure convenience for consumers, allowing those without smartphones to request neighbours or friends to perform recharges on their behalf. It enhances accessibility and user-friendly interaction with the metering system, promoting smoother adoption and usage among all demographics.

C. Post-installation phase:



- **Transition from credit meters:** Addressing challenges during the post-installation phase of smart prepay meters involves implementing a seamless integration of systems to transition from old credit meters. This includes ensuring compatibility and interoperability between existing infrastructure and the new smart meter systems, minimising disruption and maximising efficiency in managing consumer accounts and energy usage data. Collaborative efforts were put in North Bihar along with utility for four months before actually installing smart meters in the field to ensure all the existing utility systems and new smart metering systems were in place and could handle this transition smoothly and efficiently. Effective communication and support during this transition phase are essential to ensure a smooth and successful adoption of the new technology and systems.

- **Debt payment flexibility:** For debt repayment against old due to credit meter, AMISP and utility can provide flexible payment options. They can suggest other alternative ways to reduce consumers' financial burden while encouraging them to adopt new technology. For instance, North Bihar Utility suggested having the facility of settling debts in an equal number of instalments by consumers, which was a great initiative and very useful for consumers in terms of their financial convenience. This feature was developed and implemented quickly in North Bihar. It helped consumers manage their finances by clearing their old debts while ensuring they have continuous access to energy at the same time. Because of this feature, the utility collected around 32% of the recharge amount against due debt without implementing any single resource for recovery. This fantastic approach promotes consumer satisfaction and fosters the adoption of smart meters. If AMISP players and utility work hand-in-hand while addressing the concerns of the end consumer, then solutions or ideas can be highly beneficial for all the stakeholders.

- **Billing resolution:** Both the utility and service provider agencies must launch targeted campaigns and doorstep services to address consumers' billing-related issues. With such direct interaction, they can resolve the issues swiftly, ensuring accurate billing. These campaigns are a great way to build customer satisfaction.

- **Support services:** The utility and AMISP can set up a round-the-clock call centre to handle consumers' issues promptly. Such a centre ensures that consumers have access to assistance 24x7 and can resolve concerns related to billing, meter functionality and usage queries.

- **Enable community for support:** Even after explaining the benefits multiple times through different channels, some people still resist smart prepay meters due to their own biases. This resistance can be addressed more effectively with support from the officials of local communities. These officials, who are already familiar with the services and were educated earlier during pre-installation phase, can play a valuable role in overcoming resistance and raising awareness about the benefits about the smart prepay solution.

- **Administration support:** Many times, incidents occur when people feel discomfort about their payment deductions, especially when their payment practices suddenly shift to a prepay mode. Additionally, some individuals require clarity on deductions, tariffs, and the accuracy of meters. It would be helpful if the administration communicated the benefits and provided clarity to address these misconceptions. People have faith in the administration staff and view the officials as impartial observers, which helps foster trust and build strong conviction among end consumers.

5. BENEFITS DELIVERY TO THE STAKEHOLDERS

- **Benefits to consumers:** The smart prepay meter system offers consumers the flexibility of a **pay-as-you-go** system and **eliminates bill shock** by providing real-time insight into their energy usage. With such insights and data, the system allows them to **manage their energy usage**, leading them to make informed decisions. With transparency on money that is being spent on energy, consumers enjoy **financial clarity**.

- **Benefits to utility:** The smart prepay meter system provides **long-term value** by offering a reliable method of revenue collection through **flexible and easy debt recovery**. It also enables better **load shift and shape management**, helping to distribute energy more efficiently across peak and non-peak hours. With such improved services and control, utilities can increase **consumer satisfaction**.

CONCLUSION

Overcoming prepayphobia requires a collaborative effort from utilities, regulators, industry-partners and communities to address concerns comprehensively. By adopting a phased approach and PPP (people, process and platform or technology) model that ensures consumer education, service reliability, and regulatory compliance, we can foster the acceptance of prepayment in smart metering. Embracing these enhances operational efficiencies for utilities and empowers consumers by providing transparent, reliable, and sustainable energy solutions. Achieving our sustainable goals necessitates proactive engagement and commitment to building a consumer-centric utility landscape in India.

REFRENCES

- CM Nitish Kumar said- INR 215 Cr profit to Bihar Discom
- 92.5% mobile in prepaid in India by Dec-23
- Bihar discom revenue details
- Online shopping platforms in prepay mode
- 1.5 Lakh crore needed in smart metering
- 11 Crore collected in a single day in North Bihar from online recharge

BIO-DATA

LOKESH DEVPURA
Secure Meters Ltd

Date of Birth:	11th September 1987
Qualification:	EMBA (IIM-Udaipur)- Pursuing PGDBA (Operations)-Symbiosis BE in ECE (Hons)
Designation:	Manager
Present Organization:	Secure Meters Ltd
Field of Expertise:	AMISP, Smart metering, Design and Communications
Mobile:	+91 90249 64809
Email:	lokesh.devpura@securemeters.com

BRIEF PROFILE

Energy professional with a Bachelor's degree in ECE (Honours), currently pursuing an Executive MBA from IIM, Udaipur. In my career focused on the energy sector, I have developed expertise in technical analysis and business strategy.

I have showcased my expertise in contract management and comprehensive assessments for public-private partnerships, focusing particularly on Advanced Metering Infrastructure services such as AMISP and MBC. Lately, I have been working on brand building and corporate communications.

I've led initiatives that enhance efficiency and innovation in distribution operations for major utilities such as TPDDL, BESCOM and UPPCL. I have expertise in research and development, hardware development, sales and building effective marketing and business development strategies.

As a tech enthusiast, I enjoy advising clients from various industries on adopting cutting-edge solutions that drive business growth and transformation. I am dedicated to effectively integrating technology into business practices to achieve measurable results for all the relevant stakeholders.

BIO-DATA

BHAVIK TALESRA
Secure Meters Ltd

Date of Birth:	12th November 1991
Qualification:	EMBA (IIM-Udaipur) - Pursuing BE in ECE
Designation:	Manager
Present Organization:	Secure Meters Ltd
Field of Expertise:	Product management, AMISP, Smart Metering, Consumer handling
Mobile:	+91 77376 20705
Email:	bhavik.talesra@securemeters.com

BRIEF PROFILE

Experienced energy professional with a Bachelor's degree in ECE and currently pursuing an Executive MBA from IIM, Udaipur. With over 5 years of specialisation in DCC project, UK, now currently handling AMISP and smart metering projects. I carry a deep understanding of both technical and strategic aspects of the energy sector.

My expertise extends to contract management and comprehensive assessments for public-private partnerships, with a focus on Advanced Metering Infrastructure services.

My background includes significant experience in devising effective marketing and business development strategies, handling consumers' issues and rectifying them promptly. Passionate about technology, I provide advisory services to DCC client and other utilities, helping them adopt advanced solutions to spur business growth and transformation. My commitment is to seamlessly integrate technology into business practices to deliver tangible results for all stakeholders.

ADVANCED METERING INFRASTRUCTURE DEPLOYMENT CHALLENGES

Aashish Gaur
Genus Power Infrastructure Limited

ABSTRACT

"Smart Meters Sahi Hai"

Availability of Quality of Power is basic and mandatory need of every citizen of India. Deployment of Smart metering systems will provide empowerment to End Consumers (monitor and control the usage), Provide benefits to Society (to build transparency and trust) , Build Nations (to use the resources with best capacity) and lastly help Utilities to develop processes and systems for moving the operations to next level

With this context, in July 2021, the Government of India (GoI) initiated the world's largest Advanced Metering Infrastructure (AMI) program under the Revamped Distribution Sector Scheme (RDSS) to replace 250 million electricity meters with smart prepaid meters. This program, applicable to all state-owned electricity distribution companies (Discoms), aims to modernize the power distribution sector. However, several challenges hinder the full-scale deployment of AMI systems in India, ranging from technological barriers to regulatory hurdles. This whitepaper explores the key challenges faced by AMISP in India and provides recommendations for overcoming them to ensure successful AMI deployment across the country.

INTRODUCTION

Advanced Metering Infrastructure (AMI) refers to a system that measures, collects, and analyzes energy usage data, and communicates this data between customers and utilities. AMI typically includes smart meters, communication networks, and data management systems.

An Advanced Metering Infrastructure Service Provider (AMISP) is responsible for deploying, operating, and maintaining the infrastructure necessary for the successful implementation of AMI. This includes installation of smart meters, establishment of communication networks, and integration with the utility's backend systems. AMISPs play a critical role in enabling utilities to manage energy usage more efficiently and facilitate smarter energy consumption.

Through the Revamped Distribution Sector Scheme (RDSS), the Government of India (GoI) will contribute 15% of the project cost as a grant to Discoms, which will be passed on to the AMISPs. Power Finance Corporation Ltd (PFC) and Rural Electrification Corporation Ltd (REC) are the designated nodal agencies for RDSS, managing different groups of Discoms. REC has

also issued a standard bidding document (SBD) for the appointment of AMISPs, which all DISCOMs should follow to access the grant. The AMI system must be maintained by the AMISP for approximately 93 months post-commissioning.

As of September 2024, contracts for 117 million meters have been awarded by State DISCOMs following the SBD contract terms and conditions.

The deployment proposed in AMI refers to a network of smart meters deployed in various locations such as residential and Non-Residential. These smart meters are designed to facilitate two-way communication with the HES (Head End System) and MDMS (Meter Data Management System). The HES is tasked with managing the smart meters, overseeing the communication network, and gathering data and is integrated to the Meter Data Management (MDM). The role of the MDM is to process, validate, and analyze the vast amount of data collected for various utility functions. These include billing, customer service, grid operations, and planning for demand versus supply management.

In India, smart meters are required to operate in prepaid mode and come with integrated relays that allow for remote connection and disconnection of services based on the consumer balance. At one hand, it enables Utility to control the electricity supply at end consumer premise, on the other hand, it adds complexity and places greater reliance on the communication network, making timely responses critical.

The integration of millions of hardware devices, communication networks, HES, MDM, Mobile Apps for Utility and Consumers makes AMI a complex system to implement and manage. Key challenges include achieving seamless integration, ensuring reliability, preventing obsolescence, managing ongoing maintenance, training utility staff, and educating consumers about the system.

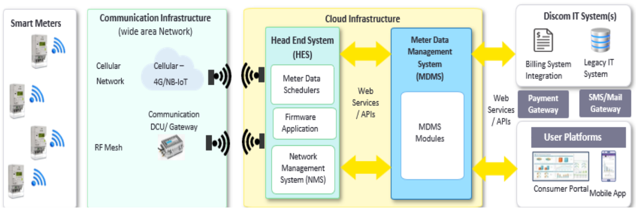


Fig. 1: Advanced Metering Infrastructure and Interfaces

Deployment Challenges & Solutions

As of 2024, only 11.5% of the target (Out of awarded contracts) has been achieved, with many AMISP and Discom facing significant challenges in deployment of AMI system. A combination of financial, technical, and policy-related issues has contributed to the slow progress. While there are success stories in few states, widespread AMI deployment remains a challenge due to India's unique socio-economic and infrastructural landscape. We can categorize key challenges as below

- SAT Process and its approvals
- New Requirements and Implementation
- Execution Challenges
- Communication Challenges
- Skill Development and Social Challenges

Let us have a detailed discussion on above key challenges.

SAT Process and its Approvals

The payment cycle for AMISP is directly connected to the successful completion of System Acceptance Tests (SAT) by the utility and strict adherence to Service Level Agreements (SLAs). However, few challenges can impact both SAT and SLA compliance:

- Frequent power outages, Disconnected, permanent disconnected, FIR registered by utility officials and many other reasons impact SLA compliance for AMISP systems. To address this, these cases need to be exempted from the AMISP scope. However, achieving this exemption requires a common understanding and approval from utilities.
- Obtaining approval for the proposed SAT from the utility is a critical challenge. The SAT must be completed according to the project's defined milestones to ensure timely progress. For AMISP, adhering to this schedule is crucial to maintaining their revenue cycle throughout the remainder of the project implementation.
- Delay in the SAT significantly increases the number of meters to be tested, creating challenges in verifying the system's ability to handle the larger volume of meters and data transactions. Ensuring the system maintains performance and stability under this increased load becomes a major challenge in such situations.
- Some test cases outlined in the SAT are particularly challenging to execute within the given timeframe due to the large volume of meters involved.
- A detailed representation of changes is proposed to MOP/REC in different forums for due updates of the processes with a pragmatic approach

New Requirements & Implementation

There are list of other issues which includes inclusion of new requirements, policy and regulatory requirements which impacts overall product and systems availability It also impacts installation progress on regular basis. And creates challenges during installation process.

Regulatory and Policy level requirements

There are requirements around common pluggable module initiative, Dual Sim/E-Sim/ Muti-profile sim in communication module, different tamper logics, display parameters requirements and its implementation, Seal requirements are posing multiple challenges around interpretation, implementation, and product changes over the period. It impacts the product and systems availability for mass production and deployments.

A set of new requirements during the execution phase, impacts multiple changes in meters firmware, software's deployment (WFM/MDMS/ HES) and field processes. It impacts the pace and maintenance of systems on a regular basis. The requirement changes are important but should be governed through change control board with due change analysis and impacts

Along with the above, implementing prepayment systems must adhere to various regulatory requirements, tariff standards, and supportive policies and incentives. In some regions, unclear or frequently changing policies can lead to frequent adjustments in the prepayment system, increasing complexity and making implementation more challenging.

Business Process Implementation

Prepayment Process is the key component of AMISP. Implementing a prepayment process in AMISP systems in India involves several challenges. Prepayment systems require users to pay for their electricity usage in advance, which necessitates integration with smart metering, billing, and data management systems. Here are some key challenges faced during the implementation of prepayment processes:

Integrating prepayment functionality with existing AMI systems, billing software, and customer management systems requires seamless coordination. Any discrepancies or integration issues can lead to errors in billing and customer accounts.

Execution Challenges:

The installation of AMI in India presents several challenges due to the unique geographic, social, infrastructural landscape, dependency of multiple stakeholders. Here are some key execution challenges specific to field installations in India:

Shut down availability for DT/Feeders:

Proper shutdowns are crucial for safely installing or upgrading metering infrastructure at the distribution transformers (DTs) or feeders. However, obtaining timely shutdowns from the Discom can be difficult. Due to the critical nature of electricity supply, many regions/area face restrictions on when and how long power can be turned off, particularly in densely populated or industrial areas.

This non-availability of proper shutdowns hampers the overall progress of system metering, leading to project delays and increased operational costs.

Lack of Feeder Information for Underground 11 KV Cables

Many feeders in India use underground 11 kV cables, and often there is a lack of proper mapping, marking, or pole painting that shows detailed feeder information. Without this information, it becomes difficult for the AMISP team to identify and map the correct feeders.

The AMISP team is then forced to rely heavily on existing Discom staff to provide accurate information. This leads to delays, errors, and dependency on Discom personnel, which can slow down the system metering process and reduce overall project efficiency.

Outdated Network Diagrams and Unavailability of unique name/codes

In many cases, the network diagrams or drawings provided by Discoms are either outdated or inaccurate. This makes it difficult for AMISP teams to locate the exact DTs or feeders, further complicating the system metering process.

In addition to the above, the unique names or codes for the DTs/Feeders are often inconsistently generated or ambiguous, causing significant challenges for the AMISP in integrating these feeders/DTs into their system.

Controlled Area Allocation by Utilities

The utility often provides specific areas (Binder/ MRU) for meter installations in a controlled manner. This structured approach, while ensuring oversight, causes process bottlenecks that hinder the AMISP team's ability to scale operations and ramp up installations efficiently. This slows down the overall project timeline.

Additionally, during the monthly billing activities of Discom, there is often non-availability or shifting of designated installation areas. This process typically takes 5-7 days for each subdivision office, leading to disruptions in installation planning, team relocations, and further delays in the overall project timeline."

Mismatch in Consumer Database

There are significant discrepancies in the consumer database maintained by the Discom's billing system, leading to multiple challenges during the installation process:

Meters Not Present on Site: In many cases, meters are listed in the billing database but do not physically exist at the installation site. This creates confusion and delays during fieldwork.

Incomplete or Inaccurate Data: Key information such as meter numbers, consumer phase details, and other essential data are often missing or incorrect in the database. This lack of accurate records hampers the installation process, as field teams must verify and correct information on-site, causing further delays.

Geographical Diversity

India's vast and diverse geography presents significant challenges for the deployment of Advanced Metering Infrastructure (AMI) in the country.

Rural and Urban Disparities: The vast geographical diversity of India poses significant challenges in deploying AMI infrastructure. In urban areas, dense population centers can complicate installation logistics, while in rural regions, the lack of basic infrastructure and reliable connectivity requires additional effort and investment to ensure smooth installation and functionality.

Weather and Terrain Issues: Many parts of India experience extreme weather conditions, such as monsoons, heatwaves, and flooding, which can delay or disrupt the installation of smart meters. Additionally, difficult terrains like mountainous or forested regions increase the complexity of both the installation and ongoing maintenance of AMI systems.

Communication Challenges

India's diverse and often underdeveloped infrastructure poses challenges for establishing reliable communication networks, especially in rural areas. Communication-related are critical since the success of the system depends heavily on reliable data transmission between smart meters, the utility, and the service provider. Here are the key communication challenges:

Network Reliability

Network reliability is a critical factor in the success of AMISP systems. Ensuring network reliability faces several challenges, which can impact the overall performance of the AMISP system.

Unstable Connectivity in Remote Areas: In rural or hard-to-reach locations, the availability of reliable communication networks (cellular, radio frequency) can be limited, leading to intermittent or failed data transmission.

Network Downtime: AMI systems require consistent, real-time data transmission, and any network downtime or disruptions can affect billing accuracy, load management, and customer services.

Bandwidth Limitations

As AMI systems scale up to include thousands or millions of meters, communication networks need to accommodate this massive scale. Ensuring that all devices can reliably send and receive data without bottlenecks is a significant challenge.

Smart meters generate large amounts of data continuously. If the communication network is not designed to handle this volume, there may be delays in data transmission, leading to inaccuracies in real-time monitoring.

Frequent power outage/Poor Power Quality:

Frequent power outages and poor power quality can significantly disrupt the operation and effectiveness of RF mesh networks used in AMI systems.

When a power outage occurs, devices within the RF mesh network, including smart meters and communication nodes, may reboot or lose power temporarily. This can lead to interruptions in data transmission and communication between nodes.

Mesh networks rely on a stable and consistent network topology to efficiently route data. Frequent power interruptions can cause devices to disconnect and reconnect, leading to frequent changes in the network configuration. This can disrupt the routing paths and increase the time required to reestablish communication between nodes.

Some feasible solutions to attend/mitigate above challenges are Hybrid communication modules having a combination of RF and Cellular, narrow band internet of things (NBIoT) and a Bluetooth local port in smart meters.

Skill Development & Social Challenges

Utility metering is a complex field, where expertise is gained through years of hands-on problem solving and project execution. AMI implementation has made it more complex.

Deploying a skilled workforce and trained DISCOM staff for AMISP projects in India presents several challenges. AMISP deployment is hampered by various technical, operational, and human resource-related challenges.

Skilled Workforce Shortage

One of the biggest challenges is the lack of a sufficiently skilled workforce to manage the technical and operational demands of AMISP projects.

AMISP projects require personnel with expertise in smart meter installation, communication networks, data analytics, and cybersecurity. The workforce must have proficiency in handling Internet of Things (IoT) technologies, data acquisition systems, and other IT infrastructure related to smart metering. The scarcity of professionals with these niche skills is a significant bottleneck.

India's vast and diverse geography, with challenging terrains in rural areas, makes it difficult to deploy a trained workforce.

Moreover, the workforce involved in traditional metering and power distribution systems often lacks the technical knowledge required for AMISP deployments. Upskilling to handle smart metering technology is necessary but time-consuming and costly.

Skilled professionals with expertise in smart technologies are in high demand across various sectors such as telecom, IT, and manufacturing. This leads to high attrition rates as trained personnel.

Social Challenges

Deploying AMISP systems in India involves navigating several social challenges. These challenges can affect the overall success and efficiency of AMISP projects. Here's a detailed look at these challenges:

Consumer Resistance

Consumers may lack awareness or understanding of the benefits and operation of AMI systems, leading to resistance or reluctance to adopt new technologies. Concerns about data privacy and the accuracy of smart meters can result in resistance to the new systems.

In certain regions, there is a risk of vandalism to installed meters, particularly if local consumers feel that the new systems are unfair or unnecessary. Additionally, meters and related equipment may be targeted for theft, especially in remote areas.

Social Economic challenges

India's diverse socioeconomic landscape means that different consumer segments may have varying levels of readiness and capability to adapt to prepayment systems. Addressing the needs of economically weaker sections can be challenging.

In lower-income areas, consumers might struggle with the upfront costs or the concept of prepaying for electricity, leading to potential implementation hurdles and vandalism of installed smart meter.

Case study of ongoing successful implementation of AMI System

- **Discom:** South Bihar Power Distribution Company Limited (SBPDCL)
- **Area:** Bhagalpur, Jamui, Shekhpura, Banka
- **Total Scope:** 1 million Smart Meter
- **Total Installation:** 0.67 million Smart Meter

Key Achievements in SBPDCL Project Implementation:

- Successfully installed 670,000 smart meters with prepaid functionality, operational from day one of installation.
- Hybrid communication modules having a combination of RF and Cellular have been deployed to mitigate the communication challenges.
- Achieved 94% daily communication success rate and over 98% success in daily auto-re-connection and recharge processes.
- Seamlessly integrated the AMISP system with key utility systems, including Billing, NFMS, and Sampurna systems.
- Conducted comprehensive consumer awareness programs to address resistance and enhance understanding of smart meters among consumers.
- Utility Initiatives for Smooth Project Implementation:
- Conducted in-depth discussions and brain-storming sessions on all processes and integration parameters with AMISP at the project initiation stage, ensuring alignment with the utility's vision and preventing unnecessary confusion.
- Strengthened IT infrastructure to efficiently handle the daily bulk data exchange between AMISP and the utility's billing system.
- Ensured secure exchange of consumer master data strictly via API to prevent any leakage of confidential consumer information.
- Generated and shared 100% unique codes with AMISP to ensure seamless mapping between network components.
- Conducted timely training sessions for utility staff to improve their ability to manage, monitor, and maintain the new infrastructure.

- Enabled instant correction of consumer information by AMISP and utility staff in case of discrepancies and provided on-demand consumer data request option for urgent situations where a consumer, area, or MRU is not assigned to a field officer, ensuring uninterrupted installation activities.

Conclusion

The deployment of smart meters in India marks a significant step toward enhancing energy efficiency and improving the operational effectiveness of utilities. However, the large-scale implementation within a short timeframe presents numerous challenges. By staying informed and utilizing both proven and innovative solutions, these challenges can be effectively addressed, leading to substantial savings in time, effort, and costs. By adopting a coordinated approach that includes policy support, financial incentives, and consumer education, India can overcome these challenges and realize the full benefits of AMI.

BIO-DATA

AASHISH GAUR

BRIEF PROFILE

I am Aashish Gaur, 19+ years of experience across Product Management, Project Management & Business Development for Smart Grid Solutions Development and AMI deployment across different Power Distribution Utilities. Managed client accounts, generated sales pitches and developed business solution to deliver Top and Bottom-line growth. Expert in handling large scale projects with focus on customer requirements, operational excellence and right use of technology.

I am presently working as AGM-Project Engineering and handling the solutions and its deployment for AMISP projects spread across different Utilities in India. We are working to define the systems, solutions, processes, deployments strategies for smooth and efficient execution of these projects. The scope encompasses around Meters, Communication, HES, MDMS, Cloud and field deployments.

I am also working in multiple National committees in BIS and CEA for formulation of standards and regulatory guidelines working with stakeholders and policy makers in India.

PERFORMANCE EVALUATION AND TESTING ANALYSIS OF ADVANCED METERING INFRASTRUCTURE (AMI) SYSTEM

Dinesh J | Shailesh Kapoor | Shivendra Kumar Sinha | Pradish M | Shivakumar V | Amit Jain
Central Power Research Institute

ABSTRACT

The Advanced Metering Infrastructure (AMI) system testing in laboratory before field deployment helps electrical utilities in reducing the duration of installation/commissioning of AMI systems. Further the AMI systems help the utilities to enhance their reliability and efficiency of electricity distribution. The evaluation of AMI system is based on actual validation process carried out at laboratory for demonstration testing performance of the AMI Service providers (AMISPs) with Smart Meters, Head End System (HES) and Meter Data Management System (MDMS) integrated with Billing Engine and customer information system/ customer relationship management (CIS/CRM). Various aspects including simulation of events, collection of load profiles and billing profiles, smart meter disconnection due to low balance and reconnection due to recharge with prepayment metering features, alerts to the consumers, service level agreement (SLA) parameter etc. are also validated during the testing process. A comprehensive and practical approach to the performance evaluation and testing of Advanced Metering Infrastructure (AMI) System done at laboratory is brought out in this paper. This paper also brings out analysis of failures during testing of various samples and this study further helps to investigate the causes and remedial actions for improvements by the manufacturers and software developers. The validated AMI systems are based on Radio Frequency (RF) and Cellular communication technologies [1].

Keywords: AMI, Firmware, HES, MDM, SLA, Smart Meter, Tamper.

1 INTRODUCTION

This paper aims to provide a comprehensive performance evaluation and testing framework for AMI systems. This study brings out the testing methodology carried out on end-to-end AMI system with IS 16444 based Smart Meters, HES and MDMS integrated with various modules including billing engine, CIS/CRM, etc. Also, detailed analysis is made on the failures that happened during the testing of various combinations of the AMI system both on RF and on cellular communication technologies. The testing of the AMI System was based on the prepayment metering feature which makes this evaluation more interesting as there are various prepayment requirements to be evaluated from low balance disconnection to reconnection on recharge of smart meter. The samples used for study are provided by AMISPs for actual laboratory testing and attempt has been made to explore the analysis of AMI system testing outcome against the defined set of parameters including data transfer accuracy, communication reliability in the HES and MDM System through Cellular and RF technologies and Service Level Agreement (SLA) parameters as prevalent for the validation purpose [2].

For the evaluation purpose twenty smart meters with at least two manufactures of smart meters with minimum five numbers of each make were considered as per Revamped Distribution Sector Scheme (RDSS) scheme. The laboratory evaluation of AMI system with combination of different makes of smart meters and HES / MDMS from various manufactures / software developers / integrators also ensures in making it an interoperable solution. The tests were carried out for six continuous days for each AMISP. The validation process covers both the operational functionalities and the functionalities associated with the SLA of the AMI system.

2 TEST SETUP

The test setup consists of smart meters mounted on meter mounting racks with individual resistive loads, Data Concentrator Units (DCU) in case of RF based meters, Head End System, Meter Data Management System, Billing Engine, Consumer Application, Simulation system for simulating tamper events and mobile interface if any. The smart meters are configured in prepayment mode and configured to the HES and MDMS [3]. Basic architecture of AMI system is shown in Fig-1.

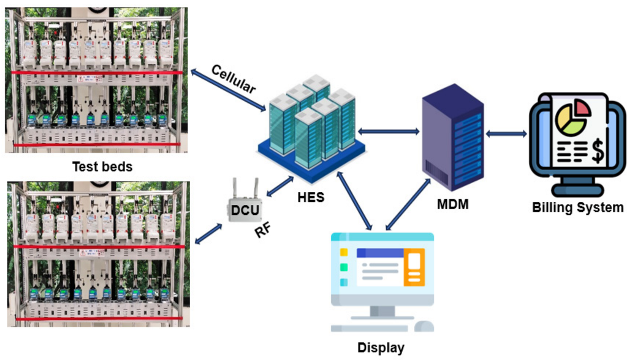


Fig-1: Basic architecture of AMI system

3 VALIDATION PROCESS OF AMI SYSTEM

3.1 Firmware Upgradation Process

Firmware, a form of software, is directly integrated into the hardware of smart meter to ensure its proper functioning. It is developed and installed by the manufacturer during the production process of smart meters / digital devices. Firmware is an essential component for computing devices. Firmware upgradation is required essentially to keep devices up to date for new developments, utility requirements, addition of new features and updating of security patch as and when needed during the life cycle of smart meter. As large number of smart meters will be in the field, the firmware upgradation process should be reliable and should not take a very long time in completing the upgradation process in the field [4].

The firmware that operates within AMI devices such as smart meters, DCU and communication modules is crucial for ensuring the functionality, security and reliability of the entire AMI system. Firmware upgradation failures can lead to significant operational disruptions, data inaccuracies and security vulnerabilities to the system. Firmware in AMI devices control critical functions such as data acquisition, processing, storage and communication to the system. Any compromise in the firmware could jeopardize the entire system. Additionally, any bugs in the smart meters affecting demand response management must be promptly addressed through firmware updates to prevent potential economic losses. Furthermore, the firmware update process poses a significant security risk that must be carefully managed [5]. From the data taken from the AMISPs demonstration testing conducted at CPRI laboratories, the statistics of test case for firmware upgrade are discussed in this section.

The average, maximum and minimum time taken by AMI systems to upgrade the firmware version of smart meter for various communication technologies, as derived from the analysis of AMISP testing results is shown in Fig-2. It is observed that AMI system based on RF technology took 37 minutes more time on average as compared to cellular technology.

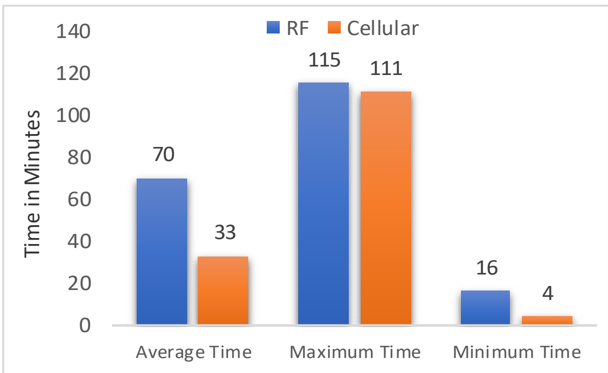


Fig-2: Time taken by firmware upgrade process

3.2 Simulation of Tamper Events

Power theft through tampering with energy meters and manipulating meter readings is a significant contributor to the revenue losses to electrical utilities. To ensure efficient electricity management, it is essential to have accurate metering, detection of unauthorized activities and establishing a precise tariff and billing system. The introduction of Smart meters replacing outdated electromechanical meters, static meters, digital meters etc., has aided utilities in detecting attempts at meter tampering. The one of the goals of smart meters is to enhance billing accuracy by detecting tampering incidents [6].

In the United Kingdom, European Union, Asia, and IEC member countries, a single-phase supply of 230V AC is delivered through a two-wire system (Phase & Neutral) from the transformer to the meter box. These two wires are designated as the Phase input (P^{in}) and Neutral input (N^{in}). In Fig-3, 1S and 2S represent phase input (P^{in}) and neutral input (N^{in}) respectively. Similarly, 1L and 2L represent phase output and neutral output respectively.

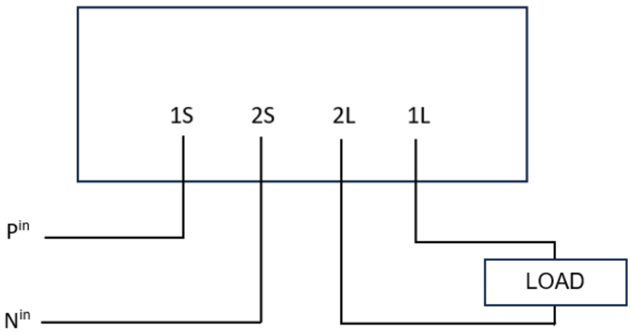


Fig-3: Energy Meter Connection Diagram

As mentioned earlier, the smart meter is capable of detecting tampering events like earth leakage and current reversal. In earth leakage detection, one of the output terminals of the energy meter is left open. The energy meter connection diagrams as shown in Fig-4 is utilized during validation process of AMISP to assess the earth leakage detection capabilities of smart meters [7].

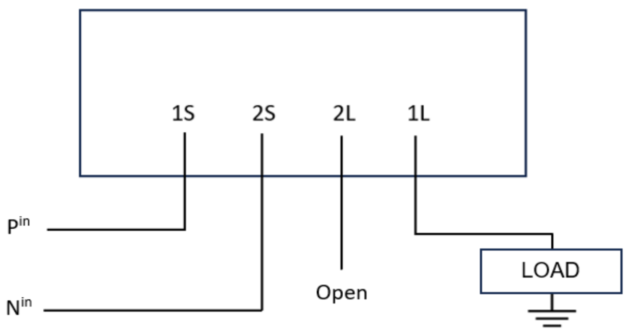


Fig-4: Energy Meter Connection Diagram for Earth Leakage Detection

Similarly, in case of detection of current reversal, input terminals of the energy meter are connected with load while output terminals are connected with supply. The energy meter connection diagrams as shown in Fig-5 is utilized during validation process of AMISP to assess the current reversal detection [6].

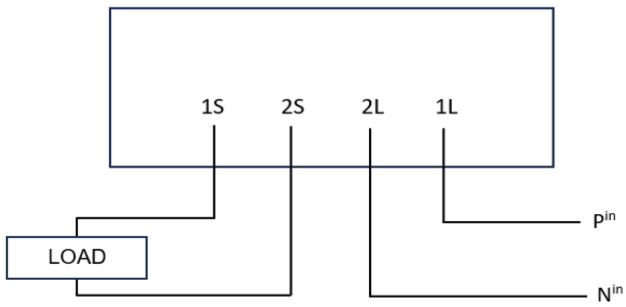


Fig-5: Energy Meter Connection Diagram for Current Reversal Detection

Smart meters are specifically engineered to capture and monitor various parameters, including the identification of theft, and communication tamper details with the Data Concentrator Unit (DCU) (for RF based AMI systems) or directly through cellular communications at regular intervals. The meter communication module then transmits the gathered information to the HES, enabling the utilities to take informed decisions such as disconnecting the load of consumers through the smart meters. This feature enables utilities to identify fraudulent customers and respond accordingly by documenting tampering incidents such as tamper tickets, tamper invoices, vigilance tickets, and complaint IDs etc. These actions are based on the metering data stored in the memory of the energy meter.

4 AMISP TESTING RESULT ANAYSIS

This section presents an analysis of the performance evaluation derived from the CPRI testing results of AMISPs. The analysis covers performance level test cases, number of testing attempts taken by AMISPs, failure analysis based on communication technology used, success rates of HES and MDM service providers, analysis based on smart meter manufacturers used by AMISPs, number of meter manufacturers and MDMS service providers integrated with HES service providers.

4.1 Analysis of Performance Level (SLA) Test Cases

Demonstration testing of the AMI system includes time-bound performance level test cases, also known as SLA functionalities, which AMISPs must pass to clear the tests. Table-1 provides the average, maximum and minimum time taken by AMI systems that have successfully passed the time-bound performance level test cases. Based on the data, it can be stated that majority of AMI systems successfully passed and met all performance level test cases within half of the defined time for each test case [8,9].

The majority of AMISPs have tested their meters configured with 15-minute profile capturing period. During the recharge reconnection test case, it was observed that the meter took an average of 7 minutes to reconnect, significantly below the defined time of 30/60 minutes. However, some AMISPs experienced delays in meter reconnection after successful recharge, with the maximum time taken being approximately 43 minutes.

Test Case	SLA	Average Time	Maximum Time	Minimum Time
One hour block load profile	5 min	01 min 17 sec	04 min 57 sec	03 sec
Block Load Profile	30 min	09 min 22 sec	28 min 46 sec	54 sec
Daily Load Profile	30 min	12 min 22 sec	29 min	17 sec
Billing profile	30 min	12 min 18 sec	25min 56 sec	03 min 04 sec
Remote Reconnect	03 min	33 sec	02 min 26 sec	02 sec
Remote Disconnect	03 min	28 sec	01 min 45 sec	03 sec
Recharge Alert	05 min	01 min 23 sec	04 min 36 sec	01 sec
Recharge Reconnect	30/60 min	07 min 11 sec	42 min 57 sec	07 sec
Tamper events	03 min	01 min 17 sec	2 min 59 sec	01 sec

Table-1: Time taken by AMISP to report data or perform the task based on test case

As discussed in the previous section, the AMI system using RF technology took longer time for firmware upgrade compared to Cellular technology. However, in all other test cases except one hour block load profile, RF technology-based AMISPs outperformed Cellular technology. This includes tasks such as collecting block load profiles, daily load profiles, billing profile data from meters, and connecting and disconnecting smart meters. Table-2 provides a complete analysis of the average time taken by AMISPs using RF and Cellular technology for each SLA-based test case.

Based on the type of smart meter used by AMISPs, only a single AMISP had come up with 10 three-phase meters. Additionally, none of the AMISPs requested tests on their systems using Power Line Communication (PLC) technology.

4.2 Analysis of Number of Testing Attempts by AMISPs

Since June 2022, the CPRI has conducted 110 tests of AMISPs. Table-3 provides details on the number of AMISPs that passed or failed, and the number of testing attempts taken to complete the validation process. Out of 110 applications, 55 AMISPs passed the test on their first attempt. However, 29 applications failed on their first attempt. Out of these, 25 underwent for a second round of testing, with 22 successfully passing and 3 failing to meet the performance criteria. Out of the 3 applications that failed on their second attempt, only one made a third attempt and passed.

Test Case	SLA	RF Average	Cellular Average
One hour block load profile	05 min	01 min 28 sec	01 min 25 sec
Block Load Profile	30 min	09 min 03 sec	09 min 28 sec
Daily Load Profile	30 min	09 min 57 sec	13 min 34 sec
Billing profile	30 min	11 min 50 sec	12 min 30 sec
Remote Reconnect	03 min	25 sec	36 sec
Remote Disconnect	03 min	22 sec	30 sec
Recharge Alert	05 min	01 min 04 sec	01 min 31 sec

Recharge Reconnect	30/60 min	03 min 35sec	07 min 05 sec
Tamper events	03 min	58 sec	1 min 24 sec

Table-2: Time taken by AMISP to report data or perform, or task based on communication technology

Attempt / Result	1st	2nd	3rd	Total
Passed	55	22	1	78
Failed	29	3	-	32

Table-3: Testing Analysis of AMISP's applications

4.3 Failure Analysis based on Communication Technology used by AMISPs

For cellular communication technology, 27 out of 32 AMISPs that did not meet the defined performance levels is shown in Fig-6, along with the specific SLA test cases. It is observed that in certain AMISPs testing scenarios, if a particular test case fails, it may impact the results of other test cases as well. For instance, if a meter got faulty, we will be unable to perform certain test cases like reconnection/disconnection of meter etc. As a result, tasks such as meter tampering, remote connect, and disconnection cannot be carried out. In this type of scenario, 6 AMISPs failed.

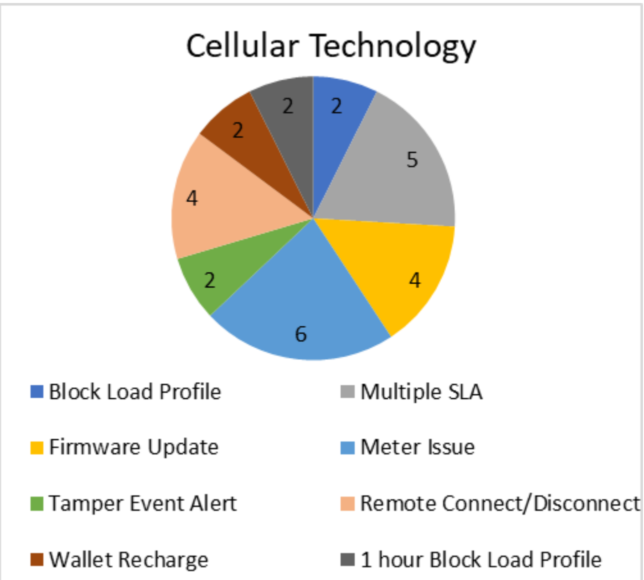


Fig-6: AMISPs Failure Analysis: Cellular Technology

In the case of RF communication technology, only 5 out of 32 AMISPs were not able to meet the defined performance level as mentioned in Fig-7.

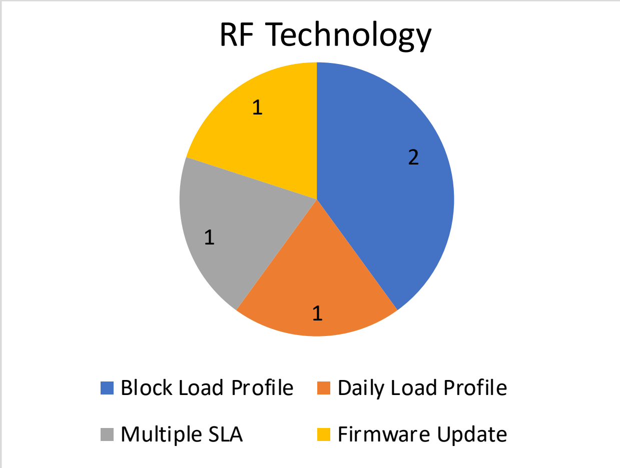


Fig-7: AMISPs Failure Analysis: RF Technology

4.4 Success rate analysis of HES, MDM service providers

As of June 2024, a total of 16 different HES systems were used by AMI service providers in laboratory testing for their demonstration. Table-4 provides the top five HES service providers, ranked according to the number of tests conducted and their success rates.

HES Service Provider	Number of Tests	Success Rate
H1	36	77.78
H2	12	75.00
H3	12	91.66
H4	08	75.00
H5	08	87.50

Table-4: Success Rate of HES Service Providers

A total of 11 MDM service providers are used by different AMISPs for demonstration testing. Table-5 shows the top five MDM service providers based on the number of tests conducted and their respective success rates.

MDM Service Provider	Number of Tests	Success Rate
M1	36	77.78
M2	21	76.19
M3	14	78.57
M4	13	84.61
M5	05	20.00

Table-5: Success Rate of MDM Service Providers

4.5 Analysis based on Smart Meter manufacturers used by AMISPs

Table-6 shows the number of AMISPs who have demonstrated their solutions with smart meter manufacturers, along with the communication technology used.

Meter Manufacturer	No of AMISPs	Cellular	RF
M1	15	11	4
M2	12	11	1
M3	27	14	13
M4	20	15	5
M5	22	09	13
M6	13	10	3
M7	11	11	0
M8	7	4	3
M9	10	10	0
M10	7	5	2
M11	6	0	6

Table-6: Smart Meter manufacturers used by AMISPs

For demonstration testing, AMISPs must use smart meters from a minimum of two different manufacturers, with a minimum of five meters from each manufacturer for interoperability of the system. During the demonstration testing AMISPs used smart meters from 16 different manufacturers fulfilling the above-mentioned validation parameters.

4.6 Analysis on meter manufacturers and MDMS service providers integrated with HES service providers

For demonstration testing, AMISPs have used various combinations of smart meters, HES service providers and MDMS service providers. Table-7 shows the number of smart meter manufacturers integrated by HES service providers ranked based on the highest number of meter manufacturers integrated.

HES Service Provider	Smart Meter Manufactures Integrated
H1	8
H2	7
H3	7
H4	3
H5	2

Table-7: Number of Meter Manufactures integrated with HES

For the integration of HES with MDMS, it is observed that out of 16 HES service providers, 9 used only their own MDMS for demonstration testing. Only 1 HES service provider utilized both their own MDMS and from other MDMS service providers. Further, 6 HES service providers used MDMS services from other providers as shown in the Fig-8.

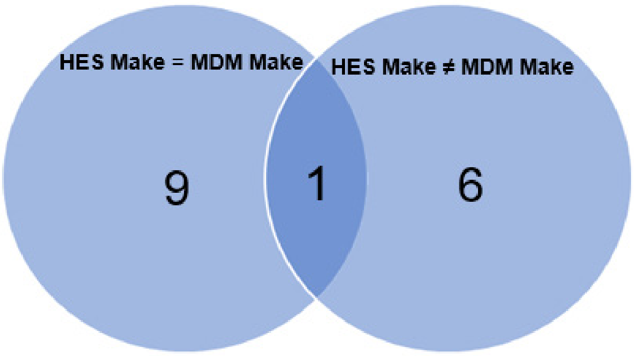


Fig-8: HES with MDM service providers statistics

5 CONCLUSION

This paper provides a detailed analysis of AMI systems testing from various perspectives, focusing on prepaid functionalities and SLA parameters. We conducted analyses on factors including communication technology and performance levels. Additionally, we examined the integration of meter manufacturers and MDMS service providers with HES service providers, revealing that most HES service providers use their own MDM systems.

The findings of this analysis can aid meter manufacturers, HES/MDM developers, and integrators in enhancing the performance of their products and services. Furthermore, the outcomes of this study will assist utilities in understanding and evaluating the performance of AMI systems for preparing tender specifications, factory acceptance testing (FAT), and site acceptance testing (SAT) requirements.

6 ACKNOWLEDGMENT

The authors would like to thank Central Power Research Institute for the support extended in carrying out this work.

7 REFERENCES

[1] J. Zheng, D. W. Gao and L. Lin, "Smart Meters in Smart Grid: An Overview," 2013 IEEE Green Technologies Conference (GreenTech), Denver, CO, USA, 2013, pp. 57-64, doi: 10.1109/GreenTech.2013.17.

[2] Rendroyoko, Ignatius & Setiawan, Antonius & Suhardi,. (2021). Development of Meter Data Management System Based-on Event-Driven Streaming Architecture for IoT-based AMI Implementation.403-07.10.1109/ICHVEPS53178. 2021.9601104.

[3] Barua, A. M., & Goswami, P. K. (2017, July). Smart metering deployment scenarios in India and implementation using RF mesh network. In 2017 IEEE International Conference on Smart Grid and Smart Cities (ICSGSC) (pp. 243-247). IEEE.

[4] S. Tonyali, K. Akkaya, N. Saputro and X. Cheng, "An Attribute & Network Coding-Based Secure Multicast Protocol for Firmware Updates in Smart Grid AMI Networks," 2017 26th International Conference on Computer Communication and Networks (ICCCN), Vancouver, BC, Canada, 2017, pp. 1-9, doi: 10.1109/ICCCN.2017.8038415.

[5] Jalil, Syed & Chalup, Stephan & Rehmani, Mubashir Husain. (2019). A Smart Meter Firmware Update Strategy Through Network Coding for AMI Network: Second EAI International Conference, SGIoT 2018, Niagara Falls, ON, Canada, July 11, 2018, Proceedings. 10.1007/978-3-030-05928-6_7.

[6] Khan, Shagufta & Saini, Manoj. (2021). A comprehensive study on energy meters and power tampering attempts. International Journal of Applied Power Engineering (IJAPE). 10. 315. 10.11591/ijape.v10.i4.pp315-325.

[7] Warudkar, Deepa, Priyamvada Chandel, and B. A. Sawale. "Anti-tamper features in electronic energy meters." International Journal of Electrical, Electronics and Data Communication 2.5 (2014): 81-84.

[8] "Request for Empanelment (RFE) of Firms for participation in RDSS AMISP tenders for providing Advance Metering Infrastructure (AMI) prepaid Solution after successful demonstration" https://recindia.nic.in/uploads/files/AMISPRFE1 032022.pdf (accessed June 2024).

[9] "Functional requirements of advanced metering infrastructure," CEA, Tech. Rep., Aug. 2016.

BIO-DATA

DINESH J
Central Power Research Institute

Date of Birth: 28.08.1998

Qualification: B.E. (ECE)

Designation: Engineering Officer

Present Organization: Central Power Research Institute

Field of Expertise: Smart Grid, Substation Automation and Cybersecurity related to Power Sector

Mobile: +91 95978 46406

Email: dineshj@cpri.in

BRIEF PROFILE

He earned his bachelor's degree in Electronics and Communication Engineering from the Government College of Engineering Thanjavur. He has been serving as an Engineering Officer at the Central Power Research Institute since 2023. At present, he is engaged with the Smart Grid Research Laboratory located in CPRI, Bangalore. His areas of interest include Smart Grid systems, Substation Automation, and cybersecurity related to Power Sector.

SHAILESH KAPOOR
Central Power Research Institute

Date of Birth: 11.01.1992

Qualification; B.Tech. (EEE)

Designation: Engineering Officer

Present Organization: Central Power Research Institute

Field of Expertise: Smart Grid, SCADA and Automation and cyber security for Power Systems

Mobile: +91 92528 94700

Email: skapoor@cpri.in

BRIEF PROFILE

He holds bachelor's degree from NIT Hamirpur in Electrical and Electronics engineering. He is working as Engineering Officer at Central Power Research Institute since 2017. He is presently associated with Smart Grid Research Laboratory at CPRI, Bangalore. His area of interests includes Smart Grid, SCADA and Automation and cyber security for Power Systems. He is a member of LITD10 JWG for cyber security.

BIO-DATA

SHIVENDRA KUMAR SINHA
Central Power Research Institute

Date of Birth:	14.05.1991
Qualification:	B.E. (EEE)
Designation:	Engineering Officer
Present Organization;	Central Power Research Institute
Field of Expertise:	Substation Automation System, Advanced Metering Infrastructure, SCADA & Smart Grid
Mobile:	+91 72503 55590
Email:	shivendra@cpri.in

BRIEF PROFILE

He holds a degree in Electrical and Electronics Engineering and is presently working as Engineering officer at the Smart Grid Research Laboratory, part of the Central Power Research Institute in Bangalore. He has also worked in PFC Limited. He is currently looking after the IEDs Conformance Testing, His area of interest is Substation Automation System, Advanced Metering Infrastructure, SCADA & Smart Grid. He has published technical papers in national and international conferences.

PRADISH M
Central Power Research Institute

Date of Birth:	14.07.1976
Qualification:	M.E., MBA
Designation:	Joint Director
Present Organization:	Central Power Research Institute
Field of Expertise:	Smart Grid, SCADA and Automation, Substation Automation Systems and cyber security for Power Systems
Mobile:	+91 94487 22416
Email:	pradish@cpri.in

BRIEF PROFILE

He holds bachelor's and master's degree in electrical engineering and master's degree in management. He is with CPRI since 2005 presently associated with Smart Grid Research Laboratory at Bangalore. His area of interests includes Smart Grid, SCADA and Automation, Substation Automation Systems and cyber security for Power Systems. He is member in IEC Technical Committee 57/ Working Group 10 and BIS sectional committees on ETD 13 and LITD 10. He has published technical papers in various national and international journals and conferences.

BIO-DATA

SHIVAKUMAR V
Central Power Research Institute

Date of Birth:	22.06.1970
Qualification:	M.E. (ECE)
Designation:	Joint Director
Present Organization:	Central Power Research Institute
Field of Expertise:	Smart grid, power system automation, cyber security and communication for utility applications
Mobile:	+91 9945430826
Email:	shiva@cpri.in

BRIEF PROFILE

He obtained his Bachelor's and master's degree in Electronics & Communication Engineering from UVCE, Bangalore University. He is with Central Power Research Institute (CPRI), Bengaluru since past 34 years. His special fields of interest include smart grid, power system automation, cyber security and communication for utility applications. He holds two patents. He is member in Bureau of Indian standards technical committees (BIS LITD 10 & BIS ETD 13), Convener of Working Panel of BIS LITD 10 – P2 – Security and Secretary of BIS LITD 10 Joint Working Group – Security. He is member of IEC TC 57/WG 15, TC 57/WG 21, and TC 13/WG 15 and Annex SIRFN of ISGAN. He is also senior member of IEEE & member IEEE SA PLC and ISGF working groups 2 & 3.

BIO-DATA

DR. AMIT JAIN
Central Power Research Institute

Date of Birth:	06.11.1967
Qualification:	Ph.D., M.Tech., B.Tech.
Designation:	Additional Director
Present Organization:	Central Power Research Institute
Field of Expertise:	Smart Grid, AMI and Smart Metering, artificial intelligence applications, power system planning, load forecasting, power system real time monitoring and control, PMU, renewable energy, reliability analysis, and sustainable development
Mobile:	+91 99029 90967
Email:	amitjain@cpri.in

BRIEF PROFILE

He is Additional Director and Group Head, HoD - Smart Grid Research Laboratory Division at Central Power Research Institute Bengaluru. He is an Electrical Engineer with M.Tech. and Ph.D. from IIT Delhi. After his Ph.D., he worked in Alstom on the development of EMS/SCADA system for the Northern Region Power Grid of India. After a stint in IT industry, he worked in Korea in 2002 as a post-doctoral researcher in the Brain Korea 21 project team of Chungbuk National University. He was Post-Doctoral Fellow of the Japan Society for the Promotion of Science (JSPS) at Tohoku University, Sendai, Japan. He also worked as a Post-Doctoral Researcher at Tohoku University, Sendai, Japan. Thereafter he joined as faculty member of IIIT, Hyderabad and headed the Power Systems Research Center where he was spearheading the Academic and research programs in IT in Power. Before joining the CPRI, he was lead consultant (Asst. General Manager) at utilities practice group at Cyient, a leading IT multinational company. His research interests are Smart Grid, AMI and Smart Metering, artificial intelligence applications, power system planning, load forecasting, power system real time monitoring and control, PMU, renewable energy, reliability analysis, and sustainable development.

TECHNICAL SESSION II

METER DATA: THE FUEL FOR INNOVATION IN DISCOMS

SMART METERING - A POWERFUL TOOL TO ENRICH CONSUMER'S EXPERIENCE

Rajesh Bansal
Consultant

ABSTRACT

Adoption and adaptation of any technology can be successful, if the user and stakeholders start leveraging full benefit out of it. Since last two & half years, Ministry of Power (MOP), is promoting the installation of Smart Meter, both at consumer and asset end. There is a plan to install almost 250,000,000 smart meters in next few years. The expected cost of this project will be around ₹2.5 trillion.

Even though government is giving certain grant, but, in practice, the cost of Smart Meter is born by utility consumer or by the citizen of Country. Thus, it is very important that maximum benefit should be leveraged out of the technology to ensure financial viability and no extra burden on consumer/ citizens.

Regarding Smart metering, technology, in general, it is observed that the maximum emphasis is on utilization of technology and data to enhance the efficiency of utility operations. Certainly, the improvement in the utility operations will improve the services and quality of power to consumer.

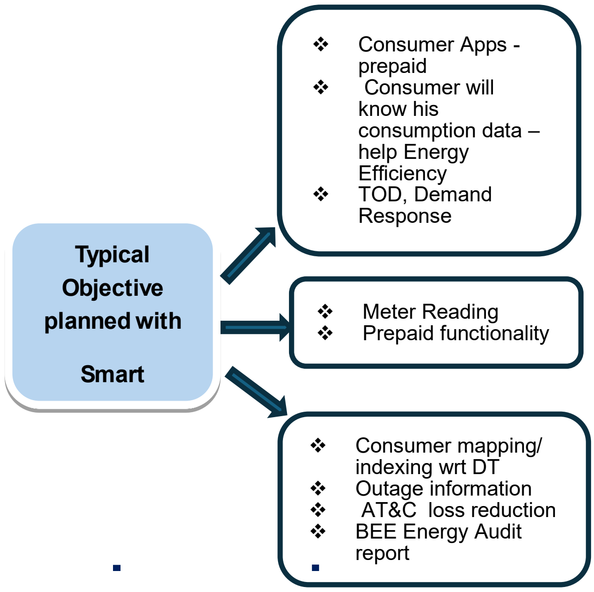
Regarding, direct benefit to the consumer, although Smart meter project executors provides consumer APPS, which provides information regarding prepaid system, billing data, load consumption data but author feel much more actionable information can be provided to consumer. The present APPS does not cover consumer all issues, concerns, and expectations. Restricting the consumer's concerns only to the billing, is not a proper justification to the invest and to the technology.

This paper is about how more information/ actionable notifications can be inferred from smart meter data so as Consumer experience can be enriched in terms of safe power, better protection, quality power, green power, lower commercial impact on consumer and finally better services to consumer. This will enrich his experience and enhance his engagement and will build trust. These benefits are invaluable, and which will really justify the cost of project.

1 INTRODUCTION

Power distribution system is witnessing a major transformation especially regarding High level of unpredictability due to renewable energy, EV charging. On the other hand, the expectation of consumer especially about the reliability and safety has gone up. There is a need to address these concerns namely large variation and unpredictable demand curve, power reliability, to minimize accidents and consequent damages, to improve commercial performance, to prevent revenue leakage. These are major issues and objectives for utility.

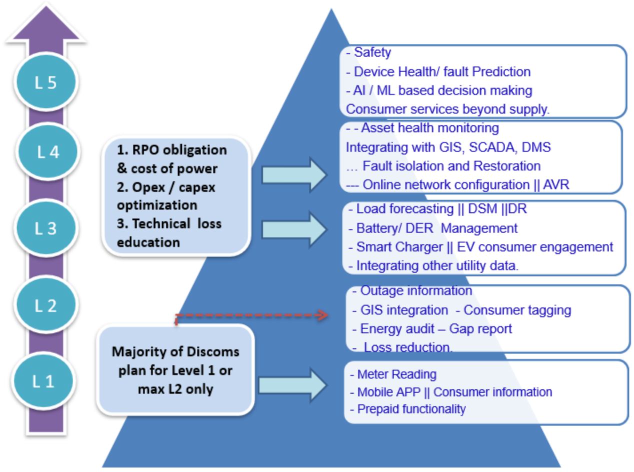
In India utilities have started installing Smart Meter, primarily for following objective:



Incidentally with such objective, to ensure financial viability is big question mark and it is hardly enriching consumer experience. The fact is even utility are not leveraging full benefits regarding utility own operations.

Installing smart metering system, data collection and generation of report with basic analytics will not sufficient to ensure success of project. Need is to address all utility objectives including issues/ concerns and expectations of consumers.

Following are list of objectives which can be successfully addressed by Smart metering technology.



1. UNDERSTANDING ABNORMALITIES IN NETWORK

Loading Pattern, network capabilities, defects in workmanship, faulty devises in network, abnormal Consumer behavior etc. CAN AFFECT ELECTRIICAL PARAMETER & PERFROMANCE OF NETWORK. Any event which can affect the electrical parameter to a level,or which can cause accident/ damage to network assets or affect life of network assets and thus NOT ACCEPTABLE is called "Electrical Abnormality".

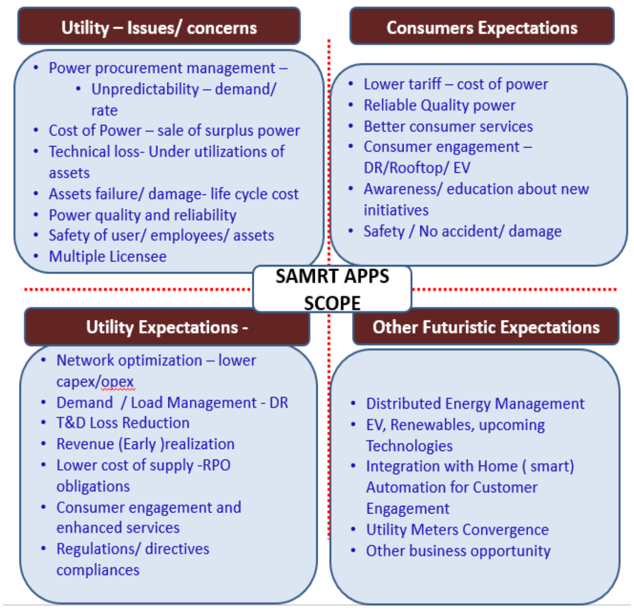
If Electrical abnormalities last for long, it can cause larger damage.

Smart metering system generates and provides data, which if properly analyze can detect abnormalities. Once such abnormalities, which have potential to cause severe unacceptable damage if are detected on time (at infant stage) and informed to concerned, one can prevent the larger damage which can happen due to these abnormalities.

2. NEED FOR SMART CONSUMER APPS

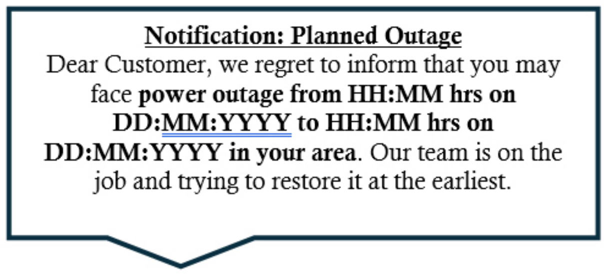
Both Utility and consumer have different issues/concerns and expectations. Few major objectives/ issues/ expectations are listed below for reference.

"Any abnormalities which can directly affect the consumer, or which can cause higher damage to consumer, or which is at consumer premises, or which is due to consumer behaviour, same should be detected and should be informed to consumer. This will enhance his experience and reduce damages thus benefits to consumers".



Following are few objectives related to can address. Need is to have a proper smart consumer Apps.

i **Safety:** After Road accident, electrical accidents are the second biggest reason for un-natural death. By proper analyzing the smart meter data, one can identify the potential cause of accident/ safety hazards.



Imagine after analyzing the meter data, utility send notification via consumer Apps about a potential safety hazard.

Notification: Pre-paid Balance
Dear Customer, your weekly electricity consumption from DD:MM:YYYY to DD:MM:YYYY is XY units. Based on your current weekly consumption your pre-paid balance of Rs AB will get over by DD:MM:YYYY. **Kindly recharge your pre-paid balance before it's exhaustion to avoid disconnection.**

ii **Pre-paid and billing system:** The consumption and billing data from smart meters combined with MDM can generate various notifications like low balance alert, recharge acknowledgements, disconnection/ reconnection alerts, weekly consumption, monthly recharge, etc. for benefit of the consumers regarding pre-paid balance.

Notification: Pre-paid Balance
Dear Customer, your weekly electricity consumption from DD:MM:YYYY to DD:MM:YYYY is XY units. Based on your current weekly consumption your pre-paid balance of Rs AB will get over by DD:MM:YYYY. **Kindly recharge your pre-paid balance before it's exhaustion to avoid disconnection.**

Notification: Low Balance
Dear Customer, your pre-paid balance is low. Your current balance of Rs XY may get exhausted soon/ may get exhausted within HH hrs as per your average daily consumption. **Kindly recharge your balance at the earliest to avoid disconnection.**

iii. **Supply Outage and Restoration Notifications:** Real-time data from smart meters enables the prompt generation of alerts regarding power outages and restoration, benefiting consumers by keeping them informed. Furthermore, consumers should receive notifications regarding planned outages and the expected restoration time, ensuring they are well-informed and prepared.

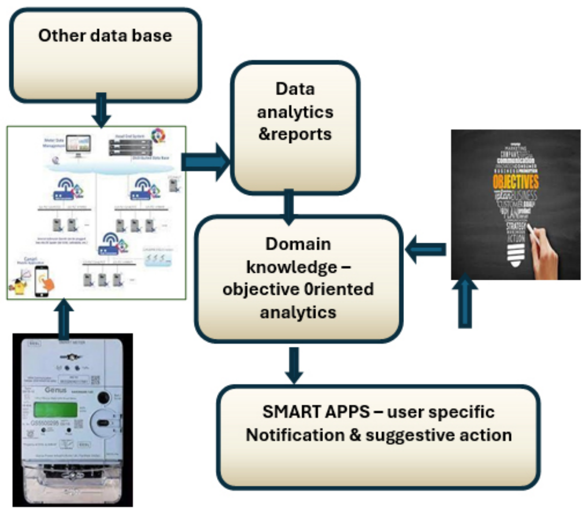
Notification: Planned Outage
Dear Customer, we regret to inform that you may face **power outage from HH:MM hrs on DD:MM:YYYY to HH:MM hrs on DD:MM:YYYY in your area**. Our team is on the job and trying to restore it at the earliest.

iv **Similarly various types of Notification can sent for various abnormalities / observation which is inferred from the data:**

- To avoid commercial penalty
- To reduce bill
- About bill, payment etc.
- Suggestion about load pattern
- Wiring defects.
- Utilities schemes

It is important to note that all Notifications need not about abnormalities and should have warning only. Notification/message can also be suggestive/ informative nature.

SMART CONSUMER APPS – NOTIFICATION GENERATION



The concept is simple.

- Identify concerns/ issues and expectations.
- Convert them into objective.
- Define what is not acceptable – abnormalities.
- How we can detect and find cause/ location
- Ensure such parameters are captured.
- Identify such event.
- Develop user (user is one who will take action) Apps.
- Send notification/ message along with what action to be taken.
- Mechanism to send ATR/ feedback.
- Enjoy achieving objective.

4. ADVANCE LEVEL OF NOTIFICATIONS:

Using domain and meter data knowledge, with the help pf AI technology notices of very advance level can be sent to consumer to achieve highest level of safety and best level of services. Following two are such examples:

- Notification about "in particular home appliance – current is leaking through appliance body". kindly get it checked.
- "Your inverter batteries are leaky and thus causing higher energy consumption and thus electricity bill.. kindly get it checked."

5. CONSUMER APPS – LEGAL REQUIREMENT

In many countries, Various Regulations, specially related safety – refer about utility Responsibility to inform any abnormalities which can affect consumer metering/ billing, safety, potential hazard to network assets to consumer and can warn them to take corrective action. In extreme case, they can even disconnect the supply.

6. PRESENT STATUS

It is important to note many "consumer notifications" can be generated even based on static meter data. Presently Very few utilities have concept of sending such notifications to consumer.

- *With the installation of smart meter – now utility cannot take an excuse about non availability of "abnormalities" information.*
- Incase of serious damage, at consumer premises, utility can be questioned.
- *Present Consumer apps available are* mainly about bill and usage pattern. Much wider information can be given to consumer justifying huge investment.
- Consumer apps should be for all category of consumers. This will enhance their experience and will build better trust and engagement.

7. CONCLUSION

Imagine a timely notification about abnormality followed by timely action by consumer, thus preventing potential accident and larger damage, the gain due to saving human life, preventing damage due to fire, same are far more valuable than project cost. All Smart metering system related service providers should develop such Consumer Apps as the fundamental advantage and need is beyond question.

With time it may become law, not in India but world over, to have smart apps generating notification for consumer (and may be for other stakeholders also). Maximum benefits from smart metering system (specially from DATA) can be leveraged when we have SMART Apps for all key stakeholders. Certainly, SMART Consumer Apps with notification system is need of hour.

This will not only minimize accident, damages due to accidents, reduce commercial disputes, have energy efficiency, mutual trust, better power quality, enrich consumer experience and ensure consumer engagement.

BIO-DATA

RAJESH BANSAL
Former CEO BSES Rajdhani Power

Date of Birth:	17th December 1964
Qualification:	BE (Electronics)
Designation:	Consultant Former CEO, BSES Rajdhani Power limited
Present Organization:	Own business (consultant)
Field of Expertise:	Meter data utilization and power distribution
Mobile:	+91 93502 61602
Email:	rajesh.bansal64@gmail.com

BRIEF PROFILE

Rajesh Bansal has done his graduation in Electronic Engineering in 1985 and started his career as Scientist in Indian Space Research Organization.

He has almost 10 years' experience in field of static meter designing and manufacturing.

In 2004, he joined BSES Delhi, Reliance group, as Head of Meter Management and Energy Audit and become Network Operation head in 2015. In July 2022, he left the position of CEO, BSES Rajdhani. BRPL, A+ grade ranked utility. He is widely travelled man and has good exposure of worldwide metering, data usage/ power distribution technology. He is a strong believer in Power of DATA and has successfully addressed all utility issues using meter and data. He is working on "Smart Apps – next step to data analytics" about to leverage maximum benefits by addressing utility objectives".

He has shared his knowledge and experience at various national/ international manufacturers/ service providers/ solution designers. His core area of interest is "meter data usage for utility objectives".

Presently, he is pursuing his passion and advising various companies/ Start Ups/ and even policy makers and training international utilities for capacity building – to leverage maximum benefits from DATA.

NETWORK OPTIMIZATION, CAPEX PLANNING AND DEMAND RESPONSE: USE CASES FOR METER DATA

Ashweni Kumar Jain | Niranjan Parkhi
Adani Electricity Mumbai Limited

ABSTRACT

"You can't manage what you can't measure". Electricity meters installed at various nodes across the electrical network not only provide the basic parameters values like energy, demand and power factor but they offer huge information in respect of operating parameters, events and timeslot wise information. In the regime of AI/ML, various other avenues like consumption patterns, alerts and dashboards, predictive and prescriptive analysis are also at disposal. Energy Meters also provide information on challenges a utility network may face going forward. Energy Audit meters installed at every distribution transformer is indicative of CAGR for downstream customer load in a pocket. It gives a huge amount of information to network and maintenance planners to mitigate the current challenges as well as prepare a long-term Capex plan for network. India reels under scorching summer heat every year with temperature soaring up to 50 Deg C in many parts. Availability of coal and hydel capacity take a toss during the peak summer season which necessitates managing peak MD. Managing load curve of utility through demand response using the energy mix wisely is altogether a new ball game. India has huge opportunities for mixing the non-conventional energy resources to meet peak MD attributing to its vast topology and inter-connected grid. This technical paper explains two use cases of Capex planning & network optimization using Energy Audit data and demand response using customer data.

Key Words: CAGR, Demand response, Network planning.

1 INTRODUCTION

Indian utilities have come along a long way in terms of metering and communication technologies, meter data management and its utilization. Static Meter installation was started in Yr.1996 in leading private utilities which was prioritized for utility interface points and HT customers. These meters were initially imported from countries like United Kingdom and Sweden. During 2003-04, static meters were installed for energy audit and LV industrial customers also. AEML-D (erstwhile R-Infra) was among the first utilities in India to install Static single-phase meters for its domestic customers with download and communication facility. During 2006-08, remote communication was established for HT customers in Mumbai with a success rate of more than 98%. With the advent of CDMA technology, communication was successfully migrated to CDMA with similar success rates. The obsolescence of CDMA technology has given way to new communication technologies like 4G LTE/PLC/RF Mesh with combination of ZigBee and IPv6. From patented technology in past, meter protocols have been standardized to DLMS(COSEM) and IEC 62056-1.

In India, first metering regulation was issued by CEA in 2006 (Installation and Operation of Meters, regulation 2006) which directed the utilities to install static meters at designated locations and set upon the methodology for ownership, settlement mechanism, periodic testing and general specification. Through amended of said regulation in 2010, CEA denoted Meter specifications more precisely including the accuracy class and conformance tests for meters. With rise in renewable energy installation, CEA through its amendment regulation 2014 made it applicable to grid interactive renewable energy plants seeking the grid connectivity at 415 V and specified the location of RE Meters and metering arrangement. In 2019, CEA issued amendment to regulation by specifying pre-paid meters for all new connections setting out a mechanism for difference in main and check meters. CEA also directed stakeholder on cyber-security and incorporation of new energy registers for reactive energy and Wh recording. CEA in its latest amendment in 2022 specified Advance Metering Infrastructure (AMI) and Advance Metering Infrastructure Service Provider (AMISP) and directed utilities to use smart meters with pre-payment facility.

Ministry of Power (MoP) vide its memorandum Mar 2015 established National Smart Grid Mission (NSGM) to accelerate smart grid deployment in India. The stakeholders are discoms, regulators, CEA and electrical manufacturers. NSGM plan and monitor implementation of the policies and programs related to Smart Grids in the country. Deployment of Smart Meters as per Table 1.

Scheme	Awarded	% of Sanctioned	Installed	% of Awarded
Feeder Meters	122,575	67%	13,029	11%
DT Meters	4,005,812	76%	40,436	1%
Consumer Meters	116,295,349	52%	11,192,728	10%
Status May 2024, Credit: National Smart Grid Mission, MoP				

Table 1 : Smart Meter deployment status, India

2 SMART METERS AND FEATURES EXCEEDING CONVENTIONAL STATIC METERS

Static meters have been in service for the last 30 years. Smart Meters have unique functionalities which empower both customers and utilities in their various monitoring and control measures. Salient features included in Smart Meter Technical specifications are:

A. Metering features – Basic metering features include programmable TOU metering, load profile and daily energy profile data, transaction events and relay control, flip-flop feature between pre-paid and post paid & vice versa, android application for customers to view consumption details, power quality parameters etc.

B. Control features – Peak load management (PLM), remote management and control on detection of theft, Remote connect and disconnect feature, connect and disconnect on contract demand violations and compliances, firm ware update.

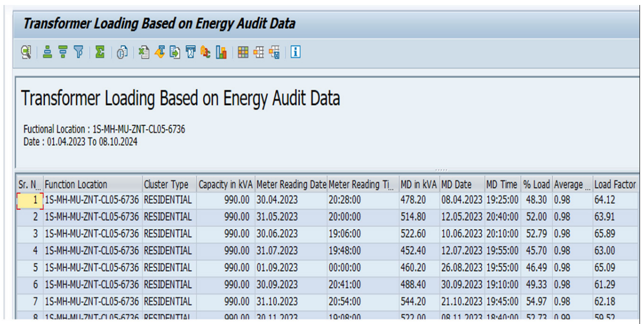
C. Communication features – Built-in RF or cellular communication modem with replaceable feature, event reporting to AMI server on finding critical anomalies, on demand bi-directional communication, Plug & play feature, DLMS/COSEM based open standard etc.

3 USE CASES OF METER DATA

Utilities like AEML-D have an open mesh network wherein the supply of customer substation (CSS) is fed from two distinct distribution substations (DSS) with one of the sources on hot standby. Through Distributed Management System (DMS), remote operation is done through control center. AEML-D through its ADMS system has achieved reliability of more than 99.998%.

Customers connected to CSS also have the facility of LT back feeding arrangement. In case of failure of HT supply of CSS or DT abnormality, customer supply is restored through LT supply through nearby DT available in LV panel of affected CSS.

AEML-D has provided 100% DT metering. DT meters are remotely read every month, and the data is populated in SAP ISU. Energy Audit function validates the meter readings and consumption details. Meter data comprising of maximum demand, load factor, PF etc. are uploaded against the unique DT IDs in SAP PM system. [Fig 1]


Transformer Loading Based on Energy Audit Data

Transformer Loading Based on Energy Audit Data

Fuctional Location : 1S-MH-MU-ZNT-CL05-6736
Date : 01.04.2023 To 08.10.2024

Sr. N...	Function Location	Cluster Type	Capacity in kVA	Meter Reading Date	Meter Reading Ti...	MD in kVA	MD Date	MD Time	% Load	Average ...	Load Factor
1	1S-MH-MU-ZNT-CL05-6736	RESIDENTIAL	990.00	30.04.2023	20:28:00	478.20	08.04.2023	19:25:00	48.30	0.98	64.12
2	1S-MH-MU-ZNT-CL05-6736	RESIDENTIAL	990.00	31.05.2023	20:00:00	514.80	12.05.2023	20:40:00	52.00	0.98	63.91
3	1S-MH-MU-ZNT-CL05-6736	RESIDENTIAL	990.00	30.06.2023	19:06:00	522.60	10.06.2023	20:10:00	52.79	0.98	65.89
4	1S-MH-MU-ZNT-CL05-6736	RESIDENTIAL	990.00	31.07.2023	19:48:00	452.40	12.07.2023	19:55:00	45.70	0.98	63.00
5	1S-MH-MU-ZNT-CL05-6736	RESIDENTIAL	990.00	01.09.2023	00:00:00	460.20	26.08.2023	19:55:00	46.49	0.98	65.09
6	1S-MH-MU-ZNT-CL05-6736	RESIDENTIAL	990.00	30.09.2023	20:41:00	488.40	30.09.2023	19:10:00	49.33	0.98	61.29
7	1S-MH-MU-ZNT-CL05-6736	RESIDENTIAL	990.00	31.10.2023	20:54:00	544.20	21.10.2023	19:45:00	54.97	0.98	62.18

Fig 1: DT consumption in SAP PM system

DT data is extensively used for network optimization and capex planning. Demand response by way of shifting the load curve to fully utilize the non-conventional supply is a new avenue available to utilities and customers.

This technical paper discusses in detail the said two use cases and provides a forward path for further evaluation and deployment.

A. Network optimization and Capex planning DTs are procured for new supply release, load augmentation and obsolescence planning. Capex planning is required to be the combination of all three factors to address the load growth in future. Mumbai has witnessed a huge rise in peak demand over the years. This summer, Mumbai registered peak demand of 4041 MW during April 2024 which is in excess of 400 MW than usual demand. AEML-D has registered peak demand in excess of 2300 MW which can be attributed to the rise in AC usage and load growth.

DT loading is discretely monitored to avoid prolonged overloading which directly affects the transformer life. Based on run-down policy, DT loading optimization is carried out as per the technical paper presented by AEML-D in Metering India 2022. Another significant component of the network is LT ACBs (Air Circuit Breaker). AEML-D has few legacy LT ACBs with Al links and are subjected to thermal stresses during peak loading. Based on DT MD analysis, AEML-D has optimized the Al link LT ACB operational limits as per following details:

Breaker Rating	De-rated Capacity (AL Links)	Suitable for DT Capacity
1600 Amps	950 A	630 kVA
2000 Amps	1200A	750 kVA
3200 Amps	1900A	1000 kVA

Table 2: LT ACB De-rated Capacity as per DT MD

Evaluation of Meter data for Capex planning: Cluster wise DT loading analysis is usually available with utilities. DT-wise CAGR is calculated based on peak MD figures for the last five years [Table 3]. Based on the current CAGR, peak demand for a cluster is projected for the next five years. To meet N-1 criterion, DT requirement is worked-out for existing pockets.

DT kVA	CAGR	MD 24	MD 23	MD 22	MD 21	MD 20
630	6%	492.6	469.2	532.2	352.2	367.8
630	6%	581.0	490.8	503.4	496.8	444.3

Table 3: CAGR calculation – DT wise

Obsolescence planning for DT has following main criterion:

a. Age of DT (highest score for age >40)

b. Loading (highest score for MD >80%)

c. Malfunction events (highest score for events > 5 in last 10 years)

d. Abnormalities events (highest score for events > 5 in last 10 years)

The final score is a x b x c x d.

DT kVA	Score1 (Age)	Score 4 Loading	Score 3 Malfunction	Score2 (Abnormality)	Final Score
630	5	5	5	5	625
	39 Yrs.	86%	5 nos.	5 nos.	
400	7	5	3	5	525
	41 Yrs.	96%	3 nos.	5 nos.	

Table 4: Obsolescence scoring for DT

DT modelling for obsolescence requires diligent analysis to foresee the failures and replace the asset in time. The similar criterion can be applied to other assets also including Switchgears, LT breakers and panels.

B. Managing load curve through demand response using the energy mix

On May 30, 2024, India's peak power demand hit a new high of 250 GW due to intense heat wave and growing power demand from Industrial and residential sectors. Peak Demand shortage of India was more than 2200 MW [Table 5]. This is attributed due to the drop in Hydel Generation and Coal shortage. Though coal contributed to 50% of total energy generation, Renewable energy use is on the rise thanks to various Indian Government initiatives.

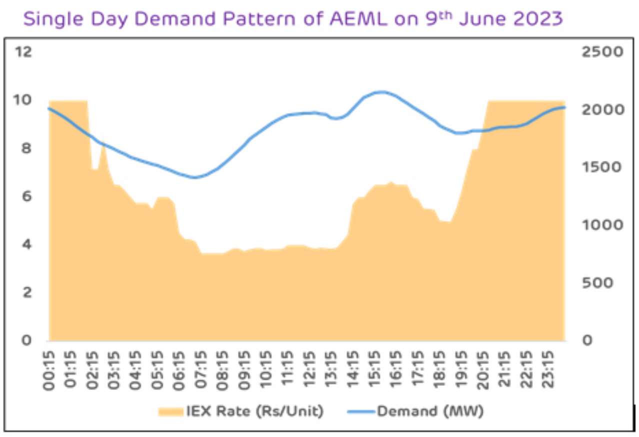
India's peak power demand met

Day	Peak Demand Met (GW)	Peak Shortage (MW)	Energy Met (MU)	Generation Outage (MW)
24-May	239.96	1,685	5,269	31,712
23-May	236.60	2,224	5,181	27,713
22-May	235.06	300	5,168	26,221
21-May	233.81	1185	5,075	27,469
20-May	228.72	11	4,995	29,581
19-May	218.50	40	4,864	32,755
18-May	229.58	0	5,085	28,893
17-May	225.93	318	5,050	29,855
16-May	226.37	132	5,016	30,351
15-May	226.15	902	4,961	27,793

Source: Grid India; GW: Gigawatt; MW: Megawatts; MU: Million Units;
Generation Outage: When a power generating unit is not operational

Table 5: India Peak power demand stats.

Commercial Building/Offices load pattern consists of two peaks namely for early morning and post noon. During that time of day only conventional (Thermal) generation is available to its full potential resulting in consumption of costly conventional power with huge carbon footprint. [Graph-1]



Graph-1: Typical single day demand curve of AEML. Energy rate (INR) Vs Demand (MW)

To manage peak loads there are 4 avenues available with utilities as mentioned [in Table 6]

Avenues Available	Measures to be taken at consumer end	Impact
Generation of RE	Provision of Rooftop solar. PV exports electricity to the grid	Reduced T&D losses due to on-site consumption; avoided need for grid-scale generation
Shifting of load	Shifting of HVAC and motive loads during non-peak periods. Avoid starting multiple loads during peak period.	Reduced energy costs due to shifting consumption to cheaper hours of the day, avoided curtailment of renewables during off-peak periods
Enhanced efficiency	Building has an insulated, envelope & an efficient HVAC system to reduce heating / cooling energy needs	Reduced costs of burning fuel to satisfy energy demand, and reduced emissions associated with lower fuel use
Reduction of load	Building dims lighting system / switch of load by a preset amount in response to grid signals while maintaining occupant visual comfort levels	Reduced investment in generation and transmission capacity due to lower peak demand

Proposed Solution - Commercial buildings are proposed for the solution implementation.

- AI/ML Modelling to predict load patterns
- AI/ML Modelling to work out DR scheme
- Use of IoT Sensors and devices to control demand
- Making Commercial Buildings grid integrated efficient buildings.
- Increase contribution of RE Power in Peak Demand

Approach – It has 3 tier approach as below

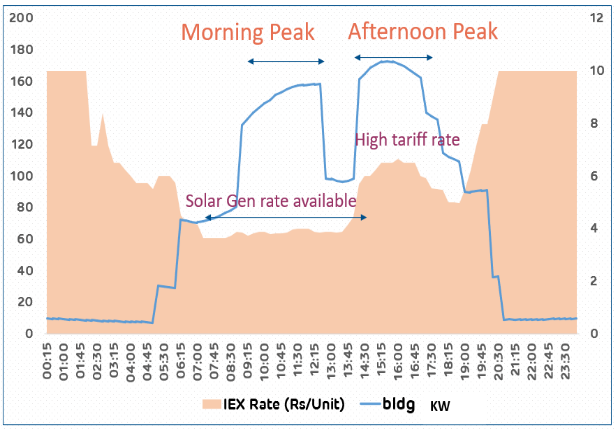
Tier 1: Building of ML Model to predict day ahead peak pattern of Commercial Load. Based on ML Model, Demand Response scheme is devised with incentives and approved through Regulatory Commission. Voluntary participation by Customers in DR scheme.

Tier 2: Identify the loads/HVAC system for moderation and integrating through HAN (Home Area Network) / BMS using IoT Devices.

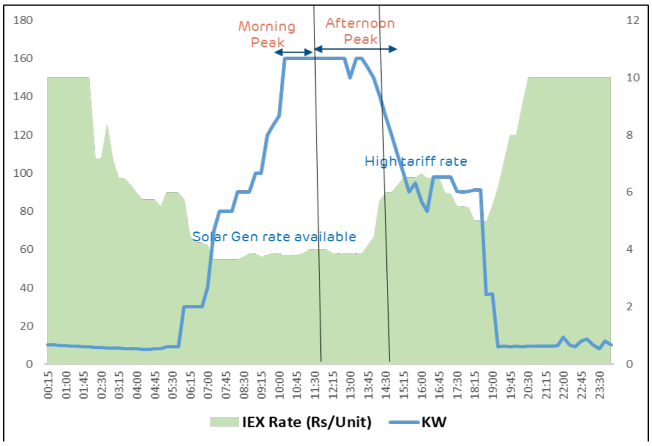
Tier 3: Shifting the Peak to mid-day to use renewable generation like Solar, wind etc.

The AI/ML model predicts the grid peak

demand and parallelly carry trend analysis of commercial building from past data. Before peaking necessary steps are taken by model via smart meters and gateway at consumer premises to shift the peak demand. Pre and Post effects of proposed solution on Peak load of commercial buildings shall be as mentioned in graphs 2 and 3 below.



Graph 2: Single Day Demand curve of Typical Commercial Building- Before



Graph 3: Single Day Demand curve of Typical Commercial Building- After

Benefits envisaged are –

- High grid stability by exhibiting Demand response program
- Effective use of RE in managing peak load
- Reduction in generation of Greenhouse gases. (1.4 million MTOe of CO2) Reduce peak load.
- Monetary benefit to consumers

Challenges –

- Customer participation in demand response program.
- Regulatory environment and approval of DR scheme.
- Cost feasible IoT sensors and communication network
- Fluctuation in fuel prices and varying power cost.
- Cybersecurity threats

The vision of a smart, two-way grid interacting with smart, grid-responsive buildings provides the promise of fortifying the system to deal with economic, security, supply and demand disruptions while leveraging new opportunities for efficiency, cost savings, resilience, and distributed energy generation.

4 CONCLUSIONS

In this paper various avenues and use cases for meter data have been discussed. With advent of AI/ML many more use cases can be generated which shall not only support utilities in conscious decision on asset portfolio management, customer engagement and empowerment but also many new avenues shall open for enhancing the operational efficiency through just in time actions for maintenance activities. With Smart Meters, utilities are better placed to serve their customers in terms of more autonomy given and more transparency in operations.

5 REFERENCES

[1] https://eu.landisgyr.com/blog/landisgyrs-communication-portfolio-complements-with-rf-mesh-ip-0

[2] https://www.inhand.com/en/support/blogs/what-is-ipv6/

[3] https://www.smart-energy.com/regional-news/asia/cyanconnode-genus-power-infrastructures/

[4] https://www.hindustantimes.com/cities/mumbai-news/heatwave-pushes-peak-power-demand-beyond-4-000-mw-101713295005372.html

[5] https://www.nsgm.gov.in/en/sm-stats-all

BIO-DATA

ASHWENI KUMAR JAIN
Adani Electricity Mumbai Limited

Date of Birth: 3rd July 1978

Qualification: BE (Electrical), PG Diploma in Thermal Power Plant Engineering, Six Sigma Black Belt, PGDBM from Emirates

Designation: Additional Vice President, Head (Diagnostic)

Present Organization: Adani Electricity Mumbai Limited

Field of Expertise: Product Engineering & Diagnostics, Revenue Metering and Energy Audit, Analytics and Strategy

Mobile: +91 93236 29444

Email: ashweni.jain@adani.com

BRIEF PROFILE

22 Years of experience in various functions of distribution utility like HT industrial Metering and billing, Product Engineering, Energy Audit, Budgeting. Currently heading the Equipment Diagnostic and Maintenance planning of AEML-D, Mumbai. Certified Energy Auditor, Six Sigma black belt and Lead Auditor for IMS. Has published more than 14 Technical papers in various forums.

NIRANJAN PARKHI
Adani Electricity Mumbai Limited

Date of Birth: 9th August 1978

Qualification: B.E.(Electrical), MBA (Finance), PGDBM (EMERITUS), Six Sigma Black belt

Designation: General Manager

Present Organization: Adani Electricity Mumbai Ltd

Field of Expertise: Diagnostics, Quality, Safety and compliance, System Controller (SCADA), HT & LT Maintenance, Asset management

Mobile: +91 93240 56709

Email: niranjan.parkhi@adani.com

BRIEF PROFILE

Has 22 yrs of experience for working in Distribution utility. Have worked in diverse background in Diagnostics, Quality, Safety and Compliance, SCADA System Control, HT & LT Maintenance, and Asset Management. Skilled in enhancing operational efficiency, optimizing asset performance, and ensuring regulatory compliance. . Worked as Lead in various projects in AEML under six sigma, Northstar Leadership program and ICQC. Currently working as Incharge-Diagnostic

METERING APPLICATIONS BEYOND BILLING

Nikhil Naik | Amit Kumar Sharma
Kimbal Technologies

ABSTRACT

Metering has long been essential in the utility sector for tracking energy usage and generating bills based on actual consumption. This paper examines the shift from traditional billing meters to modern smart systems. It focuses on the Smart Prepaid Metering System, enabling consumers to buy utility credits upfront and better manage usage. The paper also highlights Net Metering's role in integrating microgrids with conventional grids, fostering sustainable energy.

Keywords—Smart meter, Net Meter, prepaid meter, smart Grid, Renewable Energy

1 INTRODUCTION

Metering has been essential in the utility sector for accurately measuring energy consumption and enabling precise billing. However, traditional systems were limited to recording usage and billing. With digital technologies and growing demand for efficient energy management, modern metering systems have evolved significantly.

The advent of digital technologies and demand for smarter energy management have transformed metering systems. Traditional mechanical or analog meters are being replaced by advanced digital systems, known as smart meters, which offer capabilities far beyond basic consumption tracking for billing.

Smart meters mark a major advancement in metering technology, enabling two-way communication between utilities and consumers. This real-time data exchange provides insights into energy usage and supports proactive decision-making. Key benefits include improved energy efficiency, better grid management, and higher consumer engagement.

This paper explores the evolution of metering systems from basic billing tools to advanced smart solutions. It examines the benefits of modern smart meters, including the Smart Prepaid Metering System, which enables consumers to buy credits in advance and manage usage efficiently. It also discusses Net Metering, which supports microgrid integration, promotes renewable energy adoption and enhances grid stability.

This paper highlights how smart metering systems can revolutionize the utility sector, enabling efficient energy management, consumer empowerment, and sustainable energy adoption. Through case studies and discussions on challenges and future directions, it emphasizes the need for continued innovation and support to shape the future of energy consumption and distribution.

2 PEAK LOAD MANAGEMENT AND DEMAND RESPONSE

Smart meters enhance Peak Load Management (PLM) and Demand Response (DR) by providing real-time data for optimizing energy use and ensuring grid stability. Accurate monitoring offers consumers feedback to adjust usage, save energy, and lower costs, while utilities gain improved load forecasting and planning.

Automated DR enables swift responses to pricing signals, optimizing energy use and supporting dynamic pricing models. Effective PLM allows utilities to forecast peak demand, reducing the need for costly generation capacity and enabling load shifting.

Smart meters increase consumer engagement by providing detailed usage data, encouraging participation in DR programs, and helping manage demand. They also enhance grid reliability by offering real-time data, reducing blackout risks, and supporting renewable energy integration.

Cost savings for both utilities and consumers come from optimized energy use, reduced reliance on peak generation, and participation in DR programs. Smart meters promote sustainability by reducing the need for fossil-fuel-based plants and integrating renewable energy, supporting broader environmental goals.

3 MICROGRID INTEGRATION THROUGH NET METERING

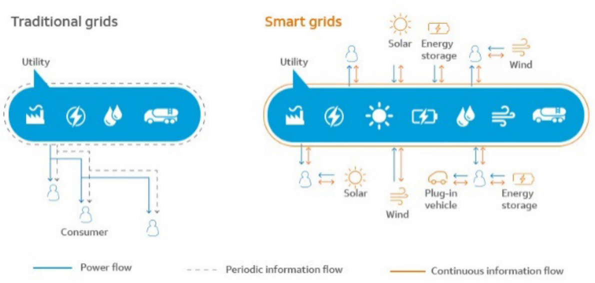


Fig-1: Smart Grid integration

Smart meters also play a crucial role in integrating microgrids into the traditional grid through Net Metering. Net Metering allows consumers who generate their own electricity (e.g., via solar panels) to feed excess energy back into the grid and receive credits on their bills.

Renewable Energy Adoption: Encourages the use of renewable energy sources by making it financially viable for consumers.

Grid Stability: Enhances grid stability and resilience by diversifying energy sources and distribution.

Environmental Benefits: Reduces reliance on fossil fuels, lowering greenhouse gas emissions.

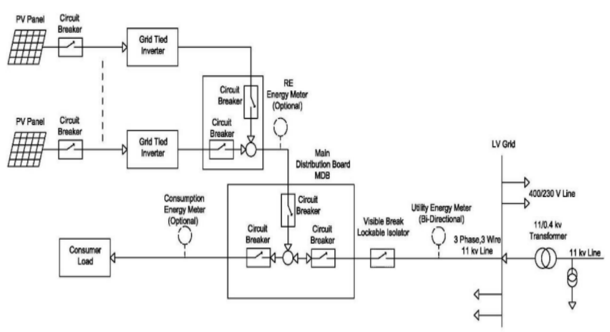


Fig-2: Solar Net Metering

4 POWER QUALITY MANAGEMENT

In smart grid systems, smart meters capture key electrical parameters at specific points in the grid. This data enables electricity distribution companies to monitor voltage usage for each user, allowing for automatic adjustments of substation voltage based on smart meter feedback.

Before smart meters, electricity distribution companies relied on engineering estimates to predict voltage needs, often sending higher voltage to ensure sufficient power for all users. This approach caused issues when actual usage differed from estimates, resulting in poor power quality and increased costs for both utilities and end-users.

Smart grid systems have eliminated these problems. Fully automated, they rely on data from smart meters for decision-making. As a result, the voltage, frequency, and current on the grid are based on actual data sent to the control centre.

5 AT&C LOSSES REDUCTION FOR DISCOMS

mart meters play a crucial role in reducing AT&C losses, enhancing the efficiency, reliability, and financial health of India's power sector. They ensure accurate billing and real-time data collection, eliminating manual errors and billing delays. Prepaid options guarantee upfront revenue collection, minimizing unpaid bills.

Smart meters also combat electricity theft by detecting anomalies and tamper attempts, enabling swift action and reducing commercial losses. They provide real-time monitoring of technical issues, optimizing load distribution and reducing energy wastage.

Moreover, smart meters improve operational efficiency by enabling remote management, lowering operational costs, and facilitating better asset management, extending infrastructure lifespan.

6 SMART METER IN THE MANAGEMENT OF ELECTRIC VEHICLE CHARGING FACILITIES

Smart meters play a crucial role in enabling smart Electric Vehicle (EV) charging by providing detailed, real-time information about electricity usage and grid conditions. This functionality supports more efficient, cost-effective, and environmentally friendly charging practices. By offering real-time data on electricity consumption, smart meters allow EV owners to monitor precisely when their vehicle is charging and how much electricity it is using. This monitoring capability helps identify the optimal times to charge, typically during off-peak hours when electricity demand and prices are lower, thereby saving money and reducing strain on the grid.

BENEFITS OF SMART METERING TECH FOR ELECTRIC VEHICLES

Energy Usage Understanding: Smart metering solutions provide detailed energy consumption data to consumers, increasing awareness and enabling informed decisions. This helps EV owners optimize charging habits and reduce energy use.

Utility Planning and Operations: Accurate and timely data from smart meters enhances utility planning and operations. This allows for better demand forecasting, optimized power purchasing, and streamlined operations, ultimately benefiting EV users.

Tariff – An important tool: Electricity tariffs are a key tool for state governments to manage EV charging. Recognizing EV charging as a distinct consumer category can simplify power connections. EV-specific tariffs offer benefits like sending price signals to users and managing load profiles. They also impact charging operator costs and the viability of public charging. Separate EV tariffs allow for incentives to encourage adoption, such as:

a. **Exempted Demand Charges:** Waiving demand charges, the fixed cost based on peak power usage, can incentivize EV charging infrastructure development. This is particularly beneficial during the early stages of EV adoption when charging demand is low.

b. **Reduced Energy Charges:** The variable cost based on electricity consumption, benefit both charging point operators (CPOs) and EV users. CPOs can lower their operating expenses, while EV users enjoy reduced charging costs. As of March 2021, 21 states and Union Territories in India have implemented EV-specific tariffs with reduced energy charges and/or demand charge exemptions

7 REDUCING ENERGY CONSUMPTION AND CARBON FOOTPRINTS WITH SMART METERS

In the face of climate change, smart meters are essential for reducing energy use and carbon emissions. By providing detailed consumption data, they empower consumers to make informed decisions and lessen their environmental impact.

Real-Time Data and Consumer Awareness

Unlike traditional meters, smart meters provide continuous, real-time energy consumption data. This allows consumers to monitor their usage and adopt energy-efficient practices.

For example, by pinpointing energy-intensive appliances and activities, consumers can take practical steps to reduce consumption. This includes unplugging unused devices, optimizing heating and cooling, and shifting high-energy activities away from peak hours.

Increased customer satisfaction is another benefit of smart meters. According to the Council on Energy, Environment, and Water (CEEW) survey, 60% of respondents expressed satisfaction with the technology's convenient bill payment and utility management features.

Accurate and Responsive Energy Management

Beyond raising consumer awareness, smart meters optimize energy management. By analyzing consumption data, these devices help allocate and utilize energy resources more effectively, minimizing waste.

Smart meters enable efficient grid management by balancing energy load, reducing the need for peak-time power generation, and supporting demand response programs. This lowers emissions and encourages consumers to shift their energy use, further reducing reliance on fossil fuels.

Efficient Use of Energy Resources

Smart meters promote efficient energy use by providing detailed consumption data. This empowers consumers to make informed decisions about their energy use and adopt sustainable practices, while enabling utilities to optimize grid operations and integrate renewables.

By providing data on energy demand and supply, smart meters help utilities reduce waste and identify inefficiencies in the grid. This leads to a more efficient energy system with a lower environmental impact.

Positive Environmental Impact

Smart meters significantly lower energy consumption, directly benefiting the environment by reducing greenhouse gas emissions from fossil fuel power plants. This reduction is vital for mitigating climate change.

Additionally, smart meters facilitate the integration of renewable energy sources by providing accurate data on production and consumption. This enables utilities to manage renewable energy variability effectively, further decreasing reliance on fossil fuels and promoting a cleaner, greener energy future.

The government aims to install 250 million smart meters by 2025 under the Smart Meter National Programme. This ambitious goal highlights its commitment to modernizing India's energy infrastructure and improving efficiency.

By providing real-time energy consumption data, smart meters empower consumers to reduce their environmental impact. This supports India's goals of addressing climate change and transitioning to a low-carbon economy.

Smart meters enable the integration of low-carbon technologies and renewables, contributing to significant carbon savings. A Delta-ee report projects a 25% reduction in CO_2 emissions by 2035 through more efficient energy use in households.

8 USE CASES AND PILOT IMPLEMENTATION

MICROGRID INTEGRATION THROUGH NET METERING

USE CASE 1: Ministry of New & Renewable Energy – RTS Programme Phase-II Grid connected Rooftop Solar Scheme & Virtual Net Metering

The Phase-II scheme aims for 40,000 MW rooftop solar capacity by 2026. Smart meters enable net metering by tracking energy generation, consumption, and export, ensuring fair billing and grid stability. They provide real-time data for consumers to optimize usage and join demand response programs. DISCOMs benefit from improved load balancing, fewer non-technical losses, and transparent transactions.

Smart meters are deployed through DISCOM-led rollouts integrated with rooftop solar systems. Residential consumers receive subsidies for installations, and DISCOMs are incentivized to enhance energy management. These meters, based on Advanced Metering Infrastructure (AMI), enable two-way communication and real-time data exchange, fostering solar investments and seamless grid integration, advancing India's clean energy transition.

The Ministry of New and Renewable Energy clarified that the Central Financial Assistance (CFA) under RTS Programme Phase-II also applies to solar plants set up under Virtual Net Metering (VNM), subject to conditions. The programme supports RTS installation in residential sectors, including individual households and Group Housing Societies/ Residential Welfare Associations. Some states and union territories allow VNM, enabling groups of consumers within the same DISCOM to install a solar plant and benefit from net metering for the power fed into the grid.

As of February 2024, India's renewable energy capacity is ~183 GW (including hydro), with distributed renewable energy (DRE) like rooftop solar contributing only ~6%. While utility-scale installations dominate, DRE has room to grow through innovative concepts like virtual net metering (VNM) and group net metering (GNM) for rooftop and ground-mounted systems. Four state commissions introduced these models: Delhi in 2019, followed by JERC, OERC, and MERC in 2023.

Promoting solar plants through virtual net metering in rural areas benefits DISCOMs by ensuring reliable daytime power for villagers, boosting income through economic activities, and increasing commercial/ industrial consumers. It also reduces network augmentation and maintenance costs while helping DISCOMs meet their Renewable Purchase Obligation (RPO) targets.

USE CASE 2: TP Renewable Solar Microgrid for Rural Electrification

Tata Power's subsidiary, TPRMG, leads India in solar microgrids, aiming for 10,000 installations. In a year, it deployed 161, mainly in Uttar Pradesh and Bihar, with a pilot in Odisha. Microgrid power, costing a fifth of diesel, makes it affordable, serving various rural needs from homes to clinics.

The company uses clustered smart meters and net metering, allowing consumers to earn credits for excess solar energy. Solar microgrids typically include PV arrays, a Power Conditioning Unit (PCU), and battery storage. The PCU manages power distribution to homes and businesses, storing surplus energy in batteries for nighttime use.

Solar microgrids are electrifying rural India, driven by public-private partnerships. Initial challenges with battery costs, diesel reliance, and high consumer expenses were overcome through innovation. Cost-effective batteries, biomass generators, and efficient appliances now make the model viable.

AT&C LOSSES REDUCTION FOR DISCOMS

USE CASE: Revamped Distribution Sector Scheme (RDSS)

India's Revamped Distribution Sector Scheme (RDSS) aims to improve the efficiency and financial health of power distribution companies (DISCOMs). It provides funding to strengthen infrastructure and is linked to achieving specific results.

The Government of India launched the Revamped Distribution Sector Scheme (RDSS) to enhance DISCOMs' efficiency and financial sustainability through result-linked financial assistance. With an outlay of ~Rs. 3.04 lakh crore over five years (FY 2021-22 to FY 2025-26), including ~Rs. 0.98 lakh crore in Government Budgetary Support, RDSS aims to:

a. Reduce AT&C losses to 12-15% by FY 2024-25.
b. Eliminate the ACS-ARR gap by FY 2024-25.
c. Improve power supply quality and affordability.

II. Prepaid smart meters are a key focus of India's RDSS, with a Rs. 1.5 lakh crore investment planned. The goal is to install 250 million meters, along with system metering infrastructure, to improve energy accounting and grid management. So far, plans for 30 states/UTs have been approved, and over 19.79 crore meters have been sanctioned.

III. Capital investment under RDSS targets loss reduction, system strengthening, and modernization. Loss reduction includes replacing bare conductors with AB cables, while system strengthening involves new substations and upgraded feeders. Modernization covers SCADA, DMS, IT/OT, ERP, and GIS applications. So far, ₹Rs. 1.21 lakh crore has been sanctioned for loss reduction works, with Rs. 5,806.48 crore released as Government Budgetary Support.

IV. Due to the reform measures under the scheme, AT&C losses have decreased to 15.41% (provisional) in FY 22-23. This reduction directly impacts the ACS-ARR gap, ultimately benefiting end consumers by ensuring quality supply.

SMART METER IN THE MANAGEMENT OF ELECTRIC VEHICLE CHARGING FACILITIES

USE CASE: EV Adoption by The Ministry of Road Transport and Highways (MoRTH)

Driven by the need for **sustainable transportation**, India has witnessed a significant rise in the adoption of **electric vehicles (EVs).** Data from the Ministry of Road Transport and Highways (MoRTH) reveals that EV sales surged by **82% year-on-year** in March 2023, reaching 139,789 units. Over the fiscal year 2022-23, total EV sales increased by an impressive **157%**, totaling 1,180,597 units. This substantial growth reflects India's shifting focus towards cleaner energy in the automotive sector, underscoring the critical role EVs will play in the country's future transportation system.

However, **widespread EV adoption requires a robust and scalable charging infrastructure**, which is currently a major challenge. **Smart metering solutions** offer a critical part of the solution to this infrastructure gap. By leveraging advanced technology and **real-time data analytics**, smart meters enable more efficient energy management, both for charging station operators and consumers.

Optimized Charging and Load Management: Smart meters can provide **dynamic pricing signals** to EV users, encouraging them to charge their vehicles during off-peak hours when electricity is cheaper and the grid is under less strain. This real-time communication between the grid and EV chargers ensures that the **charging load is distributed more evenly,** preventing grid overloads and enhancing overall energy efficiency.

Integration with Renewable Energy: Smart meters can play a vital role in integrating **renewable energy** into EV charging infrastructure. As India pushes towards increasing its share of renewable energy, smart meters can facilitate the use of **solar or wind energy** to charge EVs during peak production times, contributing to the nation's sustainability goals.

Data-Driven Decision Making: By collecting and analyzing data on charging patterns, grid performance, and energy usage, smart meters can provide valuable insights for **optimizing charging station placement** and **expanding EV infrastructure**. This data will enable utilities and policymakers to make informed decisions, ensuring that EV charging stations are available in high-demand areas while maintaining grid stability.

Support for Vehicle-to-Grid (V2G) Technology: Smart meters can enable Vehicle-to-Grid (V2G) systems, where EVs supply power back to the grid during high demand. This two-way interaction requires the precise data collection and real-time responsiveness provided by smart meters. Integrating smart meters into the EV ecosystem will help India deploy more EV charging stations while maintaining grid stability and efficiency. Smart meters also support real-time load management, dynamic pricing, and renewable energy integration, enhancing India's EV revolution. Ultimately, smart meters play a crucial role in advancing widespread EV adoption and achieving India's carbon reduction and energy sustainability goals.

9 CONCLUSIONS

Smart meters revolutionize the utility sector by providing real-time data that enhances energy management and conservation. They support peak load management (PLM) and demand response (DR) by enabling dynamic pricing models, encouraging off-peak usage, and reducing grid strain and carbon emissions. Smart meters also promote renewable energy integration through Net Metering, allowing consumers to feed surplus energy into the grid, reducing reliance on fossil fuels. They improve power quality with real-time monitoring and reduce AT&C losses by ensuring accurate billing and detecting theft. Overall, smart meters are essential for advancing energy efficiency, grid reliability, and sustainability.

10 ACKNOWLEDGMENTS

The Authors would like to express sincere gratitude to organization, Kimbal Technologies, their invaluable support and guidance throughout this research.

11 REFERENCES

1. Ghofrani, M.; Hassanzadeh, M.; Etezadi-Amoli, M.; Fadali, M. S., "Smart meter based short-term load forecasting for residential customers", 2011 North American Power Symposium, August 2011, pp. 1-5.

2. T. Ali, A. Al Mansur, Z. Bin Shams, S. M. Ferdous and M. A. Hoque, An overview of smart grid technology in Bangladesh: Development and opportunities, pp. 1-5, 2011.

3. G. R. Barai, S. Krishnan and B. Venkatesh, Smart metering and functionalities of smart meters in smart grid-a review, pp. 138-145, 2015

4. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=194770

5. https://pib.gov.in/PressReleseDetailm.aspx?PRID=1997977

6. https://www.researchgate.net/publication/343492502_The_Application_of_Smart_Meter_in_the_Management_of_Electric_Vehicle_Charging_Facilities

7. https://techobserver.in/news/opinion/can-smart-meters-make-india-energy-efficient-28530

8. https://www.niti.gov.in/site/default/files/2021-08/

BIO-DATA

AMIT KUMAR SHARMA
Kimbal Technologies

Date of Birth:	14th September 1993
Qualification;	B.E in Electronics and Communication Engineering
Designation:	Sr. Validation Engineer
Present Organization:	Kimbal
Field of Expertise:	Expertise in Validation of all types of Energy meters
Mobile:	+91 83879 18632
Email:	amit.sharma@kimbal.io

BRIEF PROFILE

Amit Kumar Sharma is a Senior Validation Engineer at Kimbal, driving key initiatives within the Customer Success team. He previously worked with Iskraemeco, Landis+Gyr, and Genus Power Infrastructures Ltd., gaining extensive validation experience. An alumnus of M.B.M. Engineering College, Jodhpur, and Birla Technical Training Institute, Pilani, he also brings hands-on expertise from roles in service and production with LMI India and Autolite (India).

BIO-DATA

NIKHIL NAIK
Kimbal Technologies

Date of Birth: 15-12-1998

Qualification: B. Tech in Electrical and Electronics Engineering

Designation: Validation engineer

Present Organization: Kimbal Technologies

Field of Expertise: Metering

Mobile: +91 70187 63407

Email: nikhil.naik@kimbal.io

BRIEF PROFILE

Nikhil Naik is a Project Manager at Kimbal, specializing in validation engineering and data validation for customer success. He brings valuable experience from his previous role as Assistant Manager at Tata Power-DDL, where he honed his skills in project planning, data analysis, and strategy execution within the advanced metering infrastructure domain. Nikhil holds a Bachelor of Technology degree in Electrical and Electronics Engineering from the National Institute of Technology, Hamirpur.

SMART METER DATA ANALYTICS A CASE STUDY FROM UTILITY PERSPECTIVE IN MP EAST DISCOM

Dr. Vivek Chandra
MP East DISCOM

Shreyash Shrivastava
Esyasoft Technologies

ABSTRACT:

The rise of smart meters installations has led to a massive collection of fine-grained electricity consumption-related data. Performing analytics on the data from utility as well as consumer perspective is vital to reap the true benefits of Smart Metering. MP is one of the few states which has a common Meter Data Management System in place, which has facilitated data analytics to a large extent. The discom has a sizable number of smart meter installations. Extensive analytics are being performed in the discom including development of a solar portal for analysis of the meter data in respect of the Solar Roof Top consumers.

Further a data analytics project on electricity theft detection carried out under Powerthon Project has added to the forte of analytics in the discom.

This paper aims at presenting a case study of the data analytics being performed in the discom.

INTRODUCTION:

With regard to Smart Meter Installation and associated analytics, East Discom in MP is one of the leading discoms in the country. The Discom has over 5 lakh smart meters including those on high value and solar roof-top consumers installed in urban and sub-urban areas across around 20 districts already in place. Further the establishment of a common meter data management system (C-MDM) in the state has facilitated data analytics leading to improved revenue protection and improvement in consumer services.

A data analytics assignment on electricity theft detection under Powerthon Project of MoP (Ministry of Power) was undertaken in the discom in year 2021-22. [1] The same has also added to the dimension of data analytics being performed in the utility.

C-MDM FOR ANALYTICS:

MP is one of the few states, where it was decided to have a common MDM in respect of all the Discoms way back in 2019. Establishment of MDM has facilitated a common platform for all sort of meter data analytics.

The architecture of the Common MDM is as under:

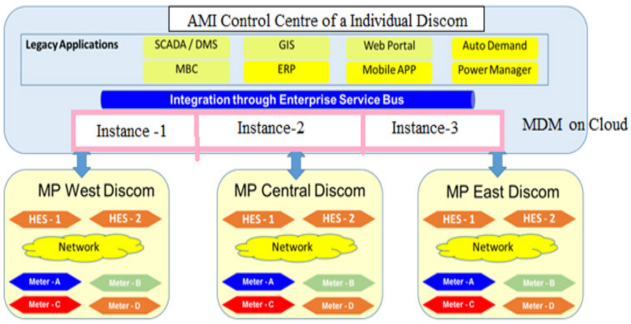


Fig-1: CMDMS Overview

SMART METER PROJECTS IN MP EAST DISCOM:

So far the discom has undertaken following three Smart Meter Projects:

S#	Particulars	Provision	Status
1	LT High Value Consumers (> 10 kW)	Across the discom	Around 16k meters installed, project is in support phase
2	Around 411 No. High Loss Feeders	10 lac meters on DTRs & consumers	4 lac meters installed
3	11 City divisions and 02 O&M divisions	8.5 lac meters on feeders, DTRs & consumers	In implementation phase

Table 1:-Smart meters Projects in MPPKVVCL

DATA ANALYTICS FROM UTILITY PERSPECTIVES:

(a) Revenue Protection :

Data analytics of consumer power consumption combined with tampers captured from the smart-meters can enable the DISCOM to identify consumption-related anomalies that can potentially signal theft. Anomalies in appliance-level consumption patterns accurately reveal theft via meter bypassing, meter tampering, tariff misuse and more.

C-MDM has a system called ATR (Action taken report) for structurally analyzing the huge amount of consumer data to extract revenue related information which can help the Discoms to identify potential theft cases & issues.

The ATR system provides ability to analyze the Meter events and validataions

S#	Event	Severity Level
1	Low/High Voltage in any phase	Low
2	Voltage unbalance	High
3	Voltage missing	High
4	Invalid voltage inputs	High
5	Overload(Current)	High
6	Load imbalance	Low
7	CT reversed	High
8	CT open	High
9	CT short / CT Bypass	High
10	High neutral current	High
11	Neutral disturbance	High
12	Abnormal external magnetic influence	High
13	Low PF	Low
14	Incorrect Phase Sequence	High

Table 2:-Smart meters Events

Validations comprising consumption anomalies

S#	Validation	Severity Level
1	Negative Consumption (kWh)	High
2	Improper MD KW Date	High
3	Improper MD kVa Date	High
4	PF > -0.8 and < 0.8	High
5	MD > CD	High
6	MDDate< Service Date	High
7	Abnormally High/Low Consumption	High
8	Zero Consumption	High
9	Consumption Compared to Last Month	High
10	Consumption as Compared to corresponding Month Last Year	High
11	LF < 5%	Low
12	LF > 100%	High
13	Night Zero Consumption	Low
14	Night consumption <= 10% of Day consumption	Low
15	Wrong Phase Association	High

Table 2:-Smart meters Validations

Workflow of the events and validations are defined in MDM for action at appropriate end.

All meter events are first analyzed by a central meter monitoring cell with a snapshot of the electrical parameters at the time of occurrence and restoration of event. If found worth exploration the event is transferred to corresponding EE (STM) for physical checking / further analysis. If any theft/tariff misuse is detected it is further transferred to EE (O&M)/ EE (City) for raising recovery.

All meter validations are analyzed by the vigilance squad and the O&M teams. After checking and further analysis due recoveries are raised.

The ATR helps automatically generate daily reports, monthly reports & service order requests for investigation & provides data records.

Meter Tampering & Flags:

Validations:

(b) Improvement in Operational Efficiency :

Asset Mapping & Consumer Indexing:

Smart Meters facilitate authentication of asset mapping and consumer indexing,

This can be achieved by mapping the last gasp of feeder meter with the last gasp of feeder meter with the last gasp of DT meters after switching off a feeder.

Further the consumer indexing can be authenticated by mapping the last gasp of consumer meters with the last gasp of DT meter after switching off a DT. [2]

This is being done by the discom to verify consumer indexing.

Monitoring Quality of supply:

On the basis of the data derived from the smart meters, low voltage pockets and load imbalance in DTs are identified. [3] Accordingly measures are undertaken for system improvement.

Identifying and mitigating load imbalance issues in certain consumer segments is crucial for improving system reliability and consumer satisfaction.

On analysis of smart meter data, it was observed that most of the Telecom tower connections have alarming imbalance of loads causing meter burnouts. On physical checking of loads it was inferred that telecommunication tower loads are single only. It was concluded that there is a need of procuring high capacity single phase meters to handle loads of such kind.

5. ADVANCED ELECTRICITY THEFT ANALYTICS THROUGH POWERTHON PROGRAM.

Under Powerthon Project launched by MoP in 2022, an agency M/s Bidgely Technologies was appointed in MP East Discom to carry out data analytics for electricity theft detection.

They used their patented energy disaggregation and machine learning algorithms to analyze the smart meter AMI data (current, voltage, power factor, MDI, meter events) along with third party weather data playing a key role in behavior modeling and anomaly detection with high confidence making the solution unique and reliable [4]. Majorly three type of cases were pointed out:

(a) Direct Theft Cases:

Few direct theft cases were pointed out using Heat Map analysis [5] of the consumption. An example of the same is illustrated as under:

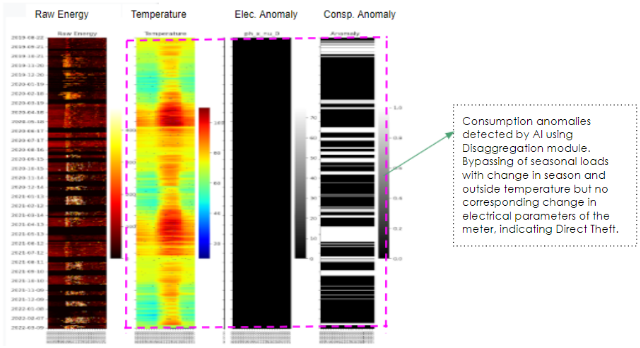


Fig-2: Visual illustration of Direct Theft with Heat map.

The figure shows 1-year of consumption pattern of the consumer, corresponding temperature during the year, electrical anomalies and consumption anomalies (white patches show drop in consumption) respectively. Consumption drops in many instances in the past with increase in outside temperature without any occurrence of meter event, indicates direct theft as in a normal behavior consumption increases with increase in outside temperature. Also repeated past instances increase the confidence of an anomalous behavior.

(b) Tariff Misuse Cases:

Domestic connection being used for Commercial activity. Subcategories of Tariff Misuse cases:

a. Non-domestic only

i. Day time commercial activity

ii. Night time commercial activity

iii. 24x7 commercial activity

b. Mixed use on same premise customer (day for commercial and night for residential or vice versa)

Few cases of Tariff misuse were detected using Heat Map analysis of the consumption. An example of the same is illustrated as under:

Visual illustration of a domestic consumer's consumption heat map (Figure 2 and 3) indicating typical SMB (Small or Medium Business) behavior detected by AI Algorithm.

The heat map is a visual representation of a consumer's interday (y axis) and intraday (x axis) consumption pattern across the whole year with brighter color indicating higher consumption & vice versa. There is a clear pattern visible on workdays & weekends with almost fix opening and closing time during weekdays.

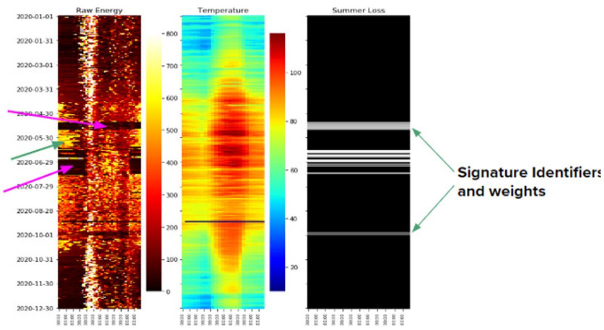


Fig-3: Visual illustration of Tariff Misuse with Heat map.

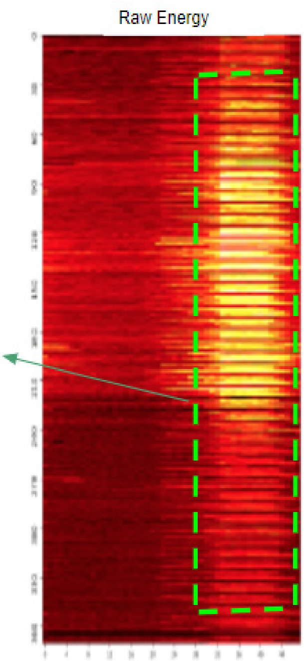


Fig-4: Visual illustration of Tariff Misuse with Heat map.

On physical inspection it was found that the consumer was indeed using the connection for warehouse, which is a commercial activity. Recovery was raised for the tariff misuse which the consumer readily paid.

c. Meter Tampering Cases:

Few meter tamper cases were detected using Heat Map analysis of the consumption. An example of the same is illustrated as under:

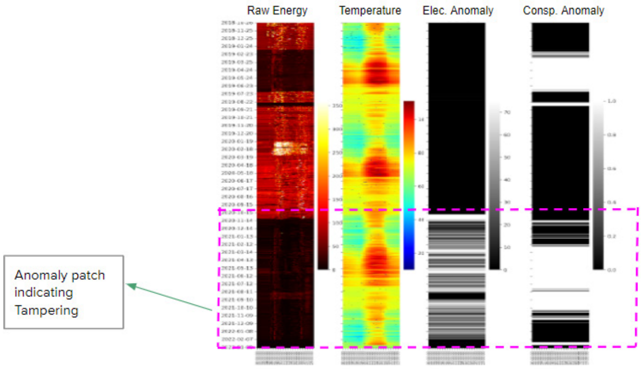


Fig-5: Visual illustration of Meter Tampering with Heat Maps.

The Heat map in figure 5 shows a 1-year of consumption pattern of the consumer, corresponding temperature during the year, electrical anomalies (white patches) and consumption anomalies (white patches represent drop in consumption) respectively. Meter tampering behavior visible for the period where there is drop in consumption with corresponding electrical anomalies. A comprehensive view of electrical & consumption anomalies topped with the disaggregation module enhances the confidence in identifying meter tampering cases while eliminating false positives.

Meter Events data along with Load Survey and Billing Profile Data of Smart Meters were utilized to identify anomalies and potential theft, focusing on events like sudden drops in consumption and repeated tampering alerts. Validation reports along with meter events reports were developed to recognize theft-associated patterns, such as Current without voltage, R phase Voltage Missing, Y phase Voltage Missing, CT Open, Abnormal Magnetic Influence etc.

Multiple reports and dashboards are created in CMDM to monitor anomalies and possible cases of electricity theft.

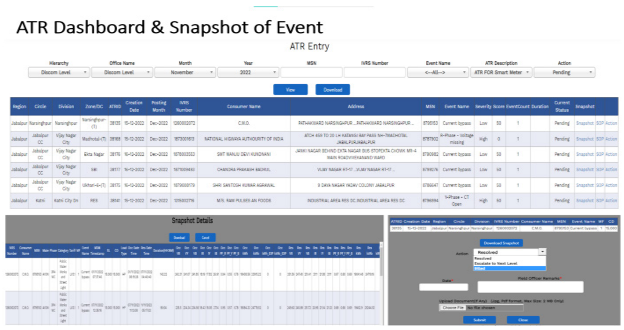


Fig-6: ATR Process Dashboard and Event Snapshots

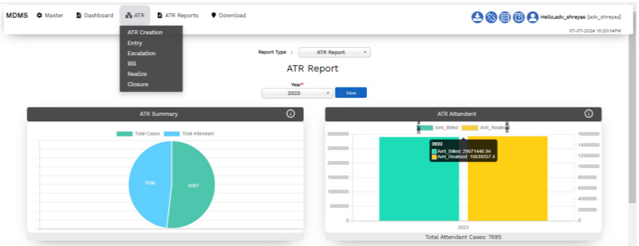


Fig-7: ATR Revenue Dashboard

This approach led to the identification and mitigation of numerous theft instances, significantly reducing non-technical losses and generating revenue, Fig 6 and Fig 7 depicts the ATR Workflow and ATR Summary of 2023 depicting the cases pointed out, amount raised and realized.

6. USING SMART METERS FOR FORECAST OF SOLAR ENERGY INJECTION

MPPKVVCL utilized smart meter data from solar consumers to monitor electricity export (generation) and import (consumption) patterns, Analyzed patterns to identify peak solar generation periods and align grid demand accordingly, Integrated insights into grid management systems to optimize overall system efficiency and reliability. Here for a particular consumer it can be seen that the monthly consumption and also observe its export and Import kWh during a day.

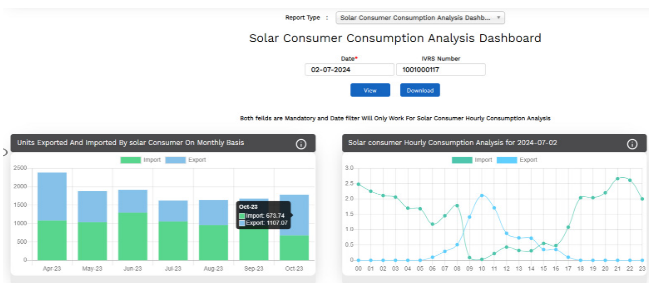


Fig-8: Solar Consumers Monthly Consumption Dashboard

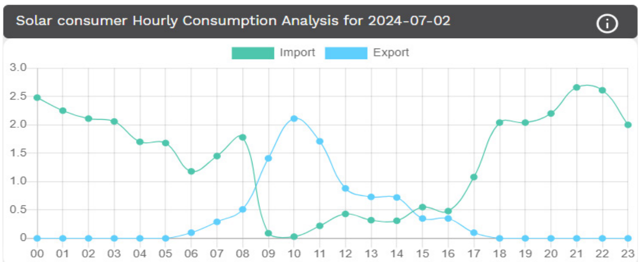


Fig-9: Solar Consumers Hourly Consumption Analysis for a Day.

Here it can be observed that for this consumer, solar panels begin exporting electricity as early as 5:00 AM, reaching peak export at around 10:00 AM. During this period, the import value decreases significantly, gradually tapering off until ceasing export by 6:00 PM. This clearly demonstrates that during daylight hours, solar power generation peaks, resulting in high export values and reduced imports, this along with Time-of-Day (TOD) analysis plays a crucial role in identifying these patterns, aiding in load forecasting and effective peak load management.

Fig 10 depicts, predicted vs actual Injection of Solar power for Solar Consumers based on the forecast using Smart Meters Data.

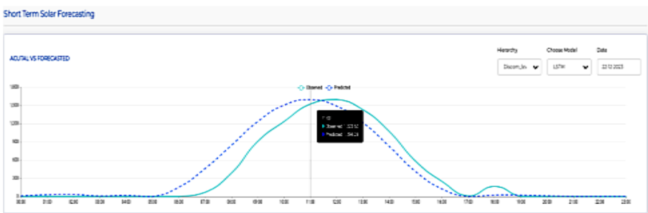


Fig-10: Solar forecast vs Actual Solar Injection Analysis for a Day.

Multiple reports have been developed for monitoring and managing solar export and import patterns using smart meters have facilitated more efficient grid operations, reducing reliance on non-renewable sources during peak periods and enhancing grid stability.

Identification of Areas with High Interruptions and Power Outages

Identifying areas with frequent power interruptions and outages is crucial for prioritizing maintenance activities and improving system reliability.[6,7,8]

Data from smart meters and their Event and Load Survey data is used to track interruptions and outages. In Outage Analysis Frequency, duration, and causes of outages were analyzed to identify high interruption areas. It is being used to investigate underlying causes of outages, such as equipment failures and overloading. Prioritized maintenance and upgrades in high interruption areas, implementing preventive measures are being taken.

Reports on feeder-wise Reliability indices like SAIFI and SAIDI are generated to analyze the number of Interruption and outage feeder-wise.

Feeder Name	Feeder Code	Total Consumer	Total events	SAIFI	SAIDI_HH:MM
11KV NAGARPALIKA	10456	4624	2572	1	0:14
11KV TOWN-3	7075	3490	2050	1	0:15
11KV DILAURA	9416	3181	8035	3	1:15
11KV BURHAR CHOWK	10472	2599	2083	1	0:14
11KV SOHAGPUR	10461	2553	8458	3	1:36
11KV CIVIL LINES	5621	2053	2051	1	2:09
11KV CITY-II	9426	1979	16134	8	3:50
11KV GANGOTRI COLONY	5396	1952	2197	1	0:43
11KV EMERGENCY	9428	1688	21522	13	6:40
11KV BHARHUT NAGAR	15665	1605	3696	2	1:13
11KV SHARDAPURAM	5398	1117	2231	2	1:36
11KV HOUSING BOARD	10471	864	4333	5	4:17
11KV KACHNAR-1	10288	705	1233	2	0:36
11KV COLLECTRATE	13730	682	473	1	0:14
11KV PILI KOTHI	5617	496	1852	4	2:29
11KV KACHNAR-2	10289	264	209	1	0:15
11KV CITY-I	9425	229	3102	14	8:30

Fig-11: Smart Meters Consumers wise SAIFI-SAIDI Report

Ensuring high power quality is essential for consumer satisfaction and the efficient operation of electrical appliances. [9,10] Analyzing smart meter Meters Load Survey data allowed us to identify and address issues such as low voltage, over-voltage, and frequent power outages within specific localities.

7. CONCLUSION & WAY FORWARD

Presently, in case of occurrence of more than one events in a Meter the events are analyzed separately (In isolation) by the technical team. It is pertinent to note that severity level of the anomaly would be more only when the two events supplement each other and make the case more severe. For example if a blood pressure patient is also suffering from diabetes then the patient is required to be examined considering both the diseases. There may be cases where two diseases are not related and don't have any combined effect. The meter events are also required to be examined with similar logic. AI based system could help in assessing the severity level of such simultaneous events in terms of probability of theft, development of which is the need of the hour. Development of such a system can pave way for a paradigm shift in the power distribution sector.

8. REFERENCES

[1] https://sineiitb.org/mop/pdf/Problem%20 Statements_Energy%20theft%20detection.pdf

[2] https://powerline.net.in/2020/11/04/ innovative-functions/

[3] https://genuspower.com/how-to-ensure-power-quality-monitoring-and-control-using-smart-metering-solutions/

[4] https://www.bidgely.com/technology/disaggregation/

[5] Weiqi Wang, Zixuan Zhou, Sybil Derrible, Yangqiu Song, Zhongming Lu,

Deep learning analysis of smart meter data from a small sample of room air conditioners facilitates routine assessment of their operational efficiency,

Energy and AI, Volume 16, 2024, 100338,

ISSN 2666-5468, https://doi.org/10.1016/j. egyai.2024.100338.

[6] Y. Wang, Q. Chen, T. Hong and C. Kang, "Review of Smart Meter Data Analytics: Applications, Methodologies, and Challenges," in IEEE Transactions on Smart Grid, vol. 10, no. 3, pp. 3125-3148, May 2019, doi: 10.1109/TSG.2018.2818167.

[7] Yash Chawla, Anna Kowalska-Pyzalska, Anna Skowrońska-Szmer, Perspectives of smart meters' roll-out in India: An empirical analysis of consumers' awareness and preferences, Energy Policy, Volume 146, 2020,111798, ISSN 0301-4215, https://doi. org/10.1016/j.enpol.2020.111798.

[8] R. Rituraj, P. Kádár and A. R. Varkonyi-Koczy, "Smart Meter: Advantages and its Roadmap in India," 2021 IEEE 4th International Conference and Workshop Óbuda on Electrical and Power Engineering (CANDO-EPE), Budapest, Hungary, 2021, pp. 131-138, doi: 10.1109/CANDO-EPE54223.2021.9667548.

[9] S. M. Sulaiman, P. A. Jeyanthy and D. Devaraj, "Smart Meter Data Analysis Issues: A Data Analytics Perspective," 2019 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS), Tamilnadu, India, 2019, pp. 1-5, doi: 10.1109/INCOS45849.2019.8951377.

[10] S. R. Biswal, T. Roy Choudhury, B. Panda, B. Nayak and G. C. Mahato, "Smart Meter: Impact and Usefulness on Smart Grids," 2021 IEEE 2nd International Conference on Applied Electromagnetics, Signal Processing, & Communication (AESPC), Bhubaneswar, India, 2021, pp. 1-6, doi: 10.1109/AESPC52704.2021. 9708492.

BIO-DATA

SHREYASH SHRIVASTAVA
Esyasoft Technologies

Date of Birth	11/03/1996
Qualification	M. E (Control Systems) B.E. (Electrical Engineering)
Designation:	**Sr.Business Analyst**
Present Organization:	**Esyasoft Technologies, Jabalpur(M.P)**

Field of Expertise:

1. MDMS & HES Management: Implementing and optimizing MDMS and HES for efficient smart meter data collection and communication.

2. AMISP Projects: Overseeing AMISP projects, ensuring successful deployment and integration of smart metering solutions.

3. Data & Theft Analysis: Analyzing smart meter data to identify consumption patterns, detect anomalies, and prevent electricity theft.

4. Load Forecasting: Developing load forecasting models to predict energy demand, aiding in effective grid management and planning.

Mobile:	**+91 8319576732, 8878383781**
Email:	**shreyash29shrivastav@gmail.com**

BRIEF PROFILE

I specialize in Meter Data Management System (MDMS), implementing and optimizing MDMS for efficient data collection, storage, and analysis of smart meter data. I manage and configure Head-End Systems (HES) to ensure seamless communication between smart meters and MDMS. I oversee Advanced Metering Infrastructure Service Provider (AMISP) projects, ensuring the successful deployment and integration of smart metering solutions.

Additionally, I conduct in-depth smart meter data analysis to identify consumption patterns, detect anomalies, and improve operational efficiency. I utilize smart meter data and advanced analytics for theft analysis, preventing electricity theft and enhancing revenue protection for utilities. I also develop and implement load forecasting models to predict future energy demand, aiding in effective grid management and planning.

BIO-DATA

DR VIVEK CHANDRA
MPPKVVCL

Date of Birth: 29/11/1967

Qualification:

- Ph.D in Computer Science
- MS in Artificial Intelligence & Machine Learning
- M. Tech (Power System Automation), RGPV
- PG Diploma in AI/ML, IIIT
- BE (Electrical Engineering), Govt. Engineering College

Designation: GM-IT

Present Organization: Madhya Pradesh Poorv Kshetra Vidyut Vitran Company Limited, Jabalpur

Field of Expertise:

- Implementation of Oracle ERP EBS
- Development of Meter Data Management System
- Development & Implementation of Meter Data Implementation System
- Development & Implementation of Advanced Consumer Care System.
- Setup of Data Ware House & development of dashboards using Power-BI.
- AI/ML
- Establishment of Tier-4 Data Centre under R-APDRP

Mobile: +91 94254 12325

Email: vivekchandra123@gmail.com

BRIEF PROFILE

I am a professional with a distinguished career in IT and power distribution management. Currently, I hold the position of General Manager (IT) at MP East Discom in Jabalpur, where I lead strategic initiatives aimed at enhancing operational efficiency and customer service through technological innovations. As the Head of IT deptt. , I have successfully led pivotal projects such as the implementation of Oracle ERP EBS and the development of Meter Data Management Systems. Notably, I established a Tier-4 Data Centre as the Engineer in charge and led the Analytics Cell for data warehousing and dashboard development.

I have received several awards for my contributions, including the National e-Governance Award from the GoI , GoMP and my organization. I am an active member of professional bodies like the Computer Society of India and the Institution of Engineers. Additionally, I serve on the Board of Studies at Jabalpur Engineering College, contributing to the advancement of IT and Computer Science education."

LEVERAGING METER DATA FOR CONSUMERS AND UTILITIES

Devanjan Dey | Ruman Maknojia | Ajit More | Vineeth Shetty
Tata Power Mumbai

1. INTRODUCTION

Tata Power – Mumbai Distribution is engaged in Retail Supply of Electricity across Mumbai License area with a base of 7.72 lakh consumer. Tata Power is a front runner in deployment of new technologies. As on date around 20,000 consumers, contributing to 80% of revenue are covered under GPRS, RF & RS485 AMR in our network. However, these meters are conventional non-smart meters. With our already acquired extensive experience in the field of AMR, we have started rollout of smart metering for our Mumbai consumers in year 2021 with the aim of fulfilling the Government directive and providing better services to our esteemed consumers. Till date, we have installed more than 1.30 lakh Smart meters at site.

TATA Power had deployed its backend Infrastructure namely Advanced metering Infrastructure comprising of Head end system (HES), Meter data management system (MDMS) backed by 4G network with end-to-end integration of Billing, Customer Relationship Management (CRM) and GIS system. TATA power had launched a unique Web portal and Mobile application namely "Know Your Electric Consumption (KYEC)".

The mobile application and portal are consumer-friendly and provide real-time energy consumption data in 15/30-minute intervals to all smart meter users. Various use cases have been developed for smart meters within the portal. With the mass rollout of smart meters, these use cases are designed to benefit both utility and consumers.

2. BENEFITS OF SMART METERS:

Smart meters offer a range of advanced features that traditional meters cannot match. Over time, the benefits of smart meters far outweigh the costs associated with their installation.

The installation of smart meters benefits utilities, consumers, and the grid by providing real-time usage data, enabling multiple applications that are not possible with traditional meters.

Due to the availability of granular consumption data, support for remote configuration changes, instant pushing of events and alarms, and a host of other features, it is prudent to use Smart Meters for various beneficial applications.

2.1 Benefits to Consumers:

This project has provided significant benefits to both internal and external stakeholders. External consumers have gained value-added services, allowing them to monitor and control their daily electricity consumption. They can now access daily energy consumption trends through Smart Meters and AMR meters.

An app has been launched to provide consumers with various online information regarding their daily consumption trends based on Smart Meter data.

Major Benefits to Smart Meter Consumers:

- Accurate and timely billing
- Potential to reduce consumption through consumption tracking and advanced alerts
- Behavioural changes induced through comparison with neighbourhood consumption
- Reduced human intervention
- Participation in Demand Response (DR)
- Consumption data visualization in an easy format with recommendations and alerts

Additionally, a smart portal is provided for consumers to view their consumption patterns and subscribe to alerts. Analytical reports shared with consumers include:

2.1.1. Dashboard:

The application is designed with the consumer's basic needs in mind. Consumer can get one shot view of his current consumption as on date, projected consumption for the billing period with comparison of peer average consumption and his previous month consumption. Higher tariff slab lines are highlighted for consumer as a ready reckoner.

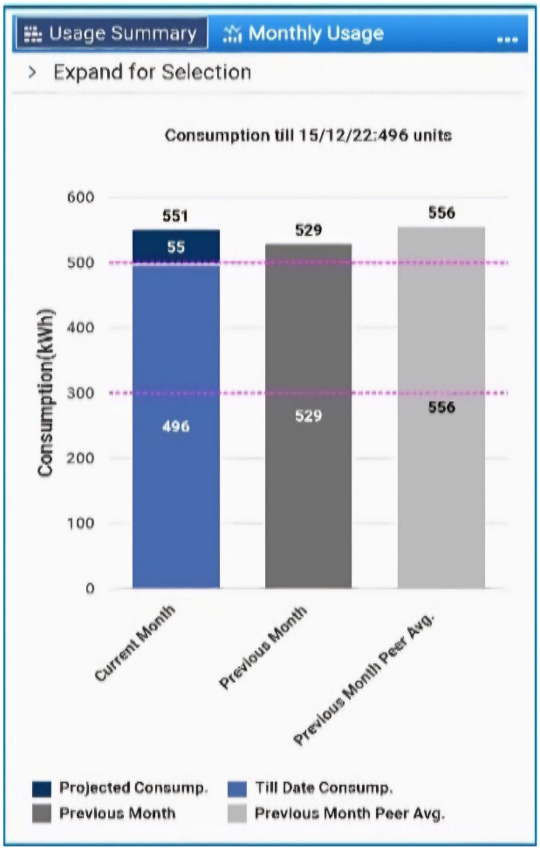
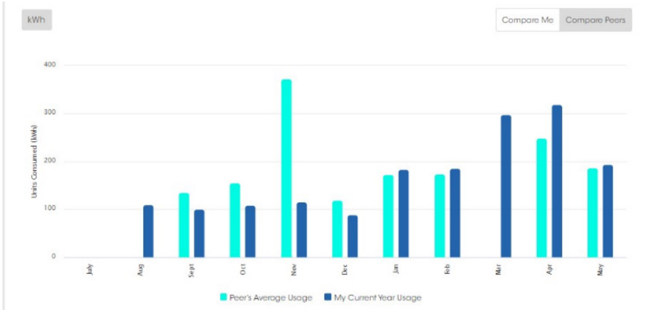
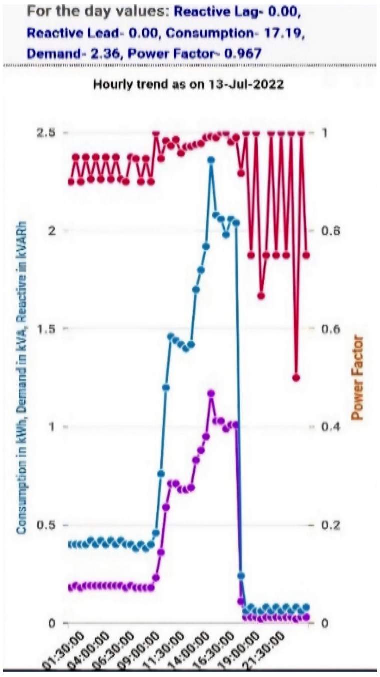


Fig-1: Dashboard Screen

2.1.2. Monthly Usage with Peer Comparison:

It shows previous 12 months consumptions & compares it with average peer consumption. It helps consumer to understand the past trends of his consumption and comparing the same with neighborhood average helps induce positive behavioral changes.





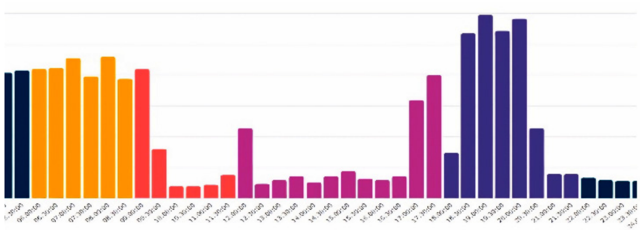
Consumer can further drill down to daily consumption by clicking on any month.

Fig-2: Monthly Usage Screen

2.1.3. Daily Usage:

Consumer can view the daily energy consumption in this graph.

Data can be visualized in multiple formats like- Daily consumption of a particular month, last 7 days, 15 days, 30 days or any desired date consumption. This gives consumer a lot of flexibility in terms of user experience.



Also, the average consumption line is given in the graph for quick comparison and identification of high usage days by the consumer.

Consumer can further drill down to daily consumption by clicking on any month.

Fig-3: Daily Usage Screen

2.1.4. Interval Usage:

It is designed to provide consumers with granular insights into their consumption data on a near real-time basis, with the presentation of 15/30-minute data varying according to consumer type to suit individual requirements. Commercial and Industrial (C&I) consumers can view 15/30-minute consumption data for kWh, kVAh, kVARh (lead and lag), demand, and power factor for any selected date, accommodating their complex usage and billing needs. They can select and unselect any parameter as needed and avoid penalties for low power factor and exceeding contract demand values by monitoring power factor and demand values.

Fig-4: Interval Usage Screen- C&I Consumers

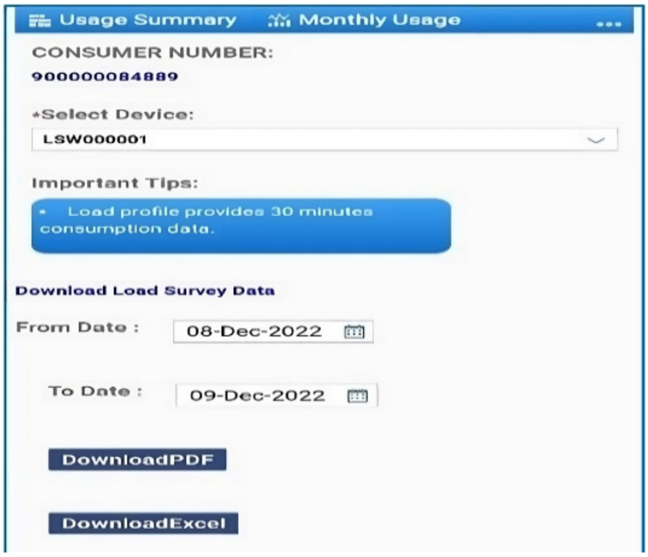
In contrast, the graph for residential consumers is simplified, focusing only on the kWh parameter, given their minimal usage and billing requirements. Residential consumers can view 15/30-minute consumption data for any selected day, with the graph color-coded to reflect TOD rates, such as highlighting the higher tariff period from 09 AM to 12 PM in red.

Fig-5: Interval Usage Screen- Residential Consumers

2.1.5. Load Survey Download:

Consumer can also download granular load profile data in excel/pdf format for their internal analysis or record purpose.

C&I Consumers will be able to download 15/30 minutes data for kWh, kVAh, kVARh-lead and lag, Demand, Power factor for any selected date, keeping in mind their complex usage and billing requirement.



Whereas the residential consumers can download the 15/30-minute consumption data in kWh.

Fig-6: Load Survey Download Screen

2.1.6. Alerts to Consumers:

Consumers may not be able to monitor their consumption regularly, so proactive alerts are designed to help them act in advance.

These alerts are tailored for different categories of consumers to assist them in consuming electricity responsibly.

Various alert use cases are as below:

Tables are given for alerts and brief condition for triggering the alert for different consumer categories-

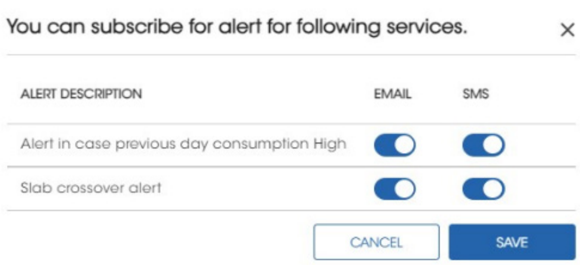
Alerts for Residential Consumers:

Alert	Condition for Alert Triggering
Drastic Increase in Consumption	If previous Day's Consumption > 200%, as compared to last 30 Days Avg. daily consumption
Higher tariff slab Cross Over	Slab cross-over based on estimated monthly consumption (300 units/ 500 units)

Alerts for C&I Consumers:

Alert	Condition for Alert Triggering
Drastic Increase in Consumption	If previous Day's Consumption > 200%, as compared to last 30 Days Avg. daily consumption
High Peak Period Consumption in a day	If Time-of-Day (TOD) wise consumption in peak Hours for previous Day > 75% of total previous day's Consumption.
High Peak Period Consumption in a month	If TOD wise consumption in peak Hours for current month > 20% of previous month's total peak hour consumption.
Demand Crossover	If demand crosses 90% of Contract Maximum Demand / Any new High Value after 90 %, within the Month.

Other than these alerts also giving Budget exceed alert, Low PF penalty alert and consumption during non-occupancy alert.



Power is given to the consumer with option of selecting the alerts and mode of receiving the alerts, through SMS or e-mail. Option is given in UI to change the preferences anytime.

Fig-7: Alert Subscription Screen

All analytics and alerts are designed in such a way that different category of consumers will have different user experience as per their requirements. Like the residential consumers will see their consumption in kWh or in INR and C&I Consumers will be able to see trends of multiple parameters like Consumption, power factor, demand, reactive power etc. Alerts are also designed suiting the different requirements of consumer category.

2.1.7. Energy Disaggregation:

Energy disaggregation analyzes electricity data to identify the energy usage of individual appliances. Using advanced algorithms and machine learning, it provides consumers with detailed insights into their energy consumption. This enables them to pinpoint inefficient devices, adjust usage for cost savings, and optimize energy management. Additionally, it enhances home automation by using real-time data to improve comfort and efficiency. By promoting more efficient energy use and reducing overall consumption, energy disaggregation supports environmental sustainability and lowers carbon footprints.

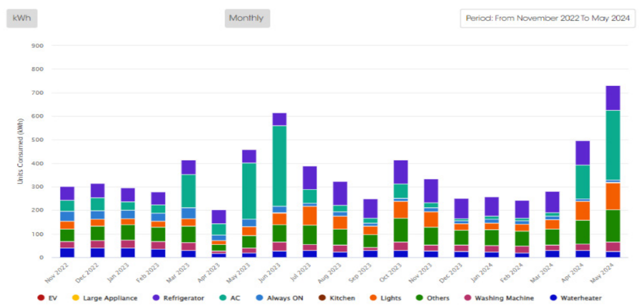


Fig-8 Energy Disaggregation Screen

2.2 Benefits to Utility:

Implementation of Smart meters are quite beneficial from utility point of view. Major benefits are automation of meter reading and billing process, reduction of AT&C losses, real time energy audit, revenue pilferage tracking and reduction and many more. Some of the benefits are listed hereunder-.

2.2.1 Automation of Billing Process:

Due to the automatic collection of billing readings, issues of incorrect readings caused by human errors are minimized. The readings are fast and accurate.

We can bill our consumers on the same day, resulting in a faster revenue cycle. Additionally, this process helps in reducing the carbon footprint.

2.2.2 Quick status Check and on-demand read:

Option to quickly check the communication status and healthiness of single / group of meters and accordingly plan any preventive/ corrective action.

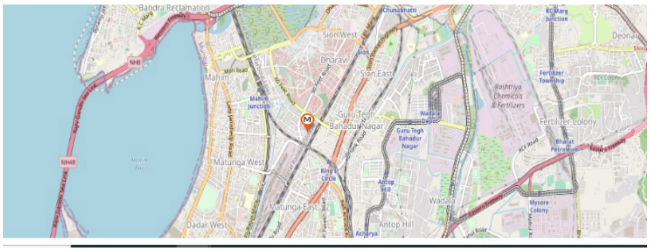


Fig-9: Geographic Location of meter

2.2.3 Remote Configuration Change

Many configuration changes mandated by regulations, such as demand integration period changes, are carried out remotely in a very short time. In the traditional method, these changes required significant on-site effort and expense, which are saved with Smart Meters.

We have already implemented mass demand integration period changes and firmware updates remotely to incorporate functional changes in Smart Meters within a short period. This has resulted in considerable time and cost savings, benefiting nearly 50,000 consumers.

2.2.4 Revenue Protection:

With the remote connect and disconnect facility, supply of non-paying consumers dis-connected directly from billing system. It resulted in reduction in revenue losses and shortening of cash cycle.

Positive behavior is induced in non-paying consumers, and fiscal condition of utility is improved to a great extent.

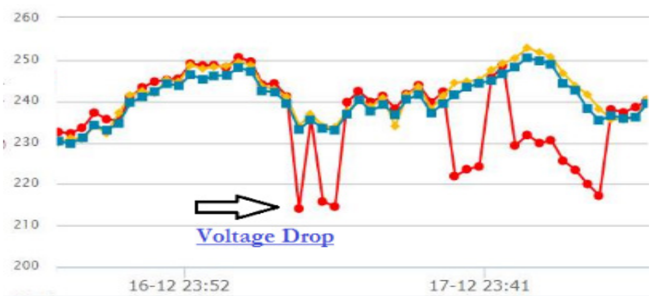
2.2.5 Identification of billing pilferage and theft cases

Availability of real time consumption pattern, events and customized alarms helps in detection of theft and revenue leakage cases.

Also, we are doing the identification meter defective and local analysis with the help of data analysis.

Many under-recording cases detected, and revenue generated.

We receive Metering Data of around 150,000 No's Meters in sever on daily basis. We get more than 20 million data values daily. We utilize this data to monitor health of metering system and ensure to find under recording cases in earliest possible time. We have developed in-house tool for analysing meter data like Instantaneous Voltage, Current, PF of every meter. This tool gives us a probable list of Metering abnormalities.



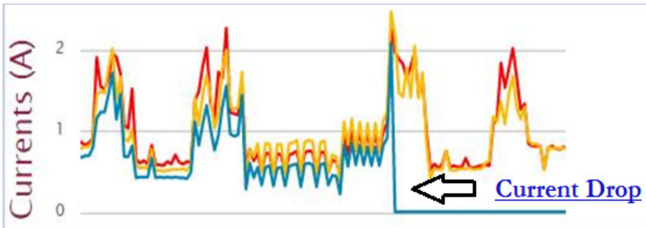


Fig-10: Analysing meter Data screen

2.2.6 Analytical Dashboard for DT operation optimization:

The in-house Analytical Dashboard for Monitoring Distribution Transformer Operational Parameters and Asset Utilization uniquely leverages AMR data to optimize transformer performance. This project offers advanced insights into loading patterns, voltage trends, and power factors, enhancing maintenance and efficiency. It incorporates real-time and historical data visualizations, predictive maintenance, and decision-making tools, ensuring a reliable and sustainable distribution network. The dashboard's scalable architecture supports future innovations in energy data analytics, significantly benefiting both utility operations and customer service. This initiative marks a transformative step in energy management and infrastructure maintenance.

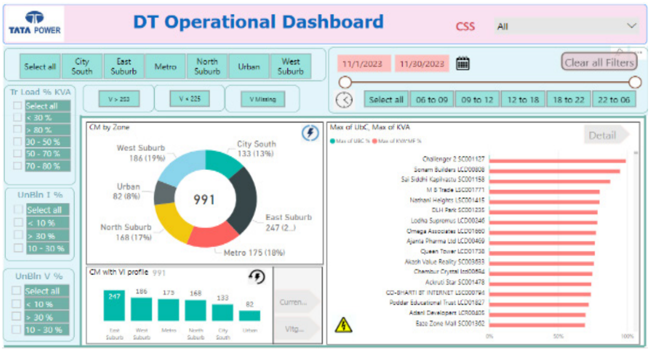
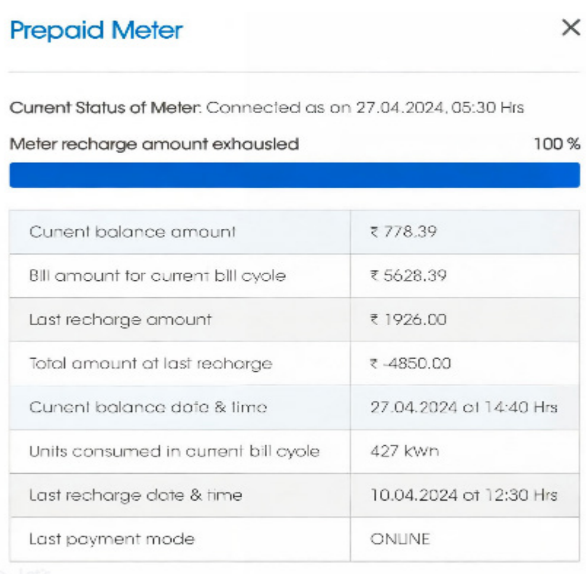


Fig-11: DT Operational Dashboard

2.2.7 Pre-paid Metering:

Pre-paid metering is offered to consumers, resulting in advanced revenue realization. This model benefits both the utility and the consumer, creating a win-win situation. We provide a dedicated usage page for pre-paid consumers and alerts for low balance, balance exhaustion, and supply disconnection. Additionally, the cost of manual meter reading is saved as readings are done remotely, Saving is achieved through remote connection and disconnection.



Prepaid Meter

Current Status of Meter: Connected as on 27.04.2024, 05:30 Hrs

Meter recharge amount exhausted 100 %

Current balance amount	₹ 778.39
Bill amount for current bill cycle	₹ 5628.39
Last recharge amount	₹ 1926.00
Total amount at last recharge	₹ -4850.00
Current balance date & time	27.04.2024 at 14:40 Hrs
Units consumed in current bill cycle	427 kwh
Last recharge date & time	10.04.2024 at 12:30 Hrs
Last payment mode	ONLINE

Fig-12: Prepaid Meter status screen

2.2.8 No Estimated Billing:

Minimizing the chances of estimated billing in the event of Lockdowns and restrictions of movement due to unprecedented situations like pandemic due to availability of data.

It also resulted in reduction in consumer complaint and helped in reduction of operational cost.

Other than that, many other benefits that can be reaped by utility:

- Quick compliance to statutory requirements, as change of meter program can be done by FOTA through remote.
- Improvement in Cashflow
- Reduction in consumer complaints in call Centers
- Improving quality of service by quickly detecting outages and fault
- Reduction in Carbon Footprint
- Providing value added services to consumers based on meter data.
- Make metering system future ready for pre-paid billing.
- Accurate load forecasting.
- Proposing modifications in Time-of-Day tariff structure based on meter data.
- Accurate monitoring of DT loading.
- Enhanced customer satisfaction.
- Faster detection of dead/defective meters
- Quickly identifying discrepancies in recorded consumption by analysis of various tamper events.
- Identification in phase unbalance
- Temperature monitoring
- Enhanced Grid Management

2.2.9 Smart Meter Operational Dashboard:

Our in-house Power BI and Power Automate dashboard unlocks valuable insights into our smart meter network. This tool empowers us to monitor, manage, and optimize our infrastructure in real-time. Some Key Benefits are:

- Network Health Overview: Instantly visualize the area-wise network, identifying online, offline, or struggling meters for prompt issue resolution.

- Data Transmission Success: By tracking data transmission success and analyzing communication data, pinpoint network issues and prioritize network upgrades in sites through boosters, IBS, or antenna extensions for optimal Smart meter performance.

- Alert Management: The dashboard proactively notifies of communication failures, minimizing downtime and ensuring service continuity.

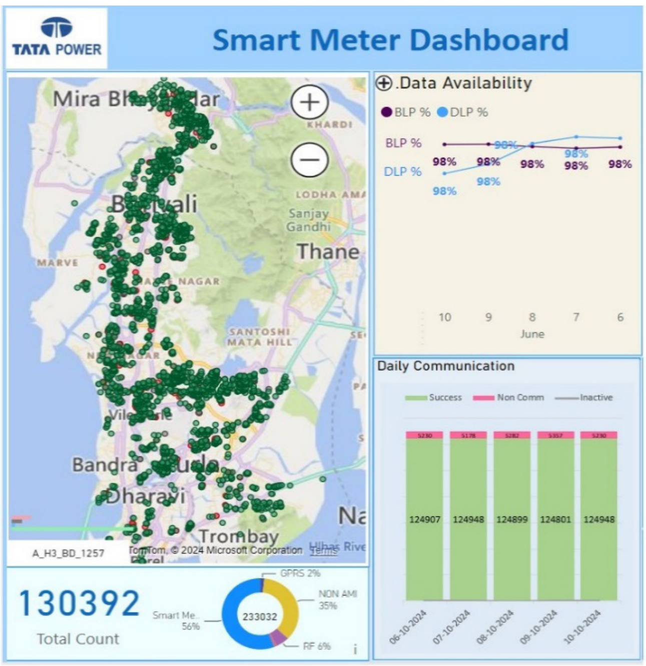


Fig-13: Smart Meter Dashboard

3. CONCLUSION:

Smart meter analytics provides numerous benefits for both utilities and consumers, making it a mutually advantageous technology. As a key component of digital transformation, its full-scale implementation brings multifaceted benefits. Compliance with industry standards is ensured through NABL accreditation of the Smart Meter Lab for IS-16444 certification.

Additionally, the adoption of smart meters allows for remote billing based on precise meter data, streamlining the billing process and enhancing accuracy. Customers receive their bills via email, WhatsApp, or SMS, and payments are made digitally.

All consumer-related processes have been digitized and automated. We are now working towards the theme “We meet customers only to greet” with the goal of covering our entire direct consumer base of 250,000 customers with smart meters by the end of FY25. This effort supports the Government of India’s guidelines for the installation of smart meters.

4. WAY AHEAD:

With ever increasing Smart Meter penetration, utilities are sitting on stockpile of useful data. It will lead to the development of much enhanced and sophisticated analytics; like real-time calculation of energy, online SAIDI, SAIFI and CAIDI calculations and alerts for Overloading/ tripping of Distribution Transformers. Further prediction of load on the consumer, zonal, and entire system level will lead to deeper engagement with customer through proactive insights & notifications. All such developments will create a next-gen electrical infrastructure where all stakeholders will be benefited due to deep insight of system & advanced analytics features.

Some advanced analytics planned by us for implementation in near future are:

- Hyper Customized and innovative alerts to consumer with de-segregation of load

- Net metering and dual source metering

- Virtual Metering & Coincident MD calculation

- Weather chart in sync with load chart

- Grid Planning Transformer load profile Analysis
- Thermal heat detection through Energy Disaggregation
- Automated Energy Audits
- Electric Vehicle (EV) Charging Management

5. REFERENCES:

[1] Ministry of Power Notification: F.No. 23/35/2019-R&R , Dated: Aug-19, 2021

[2] IS-16444 (Part-1 and Part-2) Standard for Smart Meter

BIO-DATA

VINEETH SHETTY
Tata Power Co. Ltd.

Date of Birth:	30-06-2000
Qualification:	Diploma in Electronics and Communication
Designation:	Lead Engineer
Present Organization:	Tata Power Co. Ltd.
Field of Expertise:	Smart Metering, AMR/AMI Technologies
Mobile:	+91 73535 91347
Email:	vineethshetty@tatapower.com

BRIEF PROFILE

Vineeth Shetty has been serving as a Lead Engineer in the AMR/AMI (Automatic Metering Infrastructure) department at Tata Power Mumbai for the past three years. He specializes in overseeing the communication-related activities of smart meters, RS232, RS485, and RF technologies. He holds a diploma in Electronics and Communication Engineering.

ieema your link to electricity

10th Edition METERING INDIA 2024

TECHNICAL SESSION III

METERING BEYOND TARIFF METERING

SMART METERING DATA SOLUTIONS FOR NEW USES INTEGRATION

Sébastien BRUN
EDF International Networks, France

ABSTRACT

To support the energy transition, we have developed consumer-centric solutions based on Smart Meters (SM) data:

- "Cap'ten" allows us to deal more quickly with the mass of connection requests linked to new uses;
- "ProdiGE" optimises the size of generators as accurately as possible so as to enable the "0 emissions" use;
- The regional energy assessments help local authorities to implement and monitor their energy transition policies.

1 INTRODUCTION

The energy transition, with the integration of distributed energy resources and digitalisation, are new challenges that are profoundly changing the management of distribution networks. These challenges lead to a new role for the smart Distribution System Operator (DSO) in an increasingly digital environment: the DSO as a data manager. Advanced Metering Infrastructure (AMI), with all the data it generates, is the game changer for network operations and customer management that enables the DSO to embody this new role.

Based on SM data, the French DSO "Enedis" has developed new solutions that go far beyond metering use cases: grid Operation and Maintenance (O&M), grid and asset management, losses, smart city, grid flexibilities and electric mobility, and renewable energy integration. Three applications from this last category are presented in this article. They are the subject of patent applications.

"EDF International Networks", the subsidiary that promotes Enedis expertise abroad, also offers these solutions worldwide.

2 SOLUTIONS

2.1 "Cap'ten" dynamic capacity assessment

2.1.1 Background, objective and benefits

On the one hand, from 2016, local authorities in France will have to implement the targets for the development of renewable energy and electric mobility set out in their "Territorial Climate-Air-Energy Plans". The energy transition raises the question of massive renewable energies and electric mobility connections to the grid.

On the other hand, the processing of a connection request involves a complete study, leading to an answer after several months: for example,

- The connection is possible on the existing network: fast and cheap;
- The connection requires an expensive and lengthy reinforcement of the network.

For many queries, you could move from the second to the first answer in the example above, simply by selecting an alternative location close to the original one...

<u>"Cap'ten" is a simplified connection calculation engine. It displays the hosting capacity of the distribution network on a map interface. It can be used to quickly create different connection scenarios for one or more sites.</u>

It offers a faster alternative to traditional connectivity study tools, often providing the same conclusions, for all types of connection requests (historical and new uses), that come from and are accessible to external stakeholders.

The benefits are:

- Efficiency: faster management of connection requests, for both providers and users;

- Autonomy for applicants: immediate decision-making allows them to adapt their strategies quickly without having to wait for the detailed results of each scenario study;

- Transparency to external parties for a better understanding of the DSO's responses;

- Agility: possibility to test different strategies in a few second (where to connect which site?).

2.1.2 How does it work? General operating principles

The first step is to use data...

- Network description: topology, cable and transformer impedances;

- Load profiles updated with SM data;

- Voltage profiles.

...For a simplified grid modelling:

- By considering only one connection point by and at the final end of each cable, to which all its loads are returned;

- Neglecting losses (voltage drops).

This processing is then applied to each of the nodes:

1. Add a power gradient;

2. Check voltage compliance with new voltage drops;

3. Check that the new intensity of the cable and the new power of the transformer respect the nominal regimes;

4. Repeat the operation until one of the above criteria is exceeded.

The second step is a dynamic estimate: updating of the initial one with the addition of additional loads of the user's choice.

Fig 1: Cap'ten user interface, with initial then dynamic estimation (two new loads: black points)

2.1.3 How does it work? The core calculation engine

Two matrices model the network according to Kirchhoff's laws of currents and voltages:

- "Bus to Injections Branch Currents" (BIBC) links the Bi currents of each branch to each node load;

- "Branch Currents to Bus Voltage" (BCBV) establishes the link between the voltage drop ΔV at each node and the current Bi flowing in each network branch.

The load flow modelling algorithm is an iterative process that successively calculates currents and voltage drops using the BIBC and BCBV matrices, until the voltage estimates converge.

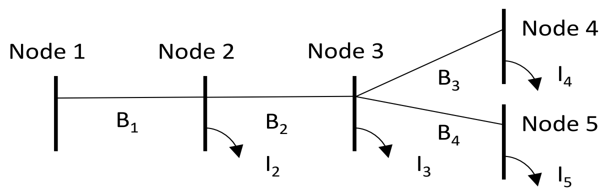


Fig 2: Example of a simplified network used to illustrate the algorithm described below

Initial step: V' is constant and V=0.

Second step: as long as V' differs from V, repeat the process:

V takes the value of V'.

Calculation of I:

$$I_i = \frac{P_i + jQ_i}{V_i}$$

Calculation of B:

$$[B] = [BIBC] * [I]$$

$$\Leftrightarrow \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \end{pmatrix}$$

Calculation of ΔV:

$$[\Delta V] = [BCBV] * [B][\Delta V] = [BCBV] * [B]$$

$$\Leftrightarrow \begin{pmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \end{pmatrix} - \begin{pmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \end{pmatrix} = \begin{pmatrix} Z_{12} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 \\ Z_{12} & Z_{23} & 0 & Z_{35} \end{pmatrix} * \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{pmatrix}$$

Estimation of V':

$$V' = V - \Delta V$$

Last step: We now have a final estimate of V' for each node and B for each branch.

2.2 Generator sizing with "ProdiGE"

2.2.1 Background, objective and benefits

Generators are often used to limit the interruption of power supply to consumers during scheduled work. Current methods for sizing generators often lead to oversizing, which means additional costs (investment, operating and maintenance costs)... And inconveniences: noise, size, and higher CO2 emissions.

As part of the "0 Emission" project, carbon-free generators (batteries and H2) have been manufactured to replace diesel generators. The use of this lower capacity equipment requires the most accurate possible forecasting of customers' energy needs. The "ProdiGE" project aims to develop a solution for the most accurate sizing of generators, for planned work, thus limiting the environmental impact.

Fig 3: A carbon-free generator

2.2.2 How does it work?

For a given Medium Voltage (MV) / Low Voltage (LV) substation and day, ProdiGE predicts:

- The energy withdrawn per time slot;
- The maximum power demand during this period.

ProdiGE is a deep learning solution based on data including but not limited to:

- Daily consumption and maximum power (SM data);
- Network description;
- Temperature.

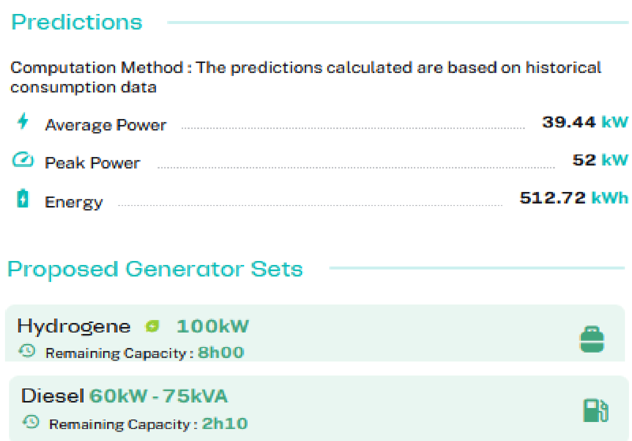


Fig 4: Example of a ProdiGE prediction and suggestion

2.3 Regional energy assessments

2.3.1 Background, objective and benefits

This is an open data report on electricity consumption and production for a given area.

The aim of this pioneering service is to support local authorities in the implementation and monitoring of their energy transition policies, by providing them with a personalised report that gives a synthetic and comparative view of electricity consumption and production data at a chosen geographical level (region/department/city/...).

2.3.2 How does it work?

The service is based on open data. It uses cartographic information from the National Geographic Institute (IGN) and data from the National Institute for Statistics and Economic Studies (INSEE), on the French population and housing, as well as the number of consumption and production sites (by sector).

It uses:

- Automation of asks (formatting and API queries in datasets);
- Annual statistical analysis of data by Artificial Intelligence (AI), for automatic text generation.

It provides a personalised description of the main characteristics of a territory. It also includes a module for comparing territories.

3 CONCLUSIONS

The AMI infrastructure, with all the data it generates, enables the DSO to assume a new role as a central actor in the energy transition, both for its internal needs in terms of network management and for the satisfaction of its customers and stakeholders.

New smart solutions for renewable energies and electric mobility are being industrialised in France, alongside the roll-out of the "Linky" AMI system. They are also available worldwide through EDF International Networks.

BIO-DATA

BRUN SÉBASTIEN
EDF International Networks

Date of Birth:	14/04/1985
Qualification:	Engineer
Designation:	Project Manager
Present Organization:	EDF International Networks
Field of Expertise:	Smart Grids and Data Solutions
Mobile:	+33 6 67 82 44 33
Email:	sebastien.brun@enedis.fr

BRIEF PROFILE

Sébastien BRUN has been working at French DSO Enedis from 2009. In particular,

- He has been deputy manager in a French Medium Voltage (MV) dispatching center;
- He has worked as a business analyst at French Smart Metering (SM) national program « Linky »: business process re-engineering on the overall Enedis activities;
- Then, he has been the national project manager for « LinkyRéseau » project: using SM Data for network operations: incidents (MV & Low Voltage, "LV") detection and diagnosis, predictive maintenance, smart planning, Non Technical Losses (NTL), GIS reliability. During his mission, Sébastien developed a new predictive maintenance solution, protected by a patent - of which he is co-depository - and for which he received, as Enedis member, an international award (ISGAN awards 2023);
- Today, he works full-time at EDF IN as a SG & Data solutions expert.

A SUSTAINABLE ELECTRICITY DISTRIBUTION MODEL FOR RURAL CONSUMERS IN INDIA SYNERGIZING BLOCKCHAIN USING SMART METER

Aurabind Pal | Raman Garg
REC Ltd

ABSTRACT

This paper proposes a novel electricity distribution model for rural India, in which urban and rural grids are treated separately and managed differently. The paper argues that privatization of distribution companies may not be the best solution for rural consumers. The paper suggests that rural grid be managed by rural electricity cooperative societies (RECS). The paper also describes how RECS can use solar power and battery swapping stations for electric vehicles to reduce dependence on grid power and improve revenue. At the same time, it proposes use of modern tools like AI-based OCR meter reading and blockchain based smart metering solution for a sustainable electricity distribution ecosystem. The paper aims to address the issues of AT&C losses, power quality, and rural development, and to synergize various government schemes related to renewable energy and electric mobility.

1 INTRODUCTION

India has achieved electrification of all its villages back in 2018 and thanks to electricity reforms, generation of power to meet the demand is not a problem. However, distribution companies (DISCOMs) still face challenges in supplying sustainable power to rural consumers. Out of 17 sustainable development goals (SDGs) formulated by the UNDP, the seventh goal SDG7 aims at ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030 [4]. The challenges associated with maintaining a sustainable power supply are complex and multi-dimensional.

Rural grid investments by DISCOMs are unattractive to investors due to low electricity demand and poverty of rural consumers [1]. However, India has achieved universal electrification by the support of Union and State Government through flagship programs like RGGVY, DDUGJY, SAUBHAGYA [4] and many other State Government sponsored schemes.

Electricity in India is a highly politicized commodity, and any change in the tariff structure or the service quality may affect the electoral outcomes. Political parties in India are known to use electricity prices as a tool to secure a win in the democratic election process. Citizens differ in their willingness to pay for electricity, and the consumer surplus and electoral uncertainty seem to influence their choices while exercising their franchise. This ultimately affects the performance of DISCOMs. One of the main reasons for the mediocre performance of DISCOMs is the high aggregate technical and commercial (AT&C) losses, which are mainly due to theft, meter tampering, billing errors, and non-payment of bills by consumers. The AT&C losses in India are around 15.4%, which is much higher than the global average of 8.6% (PWC, 2018). These losses are more prevalent in rural areas, where the cost of supply is higher, and the revenue is lower than in urban areas. Most of the distribution companies are owned by State Governments. The losses are mostly taken over by the Government increasing the burden on the State exchequer.

In recent times many Governments have come up with solutions of universal coverage of smart prepaid meters. These meters make very much sense in urban areas where the per capita consumption is high and makes good economic sense, considering the added advantages of services it brings to the table. The problem lies with rural areas where per capita consumption is low. Sometimes, per month's electricity bill may be equivalent to the opex expenditure of DISCOMs. This will make least of economical prudence for the DISCOMs and there is always issue of affordability in rural consumers.

Union Government and State Governments are working for the privatization of DISCOMs.

Privatization, in the past, has shown some encouraging results. But it is to be noted that privatization has been tried mainly in urban areas. It is important for the state governments to decide which areas in the state to open to privatization. In Maharashtra and Gujarat, privatizing predominantly industrial areas has meant improved electrical access for firms. From private companies' perspective, serving industrial customers can be comparatively easier than serving rural consumers, since the operational costs vis-à-vis collection and billing are lower for industrial consumers. Similarly, as Delhi and Mumbai's successful experiment with privatization has shown, private companies can perform well in urban areas. It will be difficult to find private companies willing to take over rural areas. Private companies would want to retain industrial and urban areas with high-paying consumers.

Privatization of electricity distribution may benefit the urban consumers, who can enjoy better quality and reliability of power supply, lower tariffs, and more choices and options. However, this may come at the expense of the rural consumers, who may face higher tariffs, lower subsidies, and less access and quality of power supply. Privatization may also create a divide between the urban and rural areas, in terms of the development and growth opportunities that depend on the availability and affordability of electricity. Therefore, privatization of electricity distribution may not be a viable or equitable solution for the whole country, unless it is accompanied by adequate regulation, competition, and social safeguards. It is seen that to compensate for the enhancement of billing efficiency due to privatization or corporatization of electricity utilities political parties vis-à-vis state governments are pushed towards subsidizing electricity.

Every year, DISCOMs estimate what tariffs should be and approach regulators with a tariff petition. Usually, tariffs differ by consumer category (domestic, agriculture, commercial, industry, and railways) and by blocks of consumption volume, with prices getting higher as consumers use more electricity. At the beginning of the year, states are supposed to announce a lump-sum direct subsidy for DISCOMs. This is called the "subsidy booked." If it has been announced, DISCOMs factor it into the petition. The petition is reviewed by the electricity regulatory commission, who may make changes. Once finished, the commission publishes the final rates as part of the "tariff order."

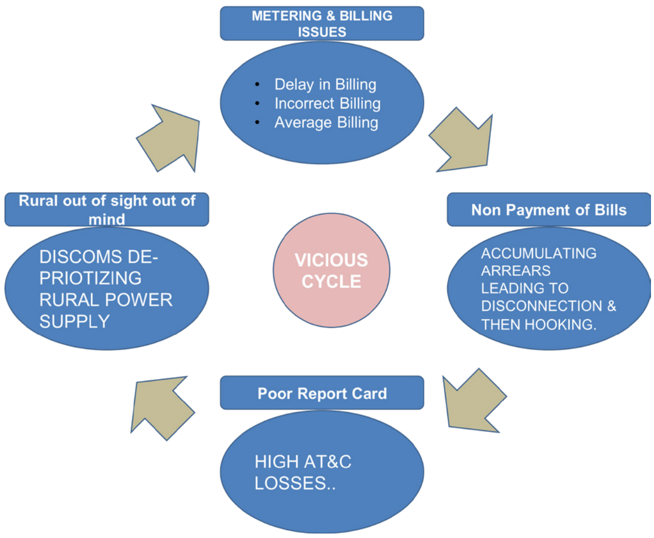


Fig-1: Issues with Rural electricity distribution sector.

The demand for electricity in India is expected to grow three times by 2040, according to the International Energy Agency (IEA, 2020). This means that more electricity will be consumed by the subsidized consumers, which will increase the subsidy costs for the state governments. On the other hand, some consumers who pay higher tariffs, such as industries and railways, may buy less electricity from the DISCOMs. They may use the open access provision, which allows them to buy electricity from other sources at competitive prices. They may also generate their own electricity using renewable energy sources, such as solar and wind. This will reduce the revenue for the DISCOMs.

Although the need to provide a sustainable power supply to the rural areas in established but the optimal way to achieve this goal is unclear. This paper advocated the involvement of cooperative businesses that balance social and economic goals and can create new possibilities for rural electricity distribution. This paper proposes a novel model of electricity distribution for rural which is not only managed by cooperative business but also operates in net-zero energy model.

2 THE PROPOSAL

This paper outlines a proposal for managing the rural electricity grid in India, based on the following points:

- Rural grid would be managed by various rural electricity cooperative societies (RECS) that would handle billing and collection.
- Each RECS would source its power from the grid as well as from solar plants installed aiming a net zero scenario.
- Each RECS would have single point metering at the distribution transformer (DTR) level, using smart, pre-paid meters with net metering facility.
- Each RECS would maintain battery swapping stations and electric vehicle (EV) charging stations and utilize solar power in captive or trade it with neighboring RECS or a dynamic load like charging stations using blockchain technology.
- Each RECS would also be engaged in financing electric autos and other commercial electric equipment to promote cottage industry and improve the region's overall economic status.

Rural Electricity Co-operative societies:

The paper proposes that the far-flung rural pockets where the utilities find difficulty in providing service be managed by community-based business. A cooperative rural distribution company usually buys power supply in large quantities from transmission companies or distribution companies themselves. The cooperative operates democratically, where each customer can vote for delegates who attend a yearly general assembly, like a stock owner meeting. The general assembly chooses an administrative council, like a board of directors. The general manager, who is like a chief executive in a private company, oversees the cooperative's management and decision making. The rural electrification board can replace the general manager if the cooperative does not perform well. The rural electric cooperatives often receive support from a bigger agency, such as the Rural Electrification Board in Bangladesh [2], which establishes standards, provides long-term financing, and monitors and supervises the cooperatives to ensure they make sensible business decisions. The cooperatives can be organized under state laws and subject to cost-based operations.

This paper proposes two alternative modes of operation, in first cooperatives buys power from the local DISCOM and distributes power as per tariff set by the regulatory body quite like a distribution licensor. While under the second alternative, cooperatives act as a billing franchisee. The cooperatives remain as a facilitator in generating bills and collection of billed amounts and depositing with DISCOM. In both cases, cooperatives are supported by a dedicated department in utility and an association to represent in regulatory body hearings. The department in DISCOM provides standards, monitoring, and supervision of cooperatives. While association may act as the voice of cooperatives in various forums.

Net Zero Scenario:

All the consumers will be mapped to a grid connected solar plant. Optimization by clustering of solar plants shall bring the costing down. The solar power thus generated will belong to the community (RECS). The solar energy thus generated can be sold to DISCOMs and the consumption of consumers can be offset of the mapped solar energy generated by virtual net metering methodology.

The RECS can implement the project in RESCO model for sustainability. At present, Govt of India and many State Govts have subsidized the capital cost of solar plant. While the subsidy fund can be transferred to the RESCO agency, and the balance amount can be retrieved out of savings in each electricity bill.

The solar power can be reconciled by net metering or gross metering manner. Under gross metering manner, DISCOMs can incentivize the scheme by declaring subsidized tariff.

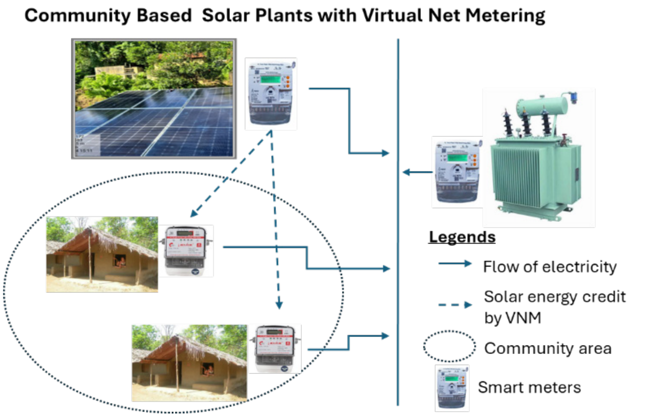


Fig-2: Solarization of a community-based distribution system.

Energy Accountability:

It is pertinent that energy consumed by consumers is reconciled with the energy recorded at the distribution transformer (DT). Although DT meters are smart meters under the scheme. While the consumer meter readings can be AI-based OCR for automated meter reading. This will exclude the inefficiency of manual meter readings. The energy details thus obtained from DT and downstream consumers shall be reconciled at the billing software level. This gap must be monitored at the DISCOM level by the department concerned and subjected to adequate governance.

Trading of Solar Energy using blockchain in smart metering:

With high penetration of solar power, scheduling of power by DISCOM will be a concern [6]. The surplus solar power thus generated may be traded with that of dynamic loads like EV chargers using blockchain technology. They can register in a blockchain-based program, which tracks and rewards their clean energy generation and consumption. The program also enables them to trade and share their excess solar power with other prosumers or EV charging stations in their neighborhood. The EV charging stations can use a mobile app based digital platform to participate in a dynamic auction, where they can bid for the cheapest and cleanest power available from the nearby prosumers. The blockchain program records and settles energy transactions, using digital transactions. The prosumers and the EV charging stations are also connected to the conventional grid, which provides backup power when needed. The proposed model creates a parallel power system, which supports the growth of both rooftop solar and EVs, while reducing the stress on the grid. Rooftop solar and EVs can complement each other and promote a clean and sustainable form of energy.

The deployment of smart meters as generation meters enables opportunity for the prosumers, the community solar here, to sell the energy surplus using blockchain. Blockchain technology is being used for smart metering systems in India, especially for P2P energy trading and renewable energy certificate. Some of the places where this technology is applied are Delhi and Uttar Pradesh. In Delhi, two power companies, BSES and Tata Power-DDL, are collaborating with India Smart Grid Forum and an Australian company called Power Ledger to conduct a pilot project on P2P energy trading.

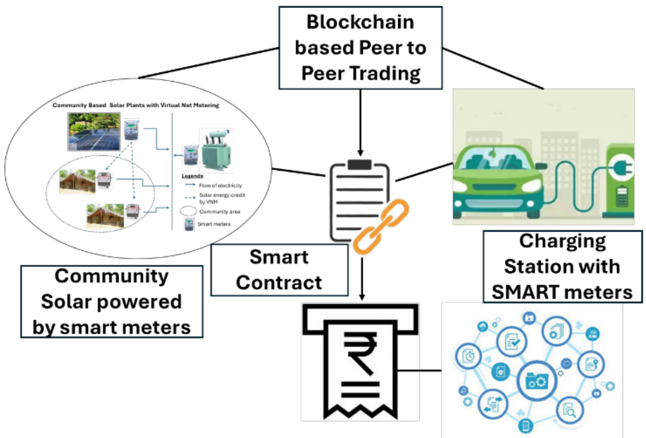


Fig-3: Energy trading using blockchain.

4 BENEFITS OF THE SCHEME

The proposed scheme can transform the subsidy system from one based on reducing tariffs to one based on supporting capital investment. This would be a more politically prudent approach, as it would reduce the burden on the government budget and the consumers' bills. Moreover, the scheme would foster the development and adoption of green technologies such as solar panels and electric vehicles, which would reduce greenhouse gas emissions and environmental pollution. The scheme would also generate more employment and income opportunities for rural areas, where the demand for reliable and affordable energy services is high. The scheme would thus create an ecosystem where both urban and rural consumers would benefit: urban consumers would have more choices and lower prices in a competitive market, and rural consumers would have more power and voice to demand the best quality and quantity of services.

5 PILOT PROJECT

Based on the proposed model, a pilot was projected in Meghalaya under the jurisdiction of MePDCL, the local DISCOM. The project aimed at addressing power shortages and billing challenges in remote areas of Meghalaya by developing sustainable distributed solar power generation and community-based power distribution models. The pilot project, named Communatization of Electricity Distribution in a Solarized Village, was conducted in Hartali Village, Amlarem Block, West Jaintia Hills. This village, recently electrified and remotely located, was chosen due to the villagers' interest and support. The project involved installing a 10 KW solar plant for 10 consumers, with the solar power generated being adjusted with actual consumption based on virtual net metering, resulting in net zero energy input to the village. The community, through the village headman, managed billing and collection, with the agent being paid a commission based on the volume of bills handled. The document highlights the project's unique aspects, such as clustering power plants to reduce costs and using virtual net metering to avoid the expense of net meters in each household. The total project cost was funded by the Central Government Subsidy (CFA) under PM-Surya ghar muft bijli yojna and contributions from MePDCL.

The pilot project has proved successful in demonstrating the following benefits to various stakeholders. Consumers, who belong to marginalized sections of society, avail benefits of electricity at a very nominal cost and distribution being managed by community, gives better representative to demand better power quality. MePDCL, need not bother of billing and collection in these remote locations, improving their AT&C. Also, the source being nearer to load, technical line loss is prevented. Earlier Meghalaya Government cross subsidized the occupants of these remote villages. In most other states the State Govt borne the subsidy burden. This may not be fiscally prudent and is very inefficient. Governments by investing in Solar plants, under this model, creates the same effect as giving subsidy annually. A capital investment is fiscally prudent at the same time generating jobs.

6 CONCLUSION

One of the ways to enhance the global position of a developing country like India is to bridge the gap between urban and rural areas and to empower the rural population. Electricity is a vital element for achieving this goal, as it enables access to education, health, communication, and livelihoods. India faces the challenge of low per capita income and high energy demand, but it also has the opportunity to harness solar energy from its abundant sunshine. The proposed scheme aims to create an incentive mechanism for rural consumers to invest in solar panels and electric vehicles, which would reduce their dependence on grid electricity and fossil fuels. By doing so, the scheme would not only transform the subsidy system from a tariff-based to a capital-based one, but also promote green technology development and adoption, lower greenhouse gas emissions and environmental pollution, and create more employment and income opportunities for rural areas. The scheme would thus benefit both urban and rural consumers by creating a competitive and sustainable energy market, where urban consumers would have more choices and lower prices, and rural consumers would have more power and voice to demand the best quality and quantity of services. The scheme would therefore contribute to making rural India more self-reliant and resilient.

8 REFERENCES

[1] Pal, Aurabind. (2022). *A Sustainable Power Distribution Model*. 10.1007/978-981-16-8727-3_9.

[2] Yadoo, Annabel & Cruickshank, Heather. (2010). *The value of cooperatives in rural electrification*. Energy Policy. 38. 2941-2947. 10.1016/j.enpol.2010.01.031.

[3] Tayal, Vaishali & Meena, Hemant & Bhakar, Rohit & Barala, Chandra. (2022). *Blockchain*

Enabled Smart Metering Solutions: Challenges and Opportunities. 902-907. 10.1109/ NPSC57038.2022.10069901.

[4] Auroshis Rout, Brijesh Mainali, Suneet Singh, Chetan Singh Solanki, Govind S. Bhati, *Assessing the financial sustainability of rural grid electrification pathway: A case study of India, Sustainable Production and Consumption*

[5] Operational Guidelines for Implementation of the component 'Central Financial Assistance to Residential Consumers' of PM-Surya Ghar: Muft Bijli Yojana

[6] Pal, Aurabind. (2020). *Solving Duck Curve Problem Due to Solar Integration Using Blockchain Technology*. 10.1007/978-981-32-9119-5_17.

BIO-DATA

AURABIND PAL
REC Ltd

Date of Birth:	15.08.1989
Qualification:	B.Tech, e-Masters-Public Policy, IIT-Kanpur (cont)
Designation:	Manager, Technical
Present Organization:	REC Ltd
Field of Expertise:	Substation Automation, IEC 61850, System Study, Sustainability
Mobile:	7077702174
Email:	apal@recindia.com

BRIEF PROFILE

Have Worked in Engineers India Ltd with experience in Engineering , Design and Project Management with focus on Substation Automation (IEC 61850 based). At REC Ltd have gathered experience in financing of power projects. Have been part of universal electrification and RDSS scheme of Govt. Of India with focus on NE states. Have worked on sustainability of electrical utilities. Have published four technical papers in International Conference with more than 10 citations. Presently working on P-to-P energy trading and platforms.

SOLAR ENERGY DISAGGREGATION USING NET-METER CONSUMPTION SIGNALS

Nisha Agarwal | A K Mayank | Basant Kumar Pandey
Bidgely Technologies Pvt. Ltd.

ABSTRACT

With increasing global emphasis on the usage of renewable energy sources for electric power production, the adoption of solar photovoltaic (PV) cells is burgeoning both at residential and commercial levels. With this rapid rise in adoption rate, utilities must come up with unique and innovative solutions to cater to these new-age customers. In this paper, we propose a solution to use smart meter technology to detect the users with PV cells at home and estimate their solar generation (kWh) at an hourly level. For detection, we have used a combination of deep learning and machine learning approaches to detect users with all three types of solar power systems, i.e., on-grid, off-grid, and hybrid while the estimation algorithm works only for on-grid systems. Both detection and estimation algorithms are designed to work with AMI data at a sampling rate lower than 60 minutes and provide highly accurate results for users all over the globe. This estimated generation when combined with the AMI meter data can then be used to recreate whole-house consumption at the given sampling interval, allowing utilities to provide appliance-level consumption and other key insights to solar customers. The presence of a large number of solar panels in a region can impact its demand for energy response. Accurate knowledge of total energy consumed by households and solar generation can help utilities efficiently power distribution and grid management. Utilities can also target customers with solar panels by providing incentives and other benefits to encourage reshaping the demand curve according to their objectives.

Keywords: Distributed Energy Resources (DER), Photovoltaic Systems, Transmission Risk Management, Solar Generation Estimation, Green Energy

1 INTRODUCTION

Renewable energy sources, such as solar, offer many environmental advantages over fossil fuels for electricity generation, but the energy produced by them fluctuates with changing weather conditions. Electrical utility companies need accurate forecasts of solar energy production in order to have the right balance of renewable and fossil fuels available [2]. Errors in the estimates could lead to large expenses for the utility from excess fuel consumption or emergency purchases of electricity from neighboring utilities. Currently, most utilities are only able to obtain net power readings, which is the production from the solar panels subtracted from electric consumption, from a home [1]. However, the inability to differentiate production from consumption leads to uncertainty on how much electricity to put into the grid and unnecessary costs for the utility. This method describes methods to solve exactly this problem. Using AMI data for a solar home, we provide the output of that home's solar panels for the given time period. This allows utilities to estimate solar in their territory, better understand their solar customers, and optimize their costs[3]. We collected solar panel and historical weather data from thousands of homes and each of their local weather stations. We describe an algorithm to detect the solar panel presence at a home given only net consumption, which allows us to train and test the model on different homes. Furthermore, a method to predict solar panel generation is presented. We present the accuracy of our solution on real life solar panel data from across the world, and how this approach can save utilities thousands of dollars in electricity costs by accurately differentiating from consumption and production in net power readings

2. METHODOLOGY

We have designed a state-of-the-art solar disaggregation pipeline that is capable of detecting solar panels and estimating their generation by using AMI data and local weather data. This comprises sophisticated machine learning and deep learning algorithms, trained over thousands of households worldwide. These algorithms are capable of estimating energy generated AMI data sampling level.

3. DATASET

1. AMI Smart Meter Data: Home net energy consumption data acquired at 5, 15, 30, or 60 minutes sampling intervals.
2. Sunrise data: Sunrise and sunset time for the given zip code.
3. Meta Data: Timezone, latitude, and longitude are used to compute irradiance.
4. Weather Data: Ambient temperature, sky cover, wind speed at a zip code level.

4. EXPERIMENTAL SETUP

The dataset comprises homes from varied geographies,The total energy consumption is collected using AMI with a sampling rate of 15 min, 30 min, or 60 min as per the configurations of the user's smart meter.

5. PROBLEM DEFINITION

The net-meter consumption[1] is the result of a summation of the energy consumed by a household and the negative of solar energy generated by the solar panel installed. This aggregate signal is a result of all the appliances running as well as the weather conditions that can cause fluctuations in the amount of solar energy generated by the panels. Fig 1. Shows an example of a user›s net energy consumption(blue line) in a day captured at a frequency of 15 mins. Our objective is to 1) Check the presence of a solar panel and 2) Estimate the generation shown as the yellow curve in fig 1. at the same frequency with which we receive the net consumption.

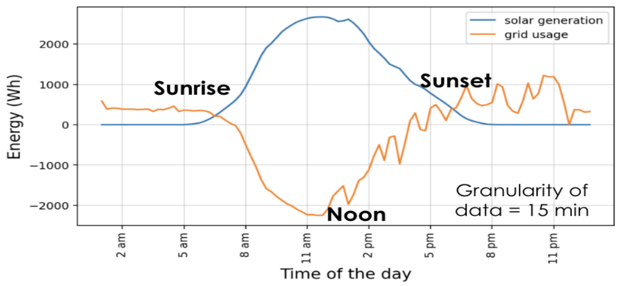


Fig 1. Daily Net consumption and Generation for a user

5.1 SOLAR PANEL DETECTION

The first step of the disaggregation process is to identify homes with solar panels installed. Some typical properties of solar users are 1) a drop in net consumption during sun presence hours due to increase in solar panel generation, 2) An hourglass pattern of the dark band created because of the drop in consumption, This hour-glass pattern can be observed due to changes in number of sun presence hours for different seasons as can be seen in Fig 2. To capture this behavior we model a Convolutional Neural Networks[4] based architecture that is able to detect these dark bands and hour-glass patterns.

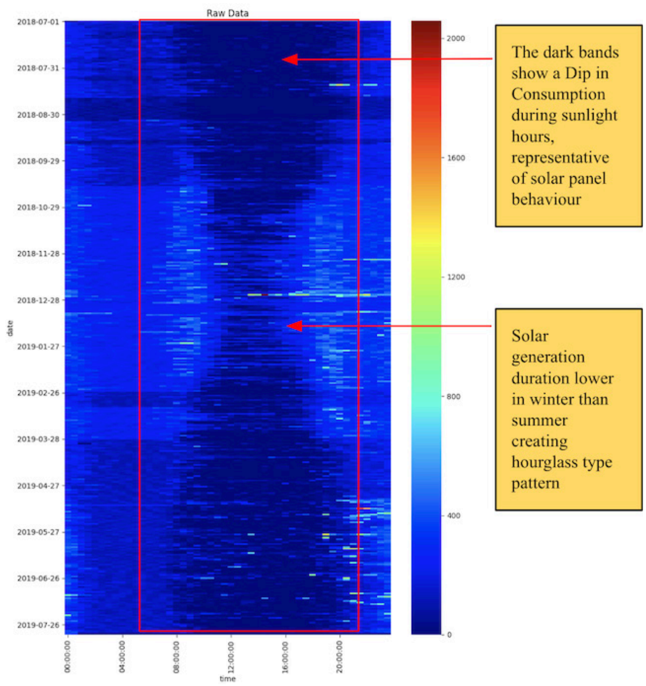


Fig 2. Heatmap of net consumption for a year of a user

5.2 ESTIMATING SOLAR PANEL GENERATION

We propose a two step approach to estimate solar generation. 1) Capacity estimation and 2) Operating Potential calculation.

5.2.1 CAPACITY ESTIMATION

The capacity estimation model leverages the sinusoidal nature of solar generation as observed in Fig 1. The transformation of the net consumption to a sinusoidal space allows us to fit a regression line for each day during sun presence hours. Such an approach allows us to determine the capacity of the solar panel by filtering days with a high r-squared score and estimating the peak generation at noon.

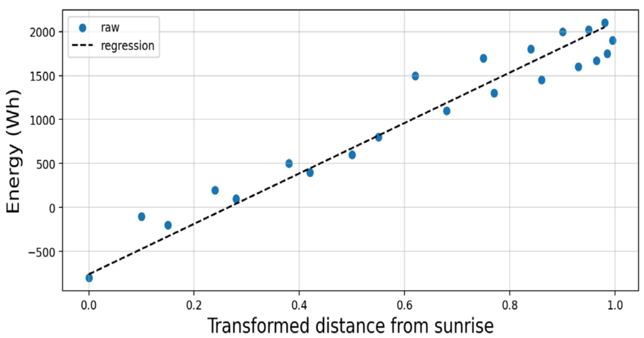


Fig 3. Sin transformation of input net consumption

5.2.2 OPERATING POTENTIAL

The solar generation for a home on any typical day follows a gaussian curve but there are a number of weather and external factors such as sky cover, wind, temperature, irradiance, angle of inclination etc. that can cause aberrations in this otherwise smooth curve as seen in Fig 4.

To handle such aberrations and come up with a generalized solution that can accurately predict these potentials across geographies, we feed in such weather, locational and consumption features to an XGBoost Model[5].

The gradient boosting mechanism helps in penalizing and solving for such abnormalities in weather data. We are thus able to calculate operating potential at the same sampling rate as the AMI data we receive for each user.

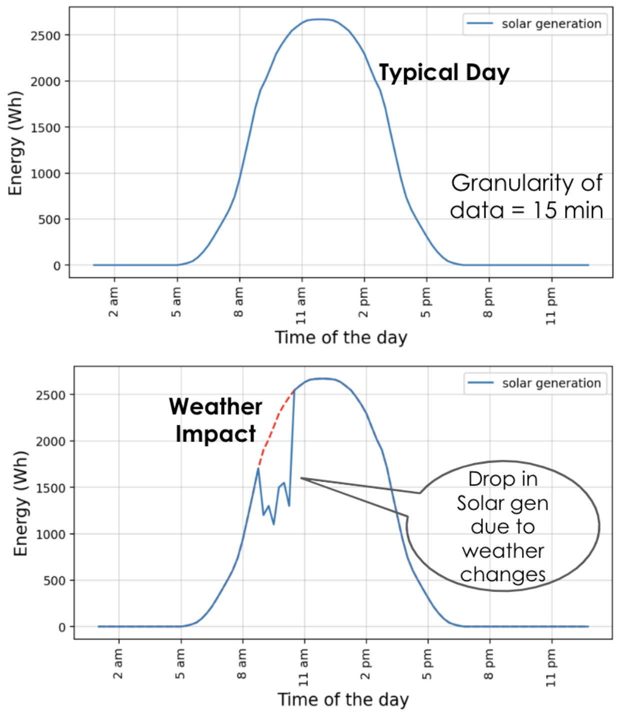


Fig 4. Operating potential on a typical vs cloudy day

5.2.3 SOLAR GENERATION ESTIMATION

We follow the workflow as given by fig 5. and combine the output of the capacity and operating potential estimator engines to get our final generation results by the following formula

Generation = Capacity * Operating Potential

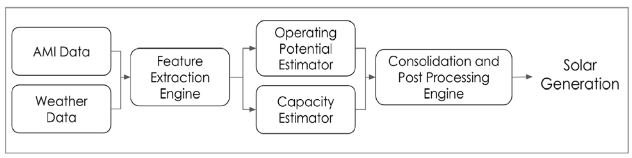


Fig 5. Solar disaggregation workflow

6. RESULT AND DISCUSSION

The performance of the framework is evaluated using four metrics

(1) Precision/Recall for Solar Detection

(2) Mean Absolute Percentage Error for capacity

(3) Mean Absolute Error for Potential

And Finally, (4) Monthly Solar Generation Mean Absolute Percentage Error

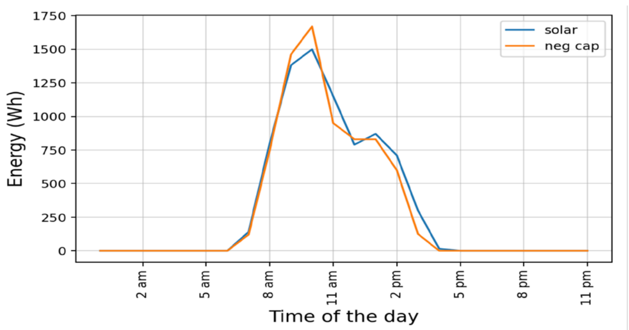


Fig 6. The model is able to account for intraday weather aberrations, the blue curve shows actual generation and the yellow shows the estimation by the xgboost model

6.1 SOLAR DETECTION

The detection of solar panels is a classification problem and the impact of False positives and negatives is substantial as it alters the demand profile of a user and sends back incorrect information to the utility. Adding back the estimated solar generation to net meter-data allows us to build the original consumption profile for a user. The impact of misclassified examples not only limits the solar module but also disaggregation of other appliances by unnecessarily tampering with the demand profile or failing to add back generation when needed. False Positives may result in detection of appliances not present and False Negatives might hamper the detection of appliances/ Underestimate their usage.

Hence we use Precision and Recall to accurately measure the models performance on ~6K solar as well as non-solar users. Table 1 shows the results

Precision	Recall
99.02%	99.43%

Table 1: Solar Detection metrics

$$Precision = \frac{TP}{TP+FP} \quad Recall = \frac{TP}{TP+FN}$$

6.2 SOLAR ESTIMATION

The objective of the framework is to accurately estimate the solar energy generated for a solar panel by taking into account the daily variations caused by weather conditions,as can be seen in Fig 6

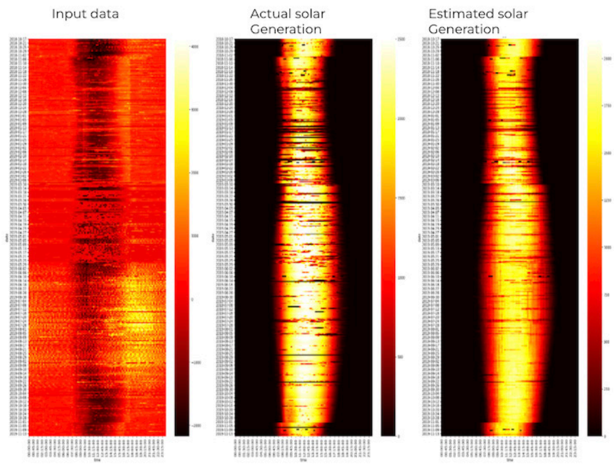


Fig 7.Inter-season variation captured

and seasonal characteristics, where solar generation is higher in summers, with a larger number of sun presence hours(as seen in Fig 7) and differing weather conditions such as sky cover, temperature etc. compared to winters

The solar generation estimation algorithm was evaluated on a test set of 5k users created from an initial 20k. For the result sanity, the test was kept separate from the training and validation set. Table 2 summarizes the results for the solar estimation algorithm. The results were evaluated using 2 different metrics viz, mean absolute percentage error (MAPE) and mean absolute error (MAE). Low MAPE and MAE represent the high accuracy of the model.

Metric	Value
Mean Absolute Percentage Error	11.73%
Mean Absolute Error	40.1 kWh

Table 2: Solar Estimation metrics

7. USE CASES

Solar detection and estimation solutions have multiple use-cases, a few of them are listed below:

Customer Satisfaction

Identifying users with solar panels can help utilities to provide a suite of solutions including disaggregation, bill prediction, next best interaction, etc, which helps in a better customer experience.

Customer Targeting

Having a solar panel is often correlated with the user being an eco-friendly user. Taking advantage of this fact, utilities can target these users for other eco-friendly products like smart thermostats and EVs.

Demand Management

Hybrid solar users not connected to the grid net-metering can be converted to net-metering helping utilities to better manage demand. In addition to these, a changed demand curve because of the solar users can cause a lot of issues for the utility[2] and by detecting and estimating solar generation, utilities get a better picture of demand rise and can take actions accordingly.

Appliance Degradation

Estimation of solar generation can help users to identify the degradation of solar panels and notify them whenever servicing is required.

8. CONCLUSION

Accurate solar detection and estimation can help utilities to better manage the demand on the grid while also deriving higher customer satisfaction. The AI-based solution presented in this paper is highly scalable and produces state-of-the-art results when tested on a robust dataset.

REFERENCES

[1]. D.R. Baker: Solar "net metering" extended by California regulators. SFGate. (2014).

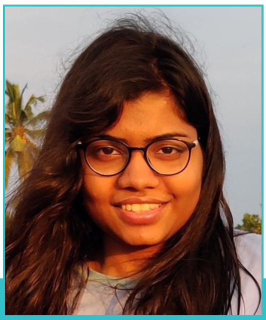
[2]. J. Postelwait: Solar Forecasting: The Next Big Thing For Solar Power?. UtilityPower Volume 16, Issue 1. (2013).

[3]. M.D. Lemonick: Solar Forecasts Could Help Electric Utilities and Climate. ClimateCentral. (2013).

[4]. Keiron O›Shea, Ryan Nash: An Introduction to Convolutional Neural Networks. (2015)

[5]. Chen, T., & Guestrin, XGBoost: A Scalable Tree Boosting System. (2016).

BIO-DATA



NISHA AGARWAL
Bidgely

Date of Birth:	07-Oct-1997
Qualification:	B.Tech IIT Roorkee
Designation:	Senior Data Scientist
Present Organization:	Bidgely
Field of Expertise:	Data Science
Mobile:	+91 75001 82645
Email:	nisha@bidgely.com

BRIEF PROFILE

Nisha is a data science professional with over 5 years of industry experience. She graduated with a degree in Electrical Engineering from the Indian Institute of Technology, Roorkee in 2019. Currently, Nisha holds the position of Senior Data Scientist at Bidgely Technologies Pvt Ltd, where she specializes in energy-driven projects such as Demand-side Management and Customer Behavioral Analysis. Her expertise extends to developing innovative solutions for smart scheduling of EV charging and home energy usage disaggregation.

BIO-DATA

BASANT KUMAR PANDEY
Bidgely

Date of Birth:	20-Aug-1986
Qualification:	B.Tech-M.Tech Dual Degree IIT Roorkee
Designation:	Director Data Science
Present Organization:	Bidgely
Field of Expertise:	Data Science
Mobile:	+91 81056 96669
Email:	basant@bidgely.com

BRIEF PROFILE

An an IIT Roorkee Graduate, Basant is a data Science professional with over 14 years of industry experience in this field. As a data science director at Bidgely Inc., he leads his team for innovations and state-of-the-art AI solutions to solve energy problems and driving a clean energy future. Prior to Bidgely, while working with Samsung Advance Research (SAIT) and Tata i-labs, he was involved in the development of ML/DL solutions in computer vision and virtual reality. Basant with dual B.Tech - M.Tech degree in Electronics and Communication Engineering, specializes in wireless communication. He has a keen interest and passion towards drawing a parallel between modern physics and ancient Vedic science.

A K MAYANK
Bidgely

Date of Birth:	07-Oct-1989
Qualification:	M.Tech, IISc Bangalore
Designation:	Principal Data Scientist
Present Organization:	Bidgely
Field of Expertise:	Data Science
Mobile:	+91 96639 03677
Email:	akmayank@bidgely.com

BRIEF PROFILE

Mayank is a data science professional with over 11 years of industry experience. He currently serves the role of Principal Data Scientist at Bidgely Technologies Pvt Ltd where he is involved in developing state-of-the-art energy forecasting & disaggregation algorithms that directly impacts millions of homes and business sites worldwide. In his past roles he was involved with developing analytics and machine learning solutions that had applications in the Airline Industry. He holds B.Tech degree in Mechanical Engineering from NIT Raipur & Master Degree in Aerospace Engineering from IISc Bangalore.

ieema your link to electricity | 10th Edition METERING INDIA 2024

TECHNICAL SESSION IV

STRATEGIC APPROACHES FOR EFFICIENT UTILITY OPERATION

FEEDER METERING: WHY SMART METERS

Shreya Shandilya | Dr. Vivek Chandra
MP East Discom

ABSTRACT

Presently in order to obtain data from feeder meters external modems based Meter Data Acquisition Systems (MDAS) are deployed by most of the Utilities across the country. Unfortunately, most of these discoms are struggling with their MDAS primarily because of persistent failures of external modems. One alternative to this is to go for Smart Meters but an obvious question that comes to mind is when the biggest benefit of smart meters i.e. remote disconnection is not feasible in feeder meters (as they are CT-operated), then why to go for smart meters for the purpose. Secondly what is the guarantee that the smart meters would be able to sustain the high voltage/current transients arising from line faults, lightning, or grid disturbances which the external modems could not. Further the replacement of healthy feeder meters (AMR) with Smart Meters owing to issues with external modems may also not be easy to justify. It may be noted that in RDSS smart meters are provisioned to be installed on DTs and at consumer end but the same are not mandated for feeder metering.

This paper deals with the aforesaid subject with regard to the problems encountered by discoms with conventional MDAS and the expected benefits of smart meters for feeder metering with facts and figures.

1 INTRODUCTION

Metering of feeders is necessary for the discoms for various functions like monitoring of power supply, Energy Audits and calculation of AT&C losses. Feeder meter data also helps in identification of overloaded feeders & PTs and calculation of reliability indices. Before R-APDRP (Re-structured Accelerated Power Development and Reforms Programme launched by Govt. of India in the year 2008-09), all feeder meters were proprietary-protocol based and were read manually or through a Meter Reading Instrument (MRI). The concept of remote meter reading started with R-APDRP with the introduction of MDAS [1]. The scope of MDAS covered the installation of external modems on feeder meters to fetch data from meters at regular intervals and transfer the same to the Central Server as depicted in figure 1 below. [1]

In the initial stage, data is gathered and stored in the form of logs and meter events. The stored data is then transmitted from the meter to the transmitting device i.e. modem. Data is retrieved through an interoperable head-end system. The raw data is then transformed into an understandable format, which is validated and standardized. This data is integrated and stored in a proper format for further query and analysis. In the last stage, information is analyzed and displayed through dashboards and reports. [2]

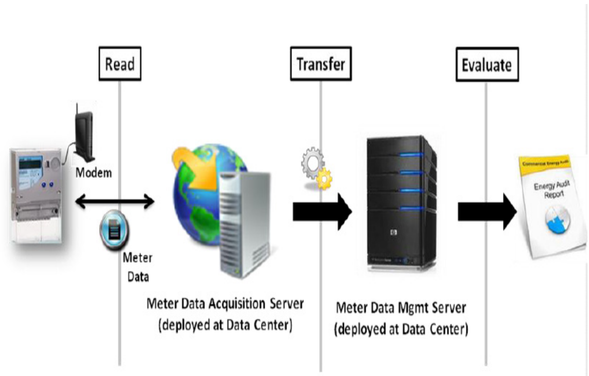


Figure 1: MDAS architecture under R-APDRP

2 LEARNINGS FROM RAPDRP:

Under R-APDRP, M-DAS was implemented in most of the discoms in the country. The major learnings from the project can be summed as under:

(i) Because of the proprietary nature of meters, the data acquisition by the centralized IT system from various makes of meters was a big challenge owing to different coding and conventions followed by different meter manufacturers. Utilities along with meter manufacturers came forward with the concept of Meter Interoperability Standards (MIOS) which helped create a common platform for meter reading using APIs (sought from the meter manufacturers) and reporting in a common data format. The move was only partially successful as the APIs of some of the models of various makes of meters could not be made available. There were some other challenges as well like the non-availability of few desired parameters in some makes and models of existing meters.

(ii) R-APDRP mandated procurement of Meters based on open protocol (called DLMS/COSEM (Device Language Message Specification/Companion Standard for Energy Meters) for future purchasing. DLMS provides guidelines for the metering data exchange and was a major step in the direction of interoperability. It provides a standard interface model that is valid for all types of energy meters including electricity, gas, and water. It also standardizes the widely used meter parameters using unique identifier codes.

(iii) Data communication cables linked problems arose [3]:

- Different communication cables were required when connecting modems to different makes of meters
- Even for the same make of meters, different cables were required for communication for different series of meters, which added to the confusion.

(vi) Data communication port of the meters posed issues at many locations due to exposure to the environment.[3]

(v) Different baud rates for different makes of meters and even for the same make of meters. This resulted in the wrong installation and configuration of modems leading to some meters not being read.

(vi) DLMS was a good solution for future purchases, but it did not provide a solution for the huge installed base of meters and as such old and new (DLMS) meters co-existed at that time.

(vii) Another challenge was a large number of external modems and/or the connecting cables getting burnt/defective due to various reasons including surges, loose connections, and improper earthing. The percentage readability in most of the discoms gradually declined.

(viii) The biggest challenge encountered was that the dependency which was earlier on meters now shifted to Modems. The modems were not interoperable. Honestly it was only the new DLMS meters that were open else everything including the modems along with the software were locked to one System Integrator(SI) due to various technical reasons. Hence the very purpose of deployment of open protocol meters (because of the use of external modems) was defeated [4].

3 MDAS POST R-APDRP:

After R-APDRP in a reasonable period, all the proprietary feeder meters were replaced by the open protocol (DLMS-compliant ones) in most of the utilities in the country,

After the end of R-APDRP fresh contracts were issued by discoms for the continuance of MDAS, however, challenges related to issues in external modems continued. Every time after expiry/termination of a contract, when a new MDAS vendor is appointed all modems and the application are required to be replaced.

The support of MDAS because of frequent cases of device failures is also a very big challenge. Because of poor percentage readability, the discoms are mostly forced to fetch feeder meter data manually through Meter Reading Instruments.

4 LAUNCH OF RFMS

In the year 2017, the Ministry of Power, GoI introduced a scheme called "11 kV Rural Feeder

Monitoring Scheme (RFMS)" and appointed REC Power Transmission Company Limited (RECPTCL) as the Nodal Agency. Under the Scheme, rural feeder meter data was desired to be acquired through external modems and sent to MDAS server for further analysis by all stakeholders as depicted in figure 2. [5]

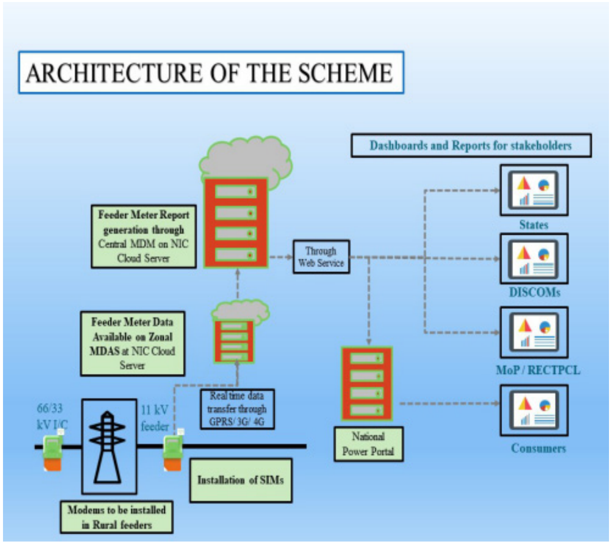


Figure 2: RFMS architecture

It was desired to develop a web-based system Rural Feeder Monitoring System through Data Logging of various essential parameters of all the 11 kV rural feeders emanating from 33/11 kV substations and make the information available online for various stakeholders including public portal, on a real-time basis for power supply monitoring, alerts, meter data analysis, information dissemination, and energy audit.

Based on tenders, contracts were issued by RECPTCL to various agencies in the domain to take up the work in most of the discoms in the country.

The project met the same fate in most of the discoms as R-APDRP, since no lesson was learnt from the earlier experience.

LAUNCH OF SMART METERS

Meanwhile smart meter was developed in the US as an improved version of the conventional open-protocol Energy meter with communication functionality having a modem as an integral part and launched in few countries. When compared to conventional Static Meters they have the following two additional features:

- Bi-directional Communication
- Remote disconnection facility

Smart Meters are considered a vital component of the proposed Smart Grid.

In India, for the nationwide rollout of smart metering, a road- map was published by MoP in 2012. [6]

The IS standards for LT Smart Meters for consumer metering in India were issued in 2015 while the same for CT-operated HT Smart Meters for feeder metering were issued in 2017. [7]

In 2022, MoP launched the RDSS program to improve the operational efficiency and financial sustainability of discoms. RDSS envisions smart metering in operational expenditure mode and provides financial support to discoms opting for prepaid smart-metering. [8]

In addition to consumer metering, the project covers system metering at the feeder and distribution transformer levels with co-mmunication features and associated advanced metering infrastructure thereby facilitating automatic measurement of energy flows at all levels for energy accounting and auditing without any human interference.

5. SMART METERS FOR FEEDER METERING

The production and deployment of Smart Meters for feeder Meters has started quite recently.

Since remote disconnection is not possible in feeder meters (as they are CT-operated), then an obvious question that comes to mind is why we require smart meters for feeder metering.

Two major lacuna in MDAS can be overcome by smart meters:

- In MDAS the Meters were interoperable but the stack (with modem) becomes non-interoperable. Smart meter shall render the system interoperable in a true sense as the modem shall be an integral part of the meter.

- The feeder meters are installed in substations that are prone to high energy transients arising from line faults, lightning, or grid disturbances. In smart meters Metal Oxide Varistors (MOVs) are used to protect against these transient surge events. Such protection was usually not available for modems that have a very high failure rate.

Other benefits of Smart Meters on Feeders:

i Enhanced Grid Monitoring and Control:

Smart meters installed on feeders provide real-time data on energy consumption, voltage levels, and load conditions. This allows grid operators to monitor the health of the distribution system more accurately and detect issues (like outages or faults) more quickly. [9, 10]

ii Improved Fault Detection and Isolation:

With smart meters, faults (like short circuits or open circuits) on feeders can be detected promptly. Automated systems can then isolate the faulty section and reroute the power to minimize outages, improving the overall reliability.

iii. Load Balancing and Optimization:

Real-time data from smart meters helps utilities manage loads more efficiently. They can predict when and where demand will peak and redistribute loads to avoid overloading transformers or other infrastructure, improving energy efficiency. [10, 11]

iv Reduced Technical and Non-Technical Losses:

Smart meters help detect energy losses, both technical and non-technical. This helps utilities reduce energy loss, improve billing accuracy, and reduce operational costs.

v. Better Demand Response Capabilities:

Smart meters on feeders shall enable utilities to implement demand response programs by incentivizing consumers to reduce their consumption during peak times. This leads to a more balanced demand on feeders and a reduced need for expensive peaking power plants.[12]

vi. Predictive Maintenance:

With continuous monitoring, smart meters can identify deteriorating equipment, such as transformers or switches, before failure occurs. Utilities can then perform maintenance proactively, reducing the likelihood of unplanned outages and lowering maintenance costs.

vii. Integration with Distributed Energy Resources (DERs):

As more distributed energy resources (like solar panels or wind farms) are added to the grid, smart meters help integrate these into the system. By monitoring how much energy is being produced and consumed, smart meters support efficient use of renewables on the distribution feeders. [11]

viii. Facilitate asset mapping & Indexing:

Smart Meters for feeder meters facilitate authentication of asset mapping and consumer indexing,

This can be achieved by mapping the last gasp of feeder meter with the last gasp of feeder meter with the last gasp of DT meters after switching off a feeder.

Further the consumer indexing is authenticated by mapping the last gasp of consumer meters with the last gasp of DT meter after switching off a DT.

ix. Micro Grid Optimization:

In the future, smart meters on feeders will support the growth of micro-grids. They will manage energy flow within micro-grids and between micro-grids and the main grid, facilitating localized energy independence and resilience, particularly in remote or disaster-prone areas. [9]

x. **Support for Electric Vehicle (EV) Charging Networks:**

As EV adoption grows, smart meters on feeders will support the management of EV charging infrastructure. They will help balance loads, manage peak demand, and integrate vehicle-to-grid (V2G) technologies where EVs supply energy back to the grid.

xi. **Advanced Data Analytics Using AI/ML:**

Artificial intelligence (AI) is already making significant strides in the energy sector, too, driving innovation and sustainability. The future will see increased use of AI and machine learning (ML) algorithms to analyze the vast amount of data collected by smart meters. AI-driven platforms, like Google's DeepMind, optimize energy consumption achieving significant energy savings. This will enhance predictive analytics, optimize energy distribution, and improve grid resilience.

6. CHALLENGES:

AMI as a component of Smart grids are vulnerable to a variety of cyber-attacks that can disrupt power supply, compromise data integrity, and threaten public safety [13]. Some common cybersecurity concerns with smart grids include:

- Malware and ransomware:

  Malicious software can infect smart grid systems and cause disruptions or lock operators out until a ransom is paid.

- Attacks against devices:

  Cyberattacks can target any IoT devices that connect and exchange data with other smart grid devices.

- Attacks against communications:

  Malicious actors can monitor or alter messages in the smart grid network.

- Attacks against the system:

  Attacks against the smart grid infrastructure are often the most disruptive and lucrative for hackers.

Some cybersecurity solutions for smart grids include: Encryption, Authentication, Network security, Network intrusion prevention system, and Network intrusion detection system.

7. LEARNINGS FROM IMPLEMENTATIONS

S#	Project	Outcome(s) & Ref
1	Smart city of Queensland, Australia	46% reduction in both peak demand and electricity consumption. (14,15).
2	California State (US)	Demand Response (DR) contributed to peak load reduction by 10%. (14,16).
3	200 SG pilot projects in US	70% of pilots have experienced enhanced reliability up to 9% Demonstrated that SG can be made self-healing and resilient. (14,15).

Table 1: Outcomes of few successful Projects

Learnings in terms of reduction in peak demand and enhanced reliability is observed in successful smart meter projects as shown in table 1

8. CONCLUSION

For Discoms, feeder metering is paramount. Looking at the persistent failures of external modem-based MDAS systems, it would be prudent to install smart meters at feeder levels as a top priority. This move is also crucial for making a seamless metering system from feeder to consumer end to reap the full benefits of Smart Metering. The combination of these technological advancements will lead to a more intelligent, efficient, and resilient energy distribution system, where smart meters on feeders play a crucial role in transforming the way energy is managed and consumed. In other words the Smart Metering Projects would yield the intended benefits only after the feeders and DTs are also equipped with smart meters.

9. REFERENCES:

[1] https://pfcindia.com/ensite/Home/VS/23

[2] https://powermin.gov.in/sites/default/files/uploads/ Final_ Revamped _Scheme_Guidelines

[3] https://www.securemeters.com/au/ news_articles/meter-data-acquisition-system-implementation-metering-international-issue-2-2013

https://powerline.net.in/2016/06/08/strategic-tools/

[4] White Paper by Infosys 'MDAS In RAPDRP- Is it Open or Proprietary?' Published in 2011.

[5] https://rfms.gov.in/

[6] https://www.nsgm.gov.in/sites/Default/files/India-Smart-Grid-Vision-and-Roadmap-August-2013.pdf

[7] https://standardsbis.bsbedge.com/BIS_SearchStandard.aspx?Standard_Number=IS+16444&id=0.

[8] https://powermin.gov.in/sites/default /files/uploads/ Final_Revamped_Scheme_ Guidelines.pdf

[9] https://www.sciencedirect.com/topics/engineering/ smart-microgrids

[10] Mouad Amqrane; Mohammed Ouassaid ,' Improving the Efficiency of the Electricity

Distribution Network Through the use of Smart Meters 'published in IEEE in Aug 2022.

[11] Gregory S. Ledva; Johanna L. Mathieu , Separating Feeder Demand Into Components Using Substation, Feeder, and Smart Meter Measurements, published in IEEE in Jan 2020.

[12] Darwish Darwazeh, Jean Duquette, Burak Gunay, Ian Wilton, Scott Shillinglaw, Review of peak load management strategies in commercial buildings, Sustainable Cities and Society, Volume 77, 2022, 103493, ISSN 2210-6707, https://doi.org/10.1016/j. scs.2021.103493.(https://www.sciencedirect.com/ science/article/pii/S2210670721007599)

[13] https://smartgrid.ieee.org/bulletins/july-2018/security-and-privacy-concerns-in-smart-metering-the-cyber-physical-aspect

[14] Ramakrishna Kappagantu, S. Arul Daniel, Challenges and issues of smart grid implementation: A case of Indian scenario, Journal of Electrical Systems and Information Technology, Volume 5, Issue 3, December 2018, Pages 453-467

[15] VassaETT, Smart grid 2013 global impact report SMARTGRID.GOV, DOE, U.S. (October 2013)

[16] EPRI, "EPRI Smart Grid Demonstration Initiative: Final Update". Available at: http://smartgrid.epri.com/Demo. aspx

BIO-DATA

SHREYA SHANDILYA
MPPKVVCL

Date of Birth:	18/07/1986
Qualification:	M.Tech (Power System Automation) B.E. (Electrical Engineering)
Designation:	DGM
Present Organization:	Madhya Pradesh Poorv Kshetra Vidyut Vitran Company Limited, Jabalpur

Field of Expertise:

- Implementation of Oracle ERP EBS in the Discom
- Development & Implementation of Meter Data Management System
- Development & Implementation of Advanced Consumer Care System
- Implementation of Smart metering system

Mobile:	94258 06060, 79875 48141
Email:	shreya.shandilya@gmail.com

BRIEF PROFILE

I have been with MP Poorva Kshetra Vidyut Vitran Company Ltd since September 2008, starting as an Assistant Engineer (City). Over the years, I have gained valuable practical knowledge of distribution systems and commercial activities. In my current role, I specialize in implementing complex systems such as Oracle ERP EBS, Meter Data Management Systems, Advanced Consumer Care Systems, and Smart Metering Systems. I also oversee Advanced Metering Infrastructure Service Provider (AMISP) projects, ensuring the successful deployment and integration of smart metering solutions. My extensive experience in these areas has significantly enhanced the efficiency and technological advancement of the Discom.

BIO-DATA

DR VIVEK CHANDRA
MPPKVVCL

Date of Birth: 29/11/1967

Qualification:

- Ph.D in Computer Science
- MS in Artificial Intelligence & Machine Learning
- M. Tech (Power System Automation), RGPV
- PG Diploma in AI/ML, IIIT
- BE (Electrical Engineering), Govt. Engineering College

Designation: GM-IT

Present Organization: Madhya Pradesh Poorv Kshetra Vidyut Vitran Company Limited, Jabalpur

Field of Expertise:

- Implementation of Oracle ERP EBS
- Development of Meter Data Management System
- Development & Implementation of Meter Data Implementation System
- Development & Implementation of Advanced Consumer Care System.
- Setup of Data Ware House & development of dashboards using Power-BI.
- AI/ML
- Establishment of Tier-4 Data Centre under R-APDRP

Mobile: +91 94254 12325

Email: vivekchandra123@gmail.com

BRIEF PROFILE

I am a professional with a distinguished career in IT and power distribution management. Currently, I hold the position of General Manager (IT) at MP East Discom in Jabalpur, where I lead strategic initiatives aimed at enhancing operational efficiency and customer service through technological innovations. As the Head of IT deptt. , I have successfully led pivotal projects such as the implementation of Oracle ERP EBS and the development of Meter Data Management Systems. Notably, I established a Tier-4 Data Centre as the Engineer in charge and led the Analytics Cell for data warehousing and dashboard development.

I have received several awards for my contributions, including the National e-Governance Award from the GoI , GoMP and my organization. I am an active member of professional bodies like the Computer Society of India and the Institution of Engineers. Additionally, I serve on the Board of Studies at Jabalpur Engineering College, contributing to the advancement of IT and Computer Science education."

TARIFF REGULATION AND STANDARDS POSES CHALLENGES TO DISCOMS

Manish Goel | Anil Kumar
Tata Power DDL

ABSTRACT

The aim of this paper is to highlight the various challenges which are faced by DISCOMs arising due to tariff regulation which is decided by State Electricity regulator. Over the period of time with the advancement of Static Energy meters, DISCOMs came to know how network parameters are affected by the tariff and how consumers are affecting our electrical system just to drive maximum benefits from the existing tariff.

1 INTRODUCTION

In early 2002, majority of the consumers were not familiar with the usage of reactive power compensation devices to meet lagging reactive power need of the induction motors and other devices which draw reactive power from the power source. However, in that era only few consumers were aware about using reactive power compensation devices and even if they were using higher rating capacitors than required, utilities network was not affected noticeably. The extra leading reactive power generated by one consumer is consumed by other therefore utility network was not affected much. As far as the billing of consumer is concerned, the tariff prevailing in many states across INDIA is "Lag only" for calculation of Apparent Energy in which extra leading reactive energy injected into network is neglected and treated as ZERO by Energy meter.

The scenario has changed now as every consumer is aware of tariff i.e. "Lag only" or "Lag +Lead" and familiar with the usage and importance of reactive power compensation devices. Despite this awareness among consumers over the period of time, tariff in many states is "Lag only" this allows consumers to use higher rating capacitor banks to achieve power factor near to unity or in the leading side. Presently in Discom with Lag only tariff, majority of the consumers injects reactive power into

Utility network and this leads to voltage regulation issues and penalty of reactive power at grid level.

The Lag only tariff regulations and metering standard also forces import mode energy meters to go into quandary condition arising due to unhealthy reactive power compensation devices of consumer or a field condition at the time of current reversal condition due to wrong connections. This condition also poses challenges to DISCOMs for accurate billing of consumers billed on Apparent energy in Lag only tariff.

2 CHALLENGES FACED BY DISCOMS

There are four major challenges faced by DISCOMS with lag only tariff which are as follows:

A. Accurate calculation of Apparent Energy

Industrial and commercial connections are billed on apparent energy i.e. kVAh. The kVAh calculation is dependent on tariff prevailing across the Discom which can be "Lag only" or "Lag + Lead".

In industrial and large commercial entities uses reactive power compensation devices which are connected in DELTA connections. As long as these devices are working fine in all three phases i.e. all three arms of DELTA connections are balanced till then there are no issues in this LAG only tariff for the calculations of Apparent Energy as balanced DELTA connected capacitor bank produces leading current which is 90-degree leading line or phase voltage fed to the consumer through distribution transformer. The Current and voltage sensed by the meter under these balanced capacitor banks are as per Figure 01.

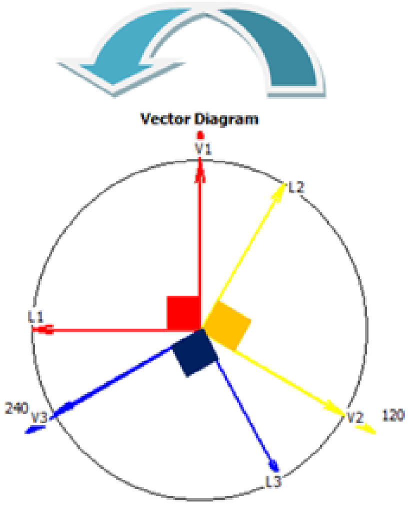


Figure 01

When these DELTA connected reactive power compensation devices i.e. capacitor bank goes unhealthy i.e. any of the capacitor in the any one or more arm of DELTA goes faulty then the angle between Phase voltage and current generated by the unhealthy delta capacitor bank produces current leading the voltage of that phase by an angle more than 90 degree & in other phases one or more phase current leads the voltage less than 90 degrees. In this scenario the voltage and current sensed by the meters are as per Figure 02. Wherein, values in front of R, Y and B indicates magnitude of reactive power leading (kVAr leading) connected to that phases.

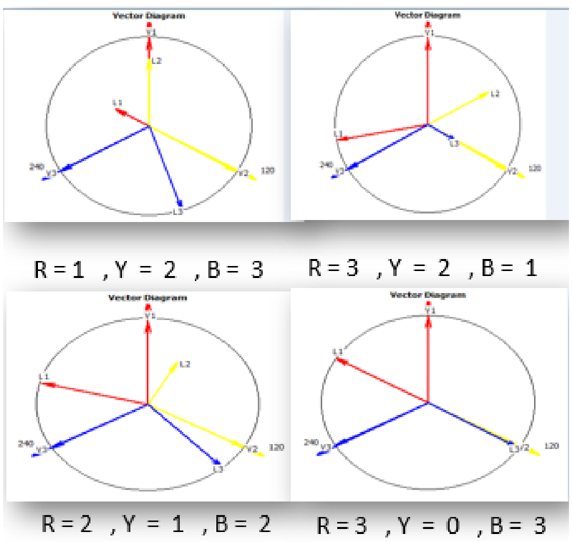


Figure 2

As per Energy meter standard IS: 14697:2021, conditions in figure 2 are similar to Energy Export mode as current is now leading the voltage by more than 90 degrees.

For an Import Energy meter, export of energy is not possible for Forward metering consumer therefore it is a condition similar to CT connection reversed or CT reversal connection.

Therefore, Energy meter programmed for "Import /forward mode" goes in to quandary state.

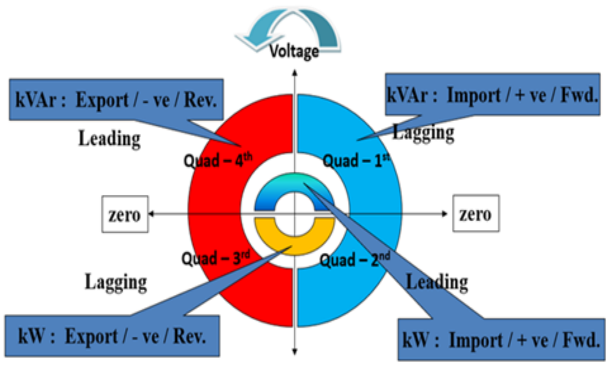


Figure 3

As per IS 14697:2021 the various Energy is exported when current lead the voltage by more than 90 degrees for more details refer Figure 3. Accordingly, this is an CT reverse connection for an Energy meter and if forward metering is done then meter will consider this leading reactive energy into lagging reactive energy and will calculate Apparent energy as per formula below (for Lag only tariff):

$$\text{kVAh} = \sqrt{(kWh^2 + (kVArh_{lag} + \underset{\text{Zero}}{\underbrace{kVArhlead}})^2)}$$

This leads to inaccurate billing as actually the reactive power is leading but due to this quandary conditions arising due to system condition created by consumer unhealthy capacitor bank and phasor position mentioned in metering standard, meter will consider this as lagging reactive power which is similar to current reversal condition.

Hence DISCOMS needs to revise the bills for those consumers whose reactive power compensation devices are unhealthy and active under no load or light load condiitons identified through meter data. Revising the bills for individual consumers are very tedious and laborious task. Thererfore we have to develop a logic in which this qaundary condition can be taken care by an Energy meter and accurate measuremnt of Apparent power can be done by Energy meter programmed for forward Import mode and lag only tariff.

B. Increased Line Losses

Technical losses of DISCOMs are also influenced by these reactive power compensation devices. Presently, most of the consumers are using capacitor bank more than required resulting in flow of excess reactive leading power in the network which also results in higher line losses and at the same time it also has an adverse effect on performance and life of electrical equipment. This further have cascading effect on higher Operation and maintenance of the network equipment and reduction in useful life of the asset.

C. Maintaining Supply Voltage

Voltage level are very critical for any equipment performance and as per The Indian Electricity Rules 1956 Section 54, Discom need to maintain the voltage levels at the point of supply within the limits as specified hereunder:

(i) In the case of low tension, ±6%.

(ii) In the case of high tension, + 6% to - 9%.

(iii) In the case of extra high tension, + 10% to -12.5%.

Presently, almost all consumers are aware about the importance of power factor and using reactive power compensation devices to meet the reactive power need. As tariff in Delhi is "Lag Only" excess leading power is not accounted for calculation of Apparent energy therefore many consumers are using over rating or excess capacitor banks than required for their load which results into voltage regulation issue. Every DISCOM is concerned and try to reduce customer complaints at the same time wants to increase customer satisfaction. As capacitor bank injects reactive leading power into network resulting in rise of voltage levels due to which consumers using appropriate ratings capacitor bank may also have to face higher voltage levels which is managed by DISCOMS by changing the position of tap changer and/or by deploying reactors at substation or appropriate levels.

D. Grid Voltage Levels

As per Chapter 6 of Indian Electricity grid code, rules for penalty and incentive for reactive power beyond and under predefined Voltage thresholds have been clarified:

1. The Regional Entity except Generating Stations pays for VAr drawal when voltage at the metering point is below 97%.

2. The Regional Entity except Generating Stations gets paid for VAr return when voltage is below 97% -

3. The Regional Entity except Generating Stations gets paid for VAr drawal when voltage is above103%

4. The Regional Entity except Generating Stations pays for VAr return when voltage is above 103%

There is situation where DISCOMs are unable to match these voltage levels thresholds under low load levels despite reactors are installed in the grid substations just to maintain Voltage thresholds, often this also leads to penalty at DISCOM due to violation of voltage thresholds. For instance, Grid loading values at SLDC – level is as follows:

GRID LOADINGS (11:48:29 HRS) 21/10/2024				
SUB-STATION	RTU*	MW	MVAR	VOLTAGE
BADARPUR	1	0	0	218
BAMNAULI	1	260	-19	394
BAWANA	1	798	-54	393
	0	269	76	392
DEV NAGAR	1	53	6	220
DIAL	1	47	-4	223
DSIDC	1	197	2	218
DWARKA	0	525	-57	219

GAZIPUR	1	91	6	0
GEETA COLONY	1	43	-9	213
GOPALPUR	1	130	-5	216
HCM LANE	0	51	6	225
HARSH VIHAR	0	377	-8	407
WAZIRPUR	0	103	-11	227
IP POWER	1	108	-16	207
KANJHAWLA	1	148	-2	217
KASHMIRI GATE	1	73	0	217
LODHI RD	1	106	-4	230

3 CONCLUSIONS

In this paper we have presented the various challenges which are faced by DISCOMS due Tariff finalized by State Electricity Regulatory commission, Metering Standard and System conditions dilemma faced by Energy Meters. The easiest way to tackle these issues is to change the tariff for all States/DISCOMS to "Lag + lead" from Lag only for apparent power calculation. Although there are many states across INDIA such as Rajasthan, Punjab, Uttar Pradesh which already have "Lag + Lead" Tariff in place.

4 REFERENCES:

[1] The Indian Electricity Rules 1956

[2] IS: 14697:2021 a.c. Static Transformer Operated Watthour Meters (Class 0.2S and 0.5S) and Var-Hour Meters (Class 0.2S, 0.5S and 1.0S)

[3] The Indian Electricity Grid Code

[4] SLDC Website

BIO-DATA

MANISH GOEL
TATA Power Delhi Distribution Ltd.

Date of Birth: 09th December 1980

Qualification: B.Tech. Electrical (NIT Kurukshetra)
PGDBM (SCDL) from IIMM Pune
Certified energy Manager from BEE

Designation: Additional General Manager

Present Organization: TATA Power Delhi Distribution Limited

Field of Expertise: Power Distribution Business(In particular Reliability improvement and loss reduction)

Mobile: 9971395357

Email: manish.goel@tatapower-ddl.com

BRIEF PROFILE

He is Head of the department SUC & Meter testing lab and presently working as additional GM in TATA Power - DDL, he is responsible for handling the power distribution business in one of the biggest and toughest circle in TPDDL. He has over 21 years of experience in the power distribution sector. In particular, he has significant experience of enforcement (theft detection and load booking), implementation of innovative ideas in power distribution for reliability improvement and reduction in no power complaints and AT&C loss reduction techniques. In these areas he has provided leadership and contributed a lot and he has worked extensively with the senior management for implementation of many projects.

BIO-DATA

ANIL KUMAR
TATA Power Delhi Distribution Ltd.

Date of Birth:	08th July 1984
Qualification:	B.Tech. Electrical (NIT Hamirpur) PGDBA (SCDL)
Designation:	Assistant General Manager
Present Organization:	TATA Power Delhi Distribution Limited
Field of Expertise:	Power Distribution Business and Energy metering
Mobile:	+91 99713 93873
Email:	anil.k@tatapower-ddl.com

BRIEF PROFILE

He is Head of the Group of Meter Testing Lab at TATA Power Delhi Distribution Limited, with the vast experience in the field of revenue protection, metering, advanced metering infrastructure deployment and quality check & development of Energy meters. He has 19 years of experience in Power Distribution Sector.

NEXT-GEN TRANSMISSION PLANNING INTEGRATING SMART METERS IN SYSTEM STUDIES

Sanika Nitin Zope
Government Engineering College

ABSTRACT

The integration of smart meters into transmission load flow studies represents a significant advancement in the accuracy and reliability of electrical grid analysis. Traditional methods of load flow studies are often prone to manual errors, more importantly analysis of real time system, which can compromise the quality of the analysis and the efficiency of the power system. This paper explores the utilization of smart meters to enhance the precision of transmission load flow studies. By leveraging real-time data collection and advanced analytics provided by smart meters, it is possible to significantly reduce human errors and improve the overall accuracy of load flow models. The study presents a comprehensive review of how smart meters contribute to more precise data acquisition, facilitates better decision-making in grid management. It also offers case studies that demonstrate the impact of smart meters on reducing errors. The results highlight the potential of smart meter technology to transform transmission load flow studies, ultimately leading to more reliable and efficient power system operations.

1 INTRODUCTION

The advent of Advanced Metering Infrastructure (AMI) represents a significant leap forward in the evolution of smart grids, offering transformative capabilities that enhance the efficiency and reliability of power systems. As the demand for electricity continues to rise and the integration of renewable energy sources becomes more prevalent, the need for precise, real-time data on energy consumption is paramount. Smart meters, a critical component of AMI, provide this essential data, enabling utilities to perform detailed load flow studies, optimize grid operations, and improve overall energy management.

This research paper explores the positive impacts of smart meters on transmission load flow studies, focusing on their role in enhancing data accuracy, enabling advanced demand-side management, and reducing transmission losses. By leveraging the capabilities of smart meters, utilities can achieve better load forecasting, improve system reliability, and reduce operational costs. Through a comprehensive review of relevant literature and case studies, this paper aims to highlight the significant benefits of smart meter integration in modern power systems, demonstrating their crucial role in the advancement of smart grids.

2 LITERATURE REVIEW

Advanced Metering Infrastructure (AMI) serves as the backbone of smart grids, enabling advanced demand-side management and accurate load profiling. This leads to better load distribution, reduced peak demands, and efficient load flow analysis. [1] AMI offers a comprehensive suite of features that enable utilities to optimize asset management, improve energy efficiency, and enhance customer engagement. Through the implementation of smart meters, utilities can perform remote diagnostics, detect potential fraud or outages, and provide advanced overload warnings, thereby optimizing the network and grid management. These capabilities lead to better scheduling, improved load profiling, and risk management [1]. Enhanced real-time monitoring capabilities of smart meter further ensure timely detection and response to anomalies, maintaining transmission network Which are crucial for effective transmission load flow studies [2].

The deployment and integration of Advanced Metering Infrastructure (AMI) in smart grids have demonstrated significant benefits in enhancing transmission load flow studies and overall grid management.

Pilot projects conducted by CLP Power Hong Kong Limited showcased the effectiveness of smart meters in real-world applications. The initial pilot involving around 4,000 customers demonstrated that customers appreciate service options that allow them to control their energy use. A subsequent larger-scale pilot with 26,000 customers further validated the benefits of demand response using AMI. These pilots provided critical insights into the costs, benefits, and challenges associated with smart meter deployment, leading to a full-scale roll-out of AMI [3].

In terms of cybersecurity, smart metering systems are designed with robust security measures to protect data integrity and prevent unauthorized access. Regular penetration tests and continuous system monitoring are essential practices to mitigate potential cyber threats, ensuring the reliability and security of the metering infrastructure [4].

Moreover, smart meters facilitate better load forecasting by providing detailed and accurate data on energy consumption patterns. This granular data helps in predicting peak demand periods and enables utilities to enhance generation efficiency and defer investments by optimizing asset utilization [5].

The ability to perform remote firmware upgrades ensures that smart meters can be continuously updated with the latest features and security measures, further enhancing their utility and reliability [6].

These benefits underscore the critical role of smart meters in modernizing and optimizing transmission networks, ultimately contributing to more efficient and reliable power systems. Research consistently supports the positive impact of smart meters, highlighting their importance in the advancement of smart grids and the optimization of transmission networks.

3 CURRENT SYSTEM STUDY PROCESS

KEY ELEMENTS:

A) Load Forecasting:

Planning Horizon: MSETCL uses PSSE for carrying out the Load Flow Studies along with various Tools to forecast and plan the load for the next five years. This involves simulating different scenarios, including peak load conditions, seasonal variations, and potential network expansions.

Simulations: Various simulations are run to analyze the system's behavior under different loading conditions. These simulations help in identifying potential bottlenecks, optimizing load distribution, and planning necessary upgrades or expansions.

B) Utilization of Load Flow Study Software:

Load Flow Study Software helps conduct load flow studies, simulate power system behavior, and plan for future demand. It integrates into client's workflows via built-in Python APIs, allowing data and models to be easily exchangeable across the industry.

- Automation and Customization: These tools offer vast automation and customization potential through their flexible APIs based on open Python technology. It provides rapid assessments for fast responses to changing network conditions and calculates area exchanges in the planning network model.

- Data Input Requirements: software requires a comprehensive .sav file that includes parameters such as bus voltages, line impedances, generation capacities and load data.

- Manual Data Entry: Currently, MSETCL engineers manually enter data into the .sav file, including historical load data, anticipated demand growth, and other network configurations. This manual process is prone to human errors and inaccuracies.

C) Python Script:

In the context of Python integration for load flow studies, the process begins with data collection and preparation. Load data is acquired from various sources, including historical records and real-time inputs from smart meters. This collected data is then formatted into a structured format suitable for input, such as CSV or Excel files. Next, Python scripts are employed to read and process this formatted data, ensuring it is ready for integration in PSSE for MSETCL's case.

The integration process involves utilizing Python APIs to input the processed data into the software, ultimately generating a comprehensive .sav file. This file includes updated parameters like bus voltages, line impedances, generation capacities, and load data. With the data integrated, the Python script automates the execution of load flow studies, simulating different load scenarios to analyze system behavior under various conditions. The results, such as voltage profiles, power flows, and system stability metrics, are then extracted and analyzed. Finally, Python is used to generate comprehensive reports and create visualizations, such as graphs and charts, to illustrate key findings and insights from the load flow studies.

D).sav File:

- Data Entry: Enter historical load data, anticipated demand growth, and network configurations manually into the .sav file, ensuring all necessary parameters like bus voltages, line impedances, generation capacities, and load data are included.

- Simulation Setup: Load the .sav file into PSSE for the simulation setup and configure the load flow study scenarios using the data from the .sav file.

- Simulation Execution: Execute the load flow simulations using the loaded .sav file and monitor the outputs, including voltage levels, power flows, and system stability.

- Result Analysis: Analyze the simulation results to identify potential issues, such as voltage drops or overloading, and use the insights gained to optimize the transmission network and plan for future demand.

SIMULATION PROCESS

Data Collection (Manually): Gather load data manually from various sources, including historical records and operational logs.

Data Formatting (Manually): Manually format the collected data into a structured format suitable for PSSE input, such as CSV or Excel files.

Python Script Read & Process Data: Use Python scripts to read and process the manually formatted data for integration.

API Calls - Input Data & Create .sav File: Utilize Python APIs to input the processed data into the software and create a comprehensive .sav file.

Load .sav File in PSSE: Load the generated .sav file into PSS®E to set up the load flow study.

Run Load Flow Studies & Observe Results: Execute load flow simulations using the loaded .sav file and monitor the results, such as voltage levels and power flows.

Report Generation & Visualization: Generate reports and create visualizations to summarize and illustrate the findings from the load flow studies.

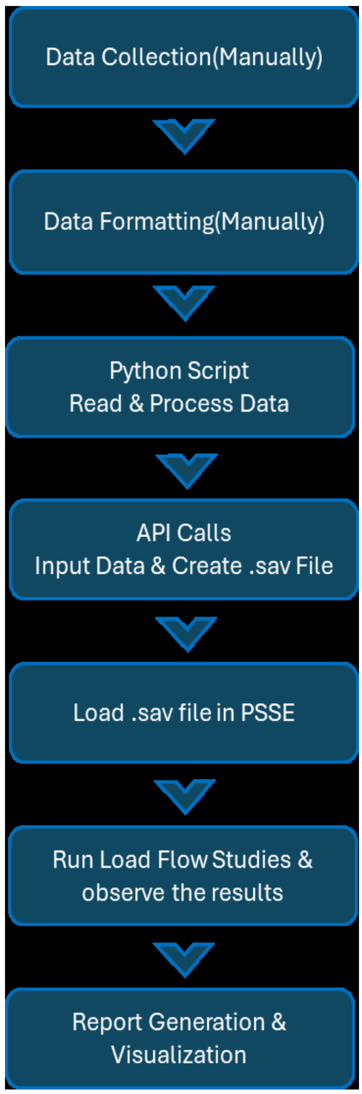


Fig-1: Current System Study Process

The Figure 2 illustrates the process of collecting and utilizing yearly maximum loading data across various zones of MSETCL.

The Load Dispatch Center (LDC) flashes the yearly maximum loading data, specifying a particular date and time. The State Transmission Utility (STU) requests maximum loading data from all seven zones.

The zones seek data from the respective circles. Circles gather data from the substations, and the collected data is sent back to the divisions. The division compiles data from substations and sends it back to the STU. Substation ABT Data: Substations prepare the loading data in an Excel file based on ABT (Availability Based Tariff) metering, and this data flows back through the chain. SAV File Creation: The STU prepares the final .SAV file, which retains data for at least two years. Utilization of SAV File: All zones utilize the SAV file for various applications, such as load flow analysis, contingency analysis, outage management, and RE connectivity, among others. This entire process, from the initial request to the utilization, takes approximately 6-8 months.

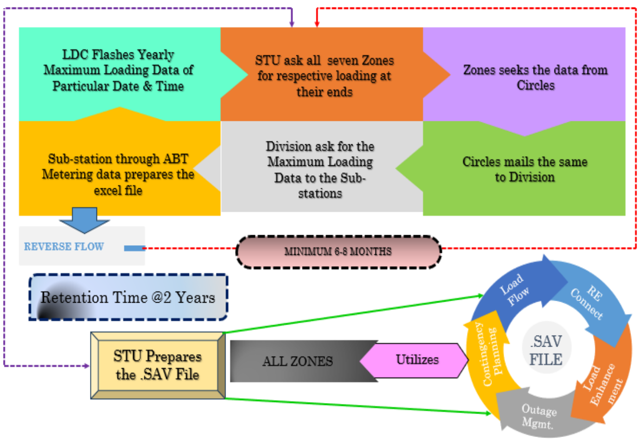


Fig. 2: Process of Existing Data Collection

4 ADVENT OF SMART METERS

SMART METER

A smart meter is an advanced energy measurement device that captures high-resolution consumption data at intervals as short as one minute and transmits this information to utility companies via Advanced Metering Infrastructure (AMI) networks. These networks typically use mesh networking protocols such as Zigbee or cellular technologies like LTE-M. Smart meters are equipped with components such as high-precision Analog-to-Digital Converters (ADCs), secure microcontrollers, non-volatile memory, and two-way communication modules. This setup supports automated meter reading (AMR), real-time monitoring, outage detection, and demand response programs, thereby enhancing the accuracy and efficiency of transmission load flow studies and grid management

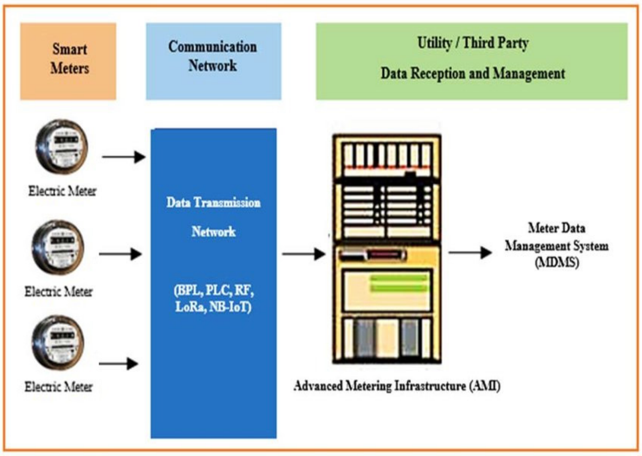


Fig-3: Flow chart of the system of AMI

SYSTEMS WITH SMART METER

(a) Meter Data Management System (MDMS): MDMS is a central repository that collects, stores, and manages data from smart meters. It processes raw data, performs validation, editing, and estimation (VEE) processes, and ensures data quality before making it available for analysis

(b) Advanced Metering Infrastructure (AMI): AMI encompasses the entire infrastructure that enables two-way communication between smart meters and utilities. It includes smart meters, communication networks, and head-end systems that manage data collection and transmission.

(c) Communication Networks: These networks facilitate the transmission of data from smart meters to central systems. Types: RF mesh networks, cellular networks (GSM, LTE), Power Line Communication (PLC), Wi-Fi

(d) Cloud-Based Platforms: Cloud platforms offer scalable storage and computing resources for managing and analyzing smart meter data. They enable utilities to perform advanced analytics, machine learning, and big data processing without investing in on-premises infrastructure. Microsoft Azure IoT, Amazon Web Services (AWS) IoT, Google Cloud IoT also use it.

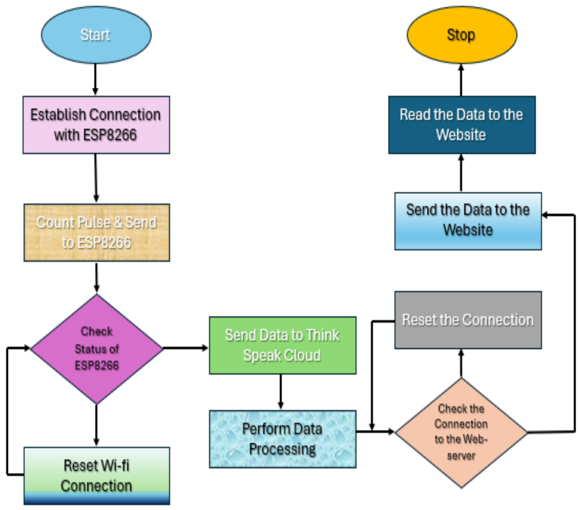


Fig-4: Flow Chart of the Complete System

CHANGES DUE TO INTRODUCTION OF SMART METERS

1 Automated Data Collection: Smart meters continuously collect and transmit data on load consumption.

2 Data Processing: Python scripts process real-time data and update the .sav file for PSSE input.

3 Simulation Execution: It uses the updated .sav file to run load flow simulations with accurate data.

4. Result Analysis: Engineers analyze the simulation results, leveraging the precision of smart meter data for better insights.

5 Optimization: Based on the analysis, the transmission network is optimized to handle current and future loads effectively. This all reduces and cancels out the chances of human errors

5 ADVANTAGES OF SMART METERS IN LOAD FLOW STUDIES

Automated Data Collection and Preparation: Smart meters enable automatic and continuous collection of load data in real-time, capturing detailed electricity consumption and other key electrical parameters. This data is directly transmitted to a central database in a standardized format, minimizing the need for manual intervention and reducing the risk of errors or delays in data preparation.

Accurate Data Input for Load Flow Analysis: Real-time data from smart meters is processed via Python scripts and integrated into transmission planning software using API calls, ensuring that the most current load information is used to update the .sav file. This automation reduces human error associated with manual data entry and enhances the accuracy of load flow models.

Improved Simulation and Scenario Analysis: With accurate, up-to-date load data from smart meters, transmission software can conduct more reliable and detailed load flow studies. High-resolution data allows for precise simulation of system behaviour under various conditions, leading to better analysis of potential outcomes and improved planning for future network operations.

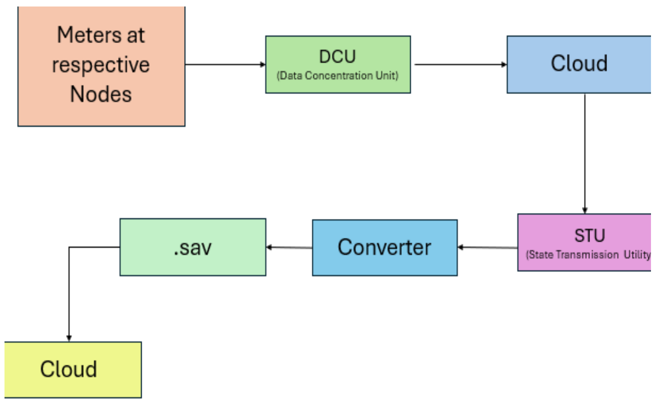


Fig-5: Proposed System Study Process

Dynamic Load Forecasting and Outage Management: Smart meters play a critical role in real-time load forecasting and managing outage scenarios. They provide detailed data that helps predict load patterns and manage the redistribution of loads during transformer or line outages. For example, in a substation with four transformers, smart meters can accurately predict how loads will shift if one transformer fails, ensuring the remaining transformers can handle the increased load without overloading. This capability enhances grid stability, improves outage management, and prevents cascading failures in the system.

Enhanced Reporting and Visualization: The integration of smart meter data significantly improves the quality of reports and visualizations generated from load flow studies. Engineers can make informed decisions by leveraging detailed, real-time data, enabling them to detect issues early, optimize network performance, and plan for future load enhancements, renewable energy integration, and contingency management.

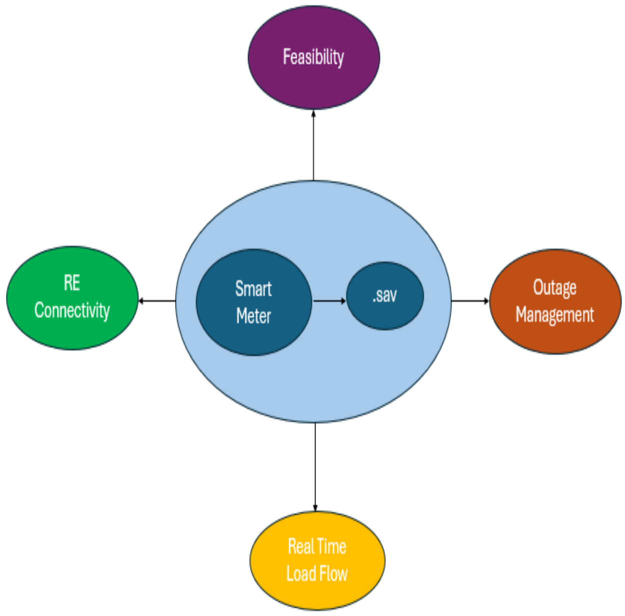


Fig-6 Real-Time Advantages of Smart Meters

Additional Considerations:

In the current system, decision-making for outage planning, contingency scenarios, renewable energy (RE) integration, and load enhancements is often based on static data that is more than a year old. This leads to inaccuracies and potential risks. By incorporating real-time data from smart meters, these challenges can be mitigated, ensuring more informed and timely decisions that enhance overall system reliability.

6 IMPLIMENTATION PROCESS

Pilot Projects:

Pilot projects at the transmission level are essential for testing the integration of smart meters into load flow studies. A pilot project with Chatrapati Sambhaji Nagar Division which includes 18 substations can be chosen as a pilot project.

Key takeaways include the ability of smart meters to provide accurate, real-time data for better grid management and the need for robust infrastructure and automation tools to support large-scale deployment. To scale these pilots, utilities should follow a phased roll-out, implement continuous monitoring, and ensure close collaboration with technology providers to refine integration processes before full-scale implementation.

Conducting such pilot projects to test the integration of smart meter data with PSSE. These projects will help identify potential challenges and fine-tune the data integration process.

Gather feedback from the pilot projects and make necessary adjustments to the data collection and integration processes.

Full-Scale Deployment:

Full-scale implementation of smart meter integration at the transmission level is a critical step toward modernizing grid operations. Building on successful pilot projects, utilities can scale deployment by leveraging real-time data from smart meters to improve load forecasting, reduce transmission losses, and enhance outage management. For example, utilities implementing smart meters across the entire grid can automate data collection, minimize manual errors, and enable more accurate load flow studies in real time.

To ensure successful full-scale implementation, utilities should adopt a phased roll-out approach, gradually expanding smart meter integration while continuously monitoring system performance. Robust communication networks, staff training, and collaboration with technology partners are essential to address challenges such as data management and scalability. This process allows utilities to optimize transmission systems efficiently and improve long-term grid reliability.

Phased Roll-Out: Implement a phased roll-out of smart meters across MSETCL's network, ensuring a smooth transition from manual data entry to automated data collection.

Training and Support: Provide training to engineers and technicians on the new processes and tools, ensuring they are well-equipped to manage and utilize the smart meter data effectively.

7 DISCUSSIONS

Full scale Deployment is a viable option in case of smart meters as far as transmission system is concerned. Because the primary need of smart metering in transmission is to monitor accurate data at regular and minute time intervals, to regulate and plan for outage management and other infrastructure. This can only be achieved if deployment of smart meters is on the same level as the power system, because the data from various regions needs to be monitored and stored at the same instance, due to interconnection of numerous grids and variety of sources. This will increase the reliability of metering. An additional step we can take is by deploying pilot projects that are static in nature just to observe the potential challenges and trouble shoot them while implementing the corrections in a full-scale dynamic system.

8 CONCLUSIONS

With a growing demand of electricity and ever-increasing complexity of power system due to numerous energy sources and variety of loads, smart meters have become a need of the modern electricity transmission. It is important to minimize the losses in their experimentation in practical environments as also it is essential that testing in this field must be incremented to a scale such that novel and lossless technologies could enter the market sooner

9 REFERENCES

[1] *Application of Advanced Metering Infrastructure in Smart Grids Ramyar Rashed Mohassel1, Alan Fung 2, Farah Mohammadi3 and Kaamran Rahimyar*

[2] *Chan, J., Ip, R., Cheng, K. W., & Chan, K. S. P. (2019). Advanced Metering Infrastructure Deployment and Challenges. Proceedings of the 2019 IEEE PES GTD Asia. CLP Power Hong Kong Limited.*

[3] *Chen, Z.; Amani, A.M.; Yu, X.; Jalili, M. "Control and Optimization of Power Grids Using Smart Meter Data: A Review." Sensors, 23(2023): 2118.*

[4] *Agrahari, S., Chhetri, A., Yadav, A., & Joshi, T. P. (2022). "Smart Meter Reading with Cloud Computation." Minor Project Final Report, Tribhuvan University, Institute of Engineering, Thapa thali Campus.*

[5] *CLP Power Hong Kong Limited. (2019). Pilot Programs and Full-scale AMI Deployment. In J. Chan, R. Ip, K. W. Cheng, & K. S. P. Chan, Advanced Metering Infrastructure Deployment and Challenges (pp. 11-20).*

[6] *A Server Based Load Analysis Of Smart Meter Systems -S.ELAKSHUMI, A. PONRAJ*

[7] *Design Simulation and Implementation Of a Smart Net Metering System for the Distributed PV and Grid Connected Customers – Haider Mahumud Bijoy, Md Mahadi Hasan, Md Asadur Jaman, Muhbiul Haque Bhuyan.*

[8] *Smart Energy Meter Implementation: Security Challenges and Opportunities._ J. Reman gak Jambi, W K Wong, Filbert H. Juwodo, Foad Motalebi.*

BIO-DATA

SANIKA NITIN ZOPE
Government Engineering College

Date of Birth:	18th Dec 2004
Qualification:	T.Y. B.Tech Student
Designation:	Student
Present Organization:	Government Engineering College Aurangabad
Field of Expertise:	Electrical Engineering
Mobile:	9764195671
Email:	sanikazope12@gmail

BRIEF PROFILE

I am currently pursuing a Bachelor of Technology in Electrical Engineering at the Government College of Engineering, Aurangabad. I'm an active IEEE student member, participating in various societies, including the Industry Applications Society, Power & Energy Society, Power Electronics Society, and Women in Engineering. My areas of interest include power systems, renewable energy integration, Automation in power Systems and the application of emerging technologies in electrical engineering.

DISCRETE APPROACH OVER THE POWER QUALITY PARAMETERS MONITORED BY AN UTILITY

Dr. Manish Wath
MSEDCL

ABSTRACT

In this approach various power quality features have been studied as in recent past and upcoming future power systems is gradually becoming electronically powered. Although power electronics technology brings qualitative leap to renewable energy, microgrid technology, distributed power supplies, electric vehicles, etc, it also affects the power quality of the distribution network. This paper discusses the need for measures to address voltage fluctuations, harmonic distortion, and transient events. By implementing appropriate mitigation strategies and maintaining power quality parameters within IEEE standards, utilities can enhance system performance, reduce losses, and protect equipment. Collaboration between utilities and consumers is essential for effective power quality management.

1 INTRODUCTION

As the world's third-largest energy-consuming country, India plays a pivotal role in shaping the global energy scenario. While significant challenges remain, India is making remarkable strides in renewable energy. The country ranks fourth globally in both renewable energy installed capacity and wind power capacity, and fifth in solar power capacity. This growth aligns with India's ambitious commitment to achieve 500 GW of non-fossil fuel-based energy by 2030, as outlined at COP26. This ambitious target is a key component of India's "Panchamrit" strategy for combating climate change.

India's power sector has undergone significant improvements, with increased access to grid electricity, reduced power deficiency, and substantial growth in renewable energy capacity. However, the evolving load profile, which now includes a mix of inductive and nonlinear components, presents new challenges for power quality management. High-quality power is essential for the optimal functioning of electrical and electronic equipment, reducing downtime, minimizing faults, and improving overall efficiency and sustainability.

As India continues its journey towards a cleaner energy future, addressing power quality challenges will be crucial to ensure the efficient and reliable operation of its electrical systems.

2 UTILITY PERSPECTIVES OVER POWER QUALITY

India's vast electrical grid relies on approximately 13 million distribution transformers with a combined capacity of 6 lakh MVA. While some utilities have managed to significantly reduce the high failure rates (up to 20%) through strict quality standards, many still face challenges.

At the central level, the Central Electricity Authority (CEA) and the Central Electricity Regulatory Commission (CERC) oversee power quality regulations. State Electricity Regulatory Commissions (SERCs) enforce these regulations at the state level. Despite the existence of regulations, inconsistencies arise due to a lack of uniformity in their approach and implementation across different states.

Although basic guidelines for Power Quality meters are consistent, comprehensive monitoring mechanisms remain absent, hindering effective power quality management. Regulators monitor distribution losses and AT&C losses, and reliability indices are also considered. However, insufficient penalties for non-compliance to utilities & HT consumers weaken the enforcement of regulations, leading to potential risks in maintaining power quality standards.

India faces challenges in ensuring consistent power quality standards across its distribution systems. However, ongoing efforts to improve the reliability and efficiency of these systems are essential for meeting the growing energy demands of the country.

3 CHALLENGES

A Grid Reliability with renewable energy sources.

Integrating renewable energy sources like solar and wind into the power grid poses significant challenges for maintaining grid reliability due to their inherent variability. Wind energy depends on fluctuating wind speeds, and solar power is affected by changing weather conditions and time of day. This unpredictability leads to difficulties in ensuring stable and high-quality power supply, which traditional grids are not designed to handle. For example, variations in power output can cause voltage fluctuations and frequency instability, leading to issues such as voltage sags, swells, or outages.

In India, the challenge is heightened by ambitious targets for renewable energy, aiming for 50% of electric power capacity from non-fossil sources by 2030. This requires expanding the transmission network significantly—51,000 km of new lines and increased transformation capacity, costing around ₹2,44,000 crore. The distributed nature of renewable farms, often far from central monitoring stations, complicates real-time power quality management. Without effective oversight, the grid faces risks of interruptions and instability, particularly as the network adjusts to handle surplus power while managing power quality.

The power distribution system has been designed generally as a radial one. The centralized load dispatch centers manage the supply-demand by controlling large generating stations as per the system's demand. The installation of distributed solar generation under various scheme will provide another local source of electricity. However, after implementation of these schemes at massive scale, it will have a significant effect on the distribution system, mainly stability of Grid i.e. voltage regulation, reactive power etc.. Solar power plants may not provide sufficient reactive power to maintain grid voltage stability especially during the period when solar generation is high but demand is low.

B Grid reliability with Electric Vehicle The rise of electric vehicles (EVs) is straining electrical grids due to increased charging demand. This irregular demand disrupts the grid's balanced load profile, posing challenges for electricity companies. EV charging stations further exacerbate the issue by introducing potential power quality problems, such as harmonics and altered power factor.

EVs themselves can also impact power quality. The power electronics used in EV chargers generate harmonics, distorted waveforms that can lead to various issues like voltage sags, swells, and phase imbalances. These disturbances can undermine grid stability and efficiency, affecting both equipment performance and overall reliability.

Addressing power quality challenges is crucial for ensuring the grid's sustainability and supporting the seamless integration of EVs. Identifying and mitigating these issues is key to maintaining a reliable power supply and a sustainable energy ecosystem.

C Harmonic generators.

Harmonic generators, such as drives, LEDs, UPS systems, converters, and inverters, introduce electrical harmonics into the power network. These distortions can cause issues like overheating, reduced efficiency, and equipment malfunction. Industries like steel rolling mills, arc furnaces, textile factories, and data centers are significant contributors due to their reliance on such equipment.

Designated Consumers connected at a supply voltage of 11 kV or higher of specific industries and sectors such as Arc Furnace, Induction Furnace, Iron & Steel, Aluminium, Textile, Paper & Pulp, Chlor-Alkali, Petro-Chemical, Cement, Pharmaceuticals, IT/ ITES, Airports, Malls, Hotels, Banking, Railways/ Metros, or any other categories specified by regulatory authorities. The current harmonics they introduce into the power system must comply with the standards set forth in IEEE 519:2014, which may be updated periodically. Additionally, the voltage harmonics and Total Harmonic Distortion (THD) for each individual supply voltage must adhere to IS 17036, as it is revised over time.

The growing demand for renewable energy and EVs, combined with continued industrialization and technological advancements, puts further strain on the grid. To ensure reliable power delivery, substantial investments in upgrading outdated power grids are necessary. These older systems were not designed for modern industries' complex power needs, making infrastructure upgrades crucial to prevent disruptions and maintain efficiency.

4 NEED OF POWER QUALITY MONITORING, ANALYSING AND REPORTING

Power quality monitoring is essential for various reasons:

- **Regulatory compliance:** Adhering to regulations like CEA and IEC 61000-4-30 ensures compliance with standards.
- **Grid stability:** Monitoring helps address challenges from renewable integration and non-linear loads, mitigating voltage variations and harmonics.
- **System performance:** Understanding system performance allows for better matching of supply and customer needs.
- **Problem identification:** Targeted monitoring can identify specific issues or load-related problems.
- **Enhanced power quality service:** Collaborative efforts between providers and customers can improve power quality through measures like installing power quality meters.
- **Predictive maintenance:** Monitoring enables timely equipment maintenance to prevent failures.

To ensure regulatory compliance and maintain power quality, MSEDCL has invested in total 6,791 power quality meters. These meters are installed at nearly every distribution sub-station to monitor the 11 kV (low voltage side) of power transformers.

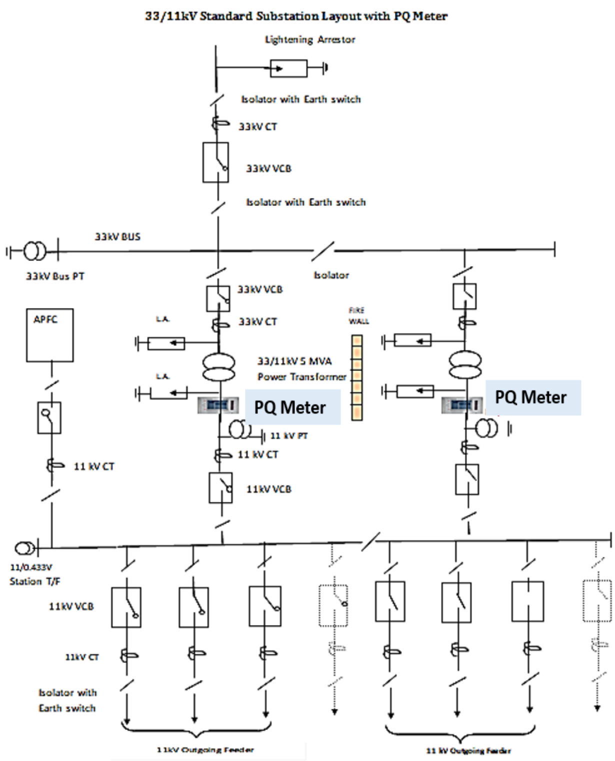


Figure 1: Location of PQ Meter

Overall, power quality monitoring is crucial for ensuring grid stability, meeting regulatory requirements, and providing reliable and efficient power supply.

5 KEY ASPECTS OF POWER QUALITY

Power Quality (PQ) refers to maintaining the voltage, current, and frequency of the power system within acceptable limits. IEEE standards, particularly IEEE 519:2014, focus on defining acceptable limits for power quality to ensure efficient and safe operation of electrical systems.

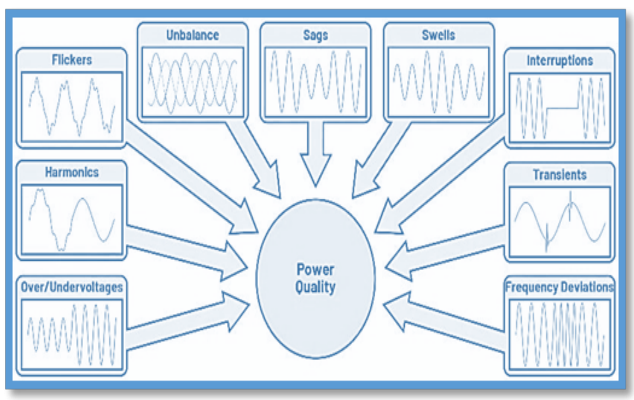


Figure 2: Characteristics of Power Quality.

Power Quality Parameters as per MERC SOP Regulations 2021 which are in line with IS 17036 and IEEE standard 519:2014:

Sr.No	Parameter	Technical Explanation	Max/Min Limit	Standard	Rationale
1	**Voltage Variation**	The deviation of the RMS (Root Mean Square) value of voltage from its nominal value.	Un +10%/-15%	MERC SOP Reg 2021(reg. 22.5)	For 6351V the lower limit will be 5398 V per limit will be 6986.1V for 100% of time(Continuous)
2	**Voltage Unbalance**	root mean square (r.m.s.) values of the line-to-line voltages (fundamental component), or the phase angles between consecutive line voltages, are not all equal.	≤ 2%	MERC SOP Reg 2021(reg. 22.7)	The voltage unbalance is calculated by finding out Negative Sequence(V2) & Positive Sequence component (V1) by using Matrix method & then using the formulaV2/V1*100.
3	**Voltage Dips/Swells**	Short-duration reductions or increases in the RMS voltage.	**Dip:** 5%-90% **Swell:** >110% of nominal voltage Duration: 10ms up to and including 1 min	MERC SOP Reg 2021(reg. 22.8)	Dip:-If the residual voltage is between 90 to 80% say 85% of vtg 440v i.e.374V persists for 200ms then such 30 events per year are permitted & upto 500ms 40 events are permitted. Swell:- If voltage increases by 10% or more & lasts between 10 & 500ms is considered as a violation
4	**Short Interruptions**	Temporary loss of voltage.	Residual Voltage <5% of nominal voltage	MERC SOP Reg 2021(reg. 22.10)	If the residual voltage is below 5 % and interruption lasts between 10 to 200 ms, is a violation. 05 nos of events per yr during the above said time range is permitted.
5	**Harmonic Distortion**	The presence of harmonic currents or voltages in the power system.	≤ 5% (individual harmonic), ≤ 8% (THD-Total Harmonics Distortion)	IS-17036	95% of each period of one week-for individual harmonics upto 25th order & 100% of time for THD upto 40th harmonics order(Samples-1008(7d*24hrs*60s/10min)
6	**Flicker (long term)**	Visible variation in light intensity caused by voltage fluctuations.	≤ 1	MERC SOP Reg 2021(reg. 22.6)	Compliance limit is 95% of each period of week. Long term flickers are to be measured for 2hrs per day in a week (24hrs*7days/2= 84 nos samples)

Table 1: PQ Parameters and its limits

6 ANALYSIS OF PQ PARAMETERS

Power quality analysis is a critical area of research in electrical engineering, focusing on ensuring that electrical power systems operate efficiently without disturbances that could affect equipment performance. The IEEE (Institute of Electrical and Electronics Engineers) has published numerous papers and standards on power quality analysis like IEEE Std 1159-2019, IEEE Std 519:2014 etc..

Techniques for Power Quality Analysis:

Power quality analysis is crucial for ensuring the reliable and efficient operation of electrical systems. Here are some common techniques used to assess power quality.

Waveform Analysis: Using tools like oscilloscopes to visualize voltage and current waveforms and identify distortions.

Harmonic Analysis: Measuring the harmonic content in the electrical system to identify and mitigate sources of distortion.

Transient Analysis: Capturing and analyzing transient events to understand their causes and impacts.

Power Factor Correction: Implementing solutions like capacitor banks to improve the power factor and reduce energy losses.

Tools and Equipment:

Power Quality Analyzers: Specialized instruments that measure various power quality parameters, including voltage, current, harmonics, and transients.

Oscilloscopes: Used for detailed waveform analysis.

Software Tools: For modeling and simulation of power quality issues and their impact on electrical systems.

Applications:

Industrial & Commercial Facilities: To ensure the reliable operation of sensitive machinery & to improve energy efficiency.

Utilities: To maintain the stability and efficiency of the electrical grid.

7 CASE STUDY

Case Study:- Power Quality and Revenue Loss in MSEDCL

Introduction:

This case study examines the challenges faced by MSEDCL, a major electricity distribution utility, in terms of power quality and revenue loss. A comprehensive analysis of 100 high-tension (HT) consumers reveals alarming trends, including excessive demand and harmonic distortion.

Problem Identification:

- **Excessive Demand:** 43 out of 100 consumers have maximum demand (MD) exceeding 1.0 MVA, and 36 have MD equal to or greater than their contracted demand (CD).
- **Harmonic Distortion:** 31 consumers have exceeded the total demand distortion (TDD) compliance limit, 10 are on the border, and 4 have crossed voltage THD compliance limits.

Sr	Upstream Tx MVA	CD KVA	MD	KVAR	ISC/IL	Current distortion TDD %	TDD Comp %	Max THD %	VTHD %
1	25	4000	3278	± 1200	49.81	23.12	8	55	4
2	100	3150	3008	-200 to +600	317	19.2	15	24	1.5
3	25	5500	5527	± 2000	29.81	8.78	8	27.5	7
4	50	2500	1403	± 500	324.3	4.15	15	80	2.5
5	100	3000	1500	-200	912.56	20.21	15	29	1.4
6	50	6207	6587	- 700 to + 1200	102.67	12.59	15	21	3.4
7	100	3301	1588	±300	576.18	2.25	15	35	2
8	50	5500	5307	600	73.01	7.02	12	10.5	1.2
9	25	10100	9986	- 4500 to + 4000	20.74	2.1	8	40	9
10	100	6340	6201	-600 to +1500	135	20.38	15	24	2
11	100	133	122	- 50 to + 10	9343.5	18.23	20	30	1
12	50	500	149	- 80	1553.9	11.04	20	25	1.1
13	25	4990	4917	- 1500 to +2000	11	8.75	5	18	1.2
14	25	3600	3697	- 4000 to + 2500	57.9	9.03	12	220	1.1
15	100	500	311	-70 to +50	2661.9	20	20	50	1.1
16	100	1900	1408	- 200 to + 300	598.19	6.47	15	22	1.5
17	50	3000	1571	130	413.62	12.06	15	16.5	1.1
18	50	2500	2097	170	255.2	4.91	15	16	0.7
19	10	1232	584	80	228.61	13.34	15	53	1.5
20	10	529	179	± 30	520.4	5.77	15	900	2.4
21	10	1665	387	-110 to +150	111.16	7.45	15	14	1
22	50	600	284	- 85	2935	12.44	20	17.9	2
23	50	3000	1411	- 200 to + 300	157.41	12.12	15	80	2.4
24	10	174	96	- 70 to + 80	528.74	21.37	15	600	5.5
25	10	400	132	± 50	491.85	13.52	15	65	2.1

Table 2: Summary of Recorded harmonics data at Pune Region

Sr	Incoming Voltage KV	Upstream Tx MVA	CD KVA	MD	KVAR	ISC/IL	Current distortion TDD %	TDD Comp %	Max THD %	VTHD %
	DHULE CIRCLE									
1	11	10	175	90	-15 to +5	1478	4.56	20	15	2.2
2	33	25	4999	3656	-150 to +750	71.8	15.31	12	23	3.8
3	33	25	2900	2845	-750 to +400	93.21	8.8	12	32	3.8
	AURANGABAD RURAL CIRCLE									
4	132	100	5500	4988	-100 to +600	138.3	5.3	7.5	7.3	2
5	33	50	10000	9888	-4000 to +3800	28.41	2.45	8	15	1.8
6	33	100	900	794	-450 to +320	1930	19.17	20	95	0.9
7	33	100	9000	5609	-1800 to +170	230.9	5.21	15	9.5	1.2
8	33	100	5000	2628	-300 to +270	425	5.96	15	14.5	1.1
9	33	50	1350	1156	-20 to +125	408.2	1.42	15	6	1.7
10	132	100	16900	18810	-12000 to +2400	88.65	3.37	6	18	0.8
11	33	100	5000	4207	+100 to +380	367.5	6.95	15	11	1.1
	AURANGABAD URBAN CIRCLE									
12	11	50	550	549	-40 to +160	1631	13.5	20	40	1.9
13	11	5	570	368	-160 to +40	190.8	3.77	15	55	1.9
14	33	100	1604	1502	-160 to +240	1890	15.07	20	21	1
15	11	50	2500	1430	-320 to +20	1496	4.04	20	33	1.6
16	33	100	8000	7763	-1700 to +300	292.2	6.88	15	16	1.2
17	11	10	500	374	-30 to +40	288.6	4.8	15	11	2.2
18	11	100	2264	2286	±750	1247	17.93	20	29	1.1
19	33	100	3900	3323	-100 to +500	200	8.9	15	12.5	0.8
20	11	50	299	167	0 to +60	3540	6.04	20	45	2.6
21	132	600	8000	7434	-2500 to +2700	1811	4.28	10	12	0.6
22	33	100	1200	874	±100	739	11.42	15	23	1
23	11	5	400	232	-20 to +50	158	2.2	15	40	3.3
24	11	50	1490	1140	±240	1255	16.5	20	48	2.3
25	33	100	995	625	-70 to +270	1048	10.66	20	37	1

Table 3: Summary of Recorded harmonics data at Ch. Sambhaji Nagar Region

Sr	Incoming Voltage KV	Upstream Tx MVA	CD KVA	MD KVA	KVAR	ISC/IL	Current distortion TDD %	TDD Comp %	Max THD %	VTHD %
	BHANDARA CIRCLE									
1	11	16	1900	1938	-90 to +280	107	15.52	15	23	5.7
2	11	10	5000	3138	-400 to +300	53.08	4.4	12	20	3.1
3	11	10	5000	3138	-120 to +120	219.1	7.47	15	500	2.3
4	33	10	1500	1233	-250 to +220	116.3	19.41	15	30	2.5
5	220	Fault level(3130 MVA)	46000	44260	-24000 to +13000	69.26	14.71	3.75	130	1.5
	NAGPUR URBAN CIRCLE									
6	33	50	5000	4357	-1300 to +600	113.3	8.04	15	16	1.2
7	33	50	2200	2200	-550	677	13.48	15	18	2.3
8	33	50	4300	3750	-270 to +370	105.3	4.9	15	7.5	2.7
9	11	10	375	100	-50 to +60	423.3	8.7	15	24	1.5
10	33	50	6500	7889	-3300 to +2000	62.6	4.42	12	20	2
11	33	50	6150	5617	-1600 to +100	75.16	5.24	12	18	2.3
	NAGPUR RURAL CIRCLE									
12	33	50	5300	5219	-3000 to +1700	79.75	9.29	12	37	3.5
13	33	50	1510	816	-150 to +20	783	6.33	15	110	3.3
14	132	200	9000	7572	-1700 to +3000	193.3	2.55	7.5	11	1.3
15	33	50	1650	1594	-400 to +350	327.1	19.16	15	32	1.7
16	33	50	1600	1094	-270 to +220	684.5	25.06	15	75	3.5
	VARDHA CIRCLE									
17	11	10	1140	630	-100 to +50	538.4	5	15	16	2.7
18	11	10	225	106	+20	1285	3.02	20	13	2.3
19	11	5	175	104	-15 to +30	780.5	3.65	15	19	2.6
20	11	10	250	99	-15 to +40	1525	7.18	20	95	2.1
21	11	10	655	901	-10 to +50	360.4	1.74	15	1000	2.1
22	33	50	9300	9178	+200 to +1050	46.4	8.35	8	9.5	2.4
23	132	100	16900	16048	-200 to +1200	59	3.3	6	4.2	1.8
24	33	50	1200	1142	-50 to +200	347	13.53	15	15.5	2.1
25	220	Fault level(728 MVA)	12000	13230	-1000 to +1600	157	3.27	3.75	75	1.3

Table 4: Summary of Recorded harmonics data at Nagpur Region

Sr	Upstream Tx MVA	CD KVA	MD	KVAR	ISC/IL	Current distortion TDD %	TDD Comp %	Max THD %	VTHD %
1	100	484	164	-40 to +40	4339	11.32	20	500	2.8
2	50	4430	4195	-1000 to -2500	92.56	33.41	12	250	14
		This consumer has HT Fixed capacitors. Major load is only in night.							
3	100	10100	9862	-4000 to +4000	50.14	3.83	12	12	5.5
		This consumer has HT Fixed capacitors. Continuous Load for 24 hours							
4	100	63	45	-25 to +30	15686	36.45	20	150	5.5
5	100	343	125	-25	18745	38.9	20	400	2.5
6	100	150	47	-15 to +20	12332	24.71	20	200	3
7	50	450	321	-50 to + 50	1450	24.56	20	40	1.6
8	50	250	216	-75	1383	19.2	20	45	1
9	50	160	99	-35	3309	27.21	20	48	2.6
10	50	800	542	-50	743	7.11	15	13.5	1.9
11	50	658	136	40	2039	6.4	20	85	1.5
12	50	315	158	0	3184	41	20	275	1.4
13	50	220	176	25	1557	3.7	20	18	1.9
14	50	6500	3250	500	144	15.41	15	23.5	1.2
15	50	3000	2600	600	171	7.17	15	16	2.6
16	50	500	535	150	516	18.52	15	50	1.8
17	100	250	110	7	6671	30.77	20	54	2.7
18	50	1101	976	-200 to + 200	159.6	3.87	15	250	6
19	100	900	503	-200 to + 200	895.66	68.28	15	180	1.1
20	100	267	134	-30 to + 30	7599.9	20.71	20	45	2.5
21	100	250	283	-50 to +20	5152.4	11.4	20	160	1.8
22	100	650	406	-30 to +50	2259.8	14.05	20	200	8
23	100	250	166	-40 to +80	3907.1	29.85	20	110	1.6
24	50	275	182	-70 to +50	1728.9	8.44	20	250	4.5
25	100	270	71	-15 to + 15	18378	14.41	20	250	3.7

Table 5: Summary of Recorded harmonics data at Konkan Region

Reactive Power Compensation: The widespread use of fixed HT side capacitors and overcompensation of reactive power contribute to amplified harmonics.

Revenue Loss: This was resulting in indirect revenue losses to utility.

Root Causes:

- **Non-compliance with Demand Limits:** Consumers exceeding their contracted demand limits are contributing to network congestion and losses.
- **Harmonic Generation:** Excessive harmonics are being generated by consumers due to nonlinear loads and improper reactive power compensation.
- **Under/Overcompensation of Reactive Power:** Incorrect reactive power compensation can amplify harmonics and lead to increased losses.

Corrective Measures:

- **Power Quality Monitoring:** Install power quality measuring meters to accurately monitor harmonic levels and identify problem areas.
- **Detuned Automatic Power Factor Control Panels:** Promote the use of these panels to mitigate harmonic distortion and optimize reactive power compensation.
- **Stricter Compliance Measures:** Enforce stricter compliance measures for new consumers to ensure they adhere to demand limits and harmonic standards.
- **Harmonic Control at PCC:** Encourage HT consumers to control harmonic currents at the point of common coupling (PCC) to reduce the overall harmonic burden on the network.

Conclusion:

The case study highlights the critical issues of power quality and revenue loss faced by MSEDCL. By implementing the recommended corrective measures, MSEDCL can improve power quality, reduce losses, and enhance the overall efficiency of its distribution network

Case Study 2:-Impact of Harmonic Distortion and Revenue Loss to Utility.

Introduction:

This case study examines the root causes of transformer noise, vibration, and overheating at a 132/33 kV substation within MSEDCL. The substation was feeding power to three steel melting plants with induction furnaces.

Problem Identification:

MSEDCL conducted measurements at the transformer and identified that voltage harmonics were significantly high, exceeding the prescribed limits outlined in IEEE 519:2014. These excessive harmonics were attributed to the three steel plants.

Data Collection and Analysis:

Detailed measurements were carried out on the 33 kV feeder at the substation for approximately 26 hours. These measurements revealed that voltage harmonics were as high as 12%, leading to excessive energy losses in the transformer.

To isolate the individual contributions of each plant, MSEDCL requested that the plants be closed alternatively for one hour. However, only two steel industries conducted a harmonic study and submitted a report claiming compliance with IEEE 519:2014 standards.

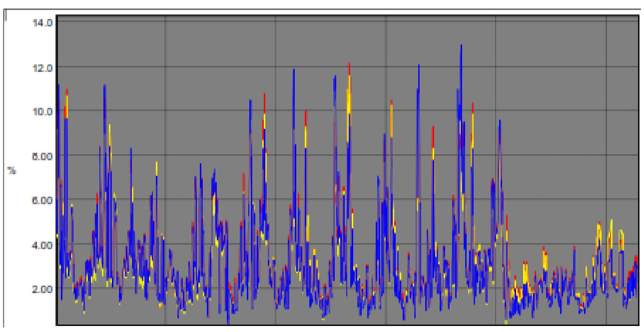


Fig 3-Voltage harmonics in r/o Steel Industry

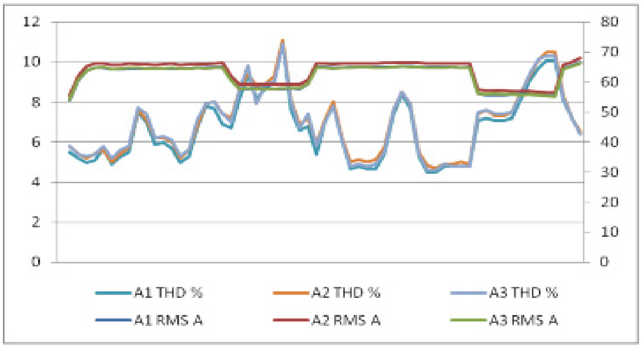


Fig 4-Current harmonics in r/o Steel Industry

Key Findings:

- **Non-compliance with IEEE 519:2014:** one Stee industry was found to be generating harmonics beyond the prescribed limits of IEEE 519:2014, including specific harmonic orders.
- **Insufficient Measurements:** Both industries had not conducted measurements for 24 hours under normal operating conditions as required by IEEE 519:2014.
- **Excessive Harmonics:** Other Steel industrys higher order harmonics were causing excessive voltage harmonics in the system.
- **Revenue Loss:** The high levels of harmonics were leading to increased energy losses in the transformer, resulting in revenue loss for MSEDCL.

Recommendations:

Based on the findings, the following recommendations were made:

- **Carry out 24-hour measurements at each plant:** To accurately assess harmonic levels and identify the root causes.
- **Reduce harmonics within IEEE 519:2014 limits:** If exceeding limits, industries should carefully select solutions to mitigate harmonics.
- **Avoid negative impact on the grid:** Industries should refrain from injecting excessive reactive energy, transients, or causing cross resonance.
- **Ensure harmonics are well below IEEE 519:2014 limits:** Adhere to the prescribed limits for both total harmonic distortion (TDD) and individual harmonic orders.

Conclusion:

The case study demonstrates the significant impact of harmonic distortion on power quality and revenue loss in MSEDCL. By addressing the root causes and implementing the recommended measures, MSEDCL can improve the overall performance of its distribution network and reduce financial losses.

Case Study 3: Power Quality Comparison between Ag-Dominated and Industrial Substations

Introduction:

This case study compares the power quality performance of two substations with different loading patterns: an agricultural (Ag) dominated substation and an industrial substation. The analysis focuses on key parameters such as voltage unbalance, sags, swells, interruptions, reverse voltage correction (RVC), frequency, and total harmonic distortion (THD).

Data Analysis:

Table 6 and 7 present the power quality data for both substations. A broad comparison reveals the following key observations:

- **Voltage Unbalance:** Both substations maintain voltage unbalance within acceptable limits, indicating good system performance.
- **Sag, Swell, and RVC:** The industrial substation experiences fewer sag, swell, and RVC events compared to the Ag-dominated substation. This is likely due to the more stable and less fluctuating nature of industrial loads.
- **Interruptions:** The Ag-dominated substation has a higher frequency of interruptions, leading to more sag, swell, and RVC events. This could be attributed to the sensitivity of agricultural loads to voltage fluctuations.
- **Frequency and THD:** The industrial

substation faces challenges with frequency and THD. The non-linear and highly fluctuating nature of industrial loads, such as arc furnaces and plastic industries, can introduce harmonics and disrupt the frequency stability of the system.

Conclusion:

The comparison of power quality data between the Ag-dominated and industrial substations highlights the distinct challenges associated with each type of load. While the industrial substation experiences fewer interruptions and voltage fluctuations, it faces issues with frequency and THD. The Ag-dominated substation, on the other hand, has more interruptions and related events.

To address these challenges, targeted measures can be implemented, such as improving system reliability, optimizing load management, and installing harmonic measurement and mitigation equipment in industrial areas. By addressing these issues, MSEDCL can enhance the overall power quality and reliability of its distribution network.

Week	Nos. of Voltage Unbalance	Sag	Swell	Short Interuptions	Flicker	(RVC)	Voltage Variation	THD	Frequency
02.09.2024 to 08.09.2024	Pass	80	43	2	Fail	103	Fail	Pass	Pass
09.09.2024 to 15.09.2024	Pass	65	58	1	Fail	78	Fail	Pass	Pass
16.09.2024 to 22.09.2024	Pass	54	43	2	Fail	76	Fail	Pass	Pass
23.09.2024 to 29.09.2024	Pass	75	46	9	Fail	101	Fail	Pass	Pass

Table 6. Events recorded at 33/11kV Kanholibara, Nagpur Rural area (AG dominated).

Week	Nos. of Voltage Unbalance	Sag	Swell	Short Interuptions	Flicker	(RVC)	Voltage Variation	THD	Frequency
02.09.2024 to 08.09.2024	Pass	40	27	0	Fail	7	Pass	Fail	Fail
09.09.2024 to 15.09.2024	Pass	7	0	0	Pass	2	Pass	Fail	Fail
16.09.2024 to 22.09.2024	Pass	13	0	1	Pass	10	Pass	Fail	Fail
23.09.2024 to 29.09.2024	Pass	26	0	3	Pass	14	Pass	Fail	Fail

Table 7. Events recorded at 33/11kV MIDC Butibori, Nagpur (Industrial Load).

Table 6 and 7 shows power quality data of two sub stations with different loading patterns Ag dominated and Industrial load respectively. As a broad comparison it is observed that voltage unbalance is well maintained in system. Due to industrial non-linear and highly fluctuating load (eg. Arc furnace and plastic industry) there is effect on frequency and THD however there are less interruptions and less sag, swell and RVC. On contrary Ag. Dominated sub-station has more interruptions due to which sag, swell, RVC events are more.

PQ parameter	Events status at Ag. Dominated S/Stn	Events status at Industrial S/Stn
Voltage Unbalance	PASS	PASS
Sag/ Swell	More	Less
Interruption	More	Less
RVC	More events	Less Events
Frequency	PASS	FAIL
THD	PASS	FAIL

Table 8. Inference from table 6 and 7.

From the above case study following generalized

statement over causes, remedial actions and execution is tabulated in Table

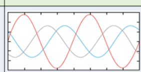
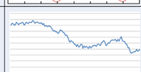
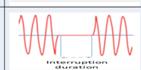
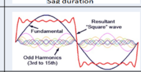
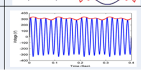
POWER QUALITY PARAMETERS	IMAGE	PROBABLE CAUSES	REMEDIAL ACTION
VOLTAGE UNBALANCE		Single-phase load imbalance	Uniform distribution of load on all phases
		Faulty conductors	Periodic maintenance / replacement of damaged conductors / cables
		Open neutrals	Proper grounding / Earthing.
VOLTAGE VARIATIONS		Fluctuations in load	Encouraging / educating consumer for PQ issues related to load fluctuation (DSM)
		Transmission line faults	Periodic maintenance.
		Poor power factor	Reactive power compensation / APFC at sub-station
VOLTAGE SHORT INTERRUPTIONS		Faults on the power system	Preventive maintenance.
		Overloading	Load control / Demand management
		Weather-related disturbances	Pre-monsoon maintenance.
VOLTAGE SAG/SWELLS		Switching off large loads	Encouraging / educating consumer
		Capacitor switching	APFC instead of manual / fixed compensation
		Power system disturbances	Preventive maintenance.
VOLTAGE HARMONICS DISTORTION		Non-linear loads (e.g., rectifiers, inverters)	Harmonic filers at consumer premises
		Resonant conditions in the power system	Plant audits for consumers for system healthiness
		Inadequate filtering	Penalty provisions as per MERC guidelines
VOLTAGE FLICKERS		Sudden Change in Loads(drives,Arc furnace)	Reactive Power control, Consumer awareness
		Uneven Load sharing	Load balancing, Voltage regulations
		Overloading of Transformers	Augmentation, Load diversion, line maintenance

Table 9-Causes & Remedial actions for PQ parameters

7 CONCLUSIONS

The comprehensive power quality analysis conducted has provided valuable insights into the electrical supply system's stability and reliability. While the system generally maintains acceptable voltage levels, occasional dips and surges require attention through measures like transient fault mitigation and voltage regulation. Harmonic distortion, a persistent issue, necessitates monitoring and mitigation strategies to protect equipment and prevent long-term problems. Additionally, the analysis identified transient events that can be addressed through surge protection measures.

By maintaining power quality parameters within IEEE standards, utilities can ensure reliable system operation, reduce losses, and safeguard equipment from damage. The growing emphasis on PQ measurement and analysis marks a significant step towards optimizing energy infrastructure. As data collection expands, utilities will gain a deeper understanding of PQ issues, enabling informed decision-making and proactive measures to improve power quality.

Key considerations for both utilities and designated consumers include:

- **Installation of power quality meters:** Accurate measurement and analysis of PQ parameters are essential for identifying and addressing issues.
- **Collaboration between utilities and consumers:** Joint efforts can lead to more effective solutions and shared benefits.
- **Implementation of mitigation measures:** Targeted measures can address specific PQ problems, such as harmonic distortion or voltage fluctuations.

This comprehensive approach, encompassing data collection, analysis, and collaborative action, is crucial for meeting the demands of a technology-driven society and ensuring a reliable and efficient power supply.

8 REFERENCES

[1] Zhao Min, Li Shunwei, Yue Yunli et al., "Performance and Influence Analysis of Power Electronics in Distribution Network[J]", China High-tech, vol. 1, pp. 149-150, 2017.

[2] Math H J Bollen and Sarah K Rönnberg, "Primary and secondary harmonics emission; harmonic interactiona set of definitions[C]", Intemational Conference on Harmonics & Quality of Power, pp. 703-708, 2016.

[3] YUAN Xiaoming, CHENG Shijie and HU Jiabing, "Dynamic Stability Problem of Multi-Scale Voltage Power Angle in Power Electronic Power System[J]", Proceedings of the CSEE, vol. 36, no. 19, pp. 5145-5154, 2016.

[4] Guo Shanghua, Huang Chun, Wang Lei et al., "Detection and Control Method of Voltage Fluctuation and Flicker[J]", Relay, vol. 32, no. 3, pp. 45-48, 2004.

[5] Hao Qi, Xiangsheng Wang, Shen Gao et al., "Research and Application of Power Quality Integrated Management System [J]", Electronic Design Engineering, vol. 25, no. 5, pp. 170-174, 2017.

[6] Aurora Gil-de-Castro, Sarah K Rönnberg and Math HJ Bollen, "A study about harmonic interaction between devices[C]", 2014 IEEE 16th International Conference on Harmonics and Quality of Power (ICHQP), pp. 728-732, 2014

[7] K Narendra, D Fedirchuk, R Midence et al., "New microprocessor based relay to monitor and protect power systems against sub-harmonics[C]", 2011 IEEE Electrical Power and Energy Conference (EPEC), pp. 438-443, 2011.

[8] Haixue Lin, "New Development of Harmonic Problems in Power Grid - On Superharmonics[J]", Supply and Electricity, vol. 1, pp. 35-38, 2016.

[9] A Larsson, "An overview of the origin and propagation of supraharmonics (2–150kHz) [J]", BrazilianJournal of Physics, vol. 32, no. 2b, pp. 483-494, 2014.

[10] Ana-Maria Blanco, Jan Meyer, Sarah Ronnberg and Math Bollen, "Survey of supraharmonic emission of household appliances [C]", International Conference on Electricity Distribution, 2017:1–5.

[11] Ana-Maria Blanco, Jan Meyer, Sarah Rönnberg and Math Bollen, "Survey of supraharmonic emission of household appliances [C]", International Conference on Electricity Distribution, 2017: 1–5.

Citation:

[1] H. Li, C. Lv and Y. Zhang, "Research on New Characteristics of Power Quality in Distribution Network," 2019 IEEE International Conference on Power, Intelligent Computing and Systems (ICPICS), Shenyang, China, 2019, pp. 6-10, doi: 10.1109/ICPICS47731.2019.8942538.

BIO-DATA

DR MANISH WATH
MSEDCL, Mumbai

Date of Birth:	21.09.1968
Qualification:	BE(Elect), M. Tech(IPS), PhD
Designation:	Chief Engineer(Testing)
Present Organization:	MSEDCL, Mumbai
Field of Expertise:	Testing
Mobile:	+91 82918 95587
Email:	mgwath42@gmail.com

BRIEF PROFILE

He is presently working as Chief Engineer in Maharashtra State Electricity Distribution Company Ltd, Mumbai. He is working in the field of Smart Energy Metering. He is having 30 years academic and power sector experience. He has received patent from Govt. of India for his innovative research on Traction metering. An innovative research on the topic Error Compensation Technique in Smart metering was done by him and patented by the Australian Government. His books published by international publisher. Moreover, his 15 research work papers published in various IEEE journals and IEEE conferences.

ieema your link to electricity | 10th Edition METERING INDIA 2024

TECHNICAL SESSION V

CYBERSECURE DIGITAL TRANSFORMATION OF DISCOMS

FUTURE STRATEGIES FOR UTILITIES IN THE NET-ZERO ERA

Sandeep Kumar Beniwal
Genus Power Infrastructures Ltd

1 ABSTRACT

This paper examines how utilities are evolving to achieve net-zero emissions through sustainable and consumer-focused strategies. As efforts to reduce carbon footprints increase, utilities are adopting practices that combine sustainability with customer engagement. It covers trends such as using renewable energy, enhancing energy efficiency, and implementing smart grid technologies. The paper also highlights the importance of consumer involvement in shaping utility strategies, including demand response programs and personalized energy solutions. By analysing recent advancements, it provides an overview of how utilities are transitioning to a net-zero future, emphasizing the need for a balanced approach that meets both environmental goals and consumer needs.

Keywords: Net-Zero Emissions, Sustainable Utilities, Renewable Energy, Energy Efficiency, Smart Grids, Demand Response, Consumer Engagement, Innovative Utility Practices, Energy Transition Case Studies, Carbon Footprint Reduction

2 INTRODUCTION

The global push for net-zero emissions has driven significant changes, with utilities leading the shift towards sustainability. Utilities are adopting greener practices and engaging consumers to address climate change, balancing the need to reduce emissions with evolving consumer demands.

India ranks fourth globally in wind power and fifth in solar power capacity, with renewable energy capacity increasing by 96% in the last 8.5 years, according to International Renewable Energy Agency (IRENA). By 2030, India aims for 500 GW of renewable capacity, a 45% reduction in carbon intensity, and the production of 5 million tonnes of green hydrogen. The country also plans to add 30 GW of offshore wind, 37.49 GW of solar parks, and triple its nuclear capacity. Currently, India's renewable capacity is 199.52 GW, a 165% rise since 2014. Fig 1 presents a global comparison of renewable energy share relative to GDP, highlighting India's position within the broader energy landscape. Meanwhile, Fig 2 illustrates the percentage contribution of various renewable energy sources within India, providing insights into the country's energy mix.

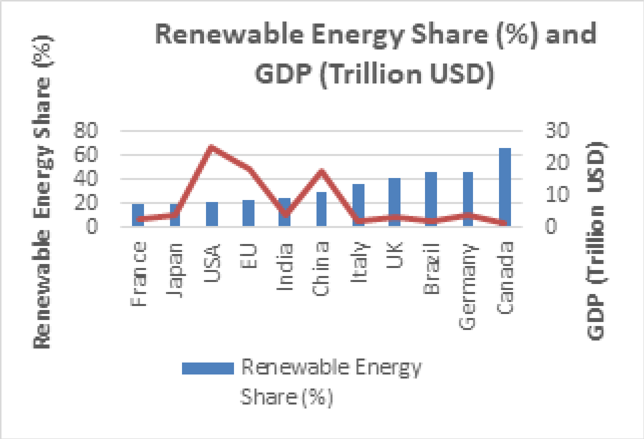


Fig 1:Global Comparison of Renewable Energy Share vs. GDP

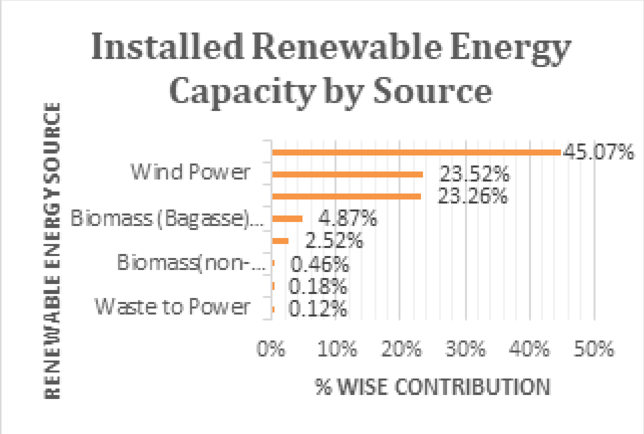


Fig 2: India, Percentage Contribution of Renewable Energy Sources

India's ambitious targets highlight the vital role of emerging economies in the global energy transition. However, challenges remain, including infrastructure investment, regulatory hurdles, and integrating renewable sources into existing grids. A key factor in overcoming these challenges is the mass rollout of smart meters, which are crucial for both utilities and prosumers. Smart meters improve energy efficiency, enable demand response, and offer better management of energy generation and consumption, contributing to the net-zero goal by supporting more flexible and responsive grids.

This paper explores how utilities are evolving to meet climate goals through technological advancements, including smart meters, and consumer engagement. The following sections will examine both sustainable practices and consumer-focused strategies, outlining the path toward a low-carbon future.

The paper is structured as follows: Section 2 reviews related work on sustainable utilities and consumer-centric approaches. Section 3 covers sustainable practices, including renewable energy, energy efficiency, and smart grids. Section 4 examines consumer-centric strategies like demand response and personalized energy solutions. Section 5 addresses challenges, focusing on technical, financial, and regulatory barriers. Section 6 discusses future directions, including emerging technologies and policy recommendations. Section 7 concludes with a summary of key findings.

3 BACKGROUND AND RELATED WORK

Utilities have traditionally focused on reliable and cost-effective service delivery, often prioritizing operational efficiency and infrastructure development. However, the urgency of climate change has shifted the paradigm, necessitating a re-evaluation of utility practices. Achieving net-zero emissions—where the total emissions produced are balanced by the amount removed from the atmosphere—requires a multifaceted approach. This includes integrating renewable energy sources, enhancing energy efficiency, and employing advanced technologies such as smart grids.

The transition to net-zero is not solely a technical challenge; it also involves significant changes in how utilities interact with and serve their customers. Modern consumers are increasingly environmentally conscious and demand greater involvement in sustainability efforts. Utilities are therefore adopting consumer-centric strategies, such as demand response programs, personalized energy solutions, and greater transparency in operations, to foster engagement and support for net-zero goals.

At COP26[1], India pledged to achieve net-zero emissions by 2070, with the power sector being a critical priority for reaching this goal ahead of other sectors in the economy.

India's goal of achieving net-zero emissions in the power sector by 2070 involves a complex strategy that includes large-scale investments in renewable energy, energy storage, and nuclear power. This transition demands significant capital, with an estimated annual investment of about USD 270 billion, totalling roughly USD 1.6 trillion by 2060[2], [3]

The power sector is pivotal in achieving net-zero energy systems, primarily through the integration of renewable energy sources, electrification, and innovative technologies. This transition necessitates a multifaceted approach to ensure reliability and flexibility in energy supply. The power sector must decarbonize to facilitate electrification in other sectors, significantly lowering overall emissions[4]

[5] explores pathways to achieving net-zero emissions by optimizing renewable energy sources and nuclear power. [6] outlines a framework for achieving a decarbonized electric grid by addressing key challenges, research needs, and data requirements. The TERI/Shell study [7] envisions India reaching net-zero emissions by 2050, highlighting the benefits of lower-carbon energy sources for growth and access. Addressing India's energy and environmental challenges requires innovative approaches to reconcile economic growth with climate action. To achieve its 2070 net-zero emissions target, India must reduce its reliance on coal and significantly increase the adoption of renewable energy [8]. Current policies aim to balance energy accessibility with environmental

sustainability, promoting renewable energy through financial incentives[9].

For energy utilities pursuing net-zero emissions, engaging consumers is essential. Successful strategies include raising awareness, leveraging consumer data, and encouraging community involvement.

Research underscores that user awareness is a critical factor in the success of Net Zero Energy (NZE) communities. In Italy, studies have demonstrated that consumers' understanding of energy efficiency directly influences their willingness to participate in NZE initiatives [10].

In the UK, the digitalization of the energy sector through smart meters has enabled the collection of comprehensive consumer data. This data is instrumental in driving behavioural changes necessary to achieve net-zero targets and is projected to generate benefits exceeding £40 billion. It is also crucial for informing both policy and business decisions[11].

The European Union's Clean Energy for All Europeans initiative highlights the importance of engaging citizen and renewable energy communities. This policy framework supports consumer participation in energy markets and fosters collective actions towards achieving net-zero emissions [12].

While these strategies show promise for enhancing consumer engagement, concerns about data privacy and potential exploitation remain significant. Addressing these concerns is essential to building trust and ensuring equitable participation in the energy transition.

Incorporating renewable energy sources (RES) into utility systems is vital for achieving net-zero emissions. This integration necessitates a variety of approaches, including sophisticated modelling, the use of advanced technologies, and the implementation of energy-efficient building designs.

Advanced strategies, including multi-objective optimization models, have been employed to simulate the integration of solar, wind, and hydrogen energy systems. For instance, a case study conducted in Iowa revealed substantial annual savings of $126,147.8 and a reduction in CO_2 emissions by 951,035.6 kg, highlighting both the economic and environmental advantages of incorporating renewable energy sources (RES) [13].

Bi-directional inverters in homes help integrate solar panels with energy storage systems, improving energy management and grid interaction. This technology is essential for net-zero energy buildings (NZEB) because it enables users to send excess energy back to the grid, supporting overall energy sustainability [14]. Research indicates that converting existing buildings into net-zero energy buildings (NZEBs) is possible with renewable energy sources (RESs). A study showed that specific building configurations can significantly enhance energy efficiency and sustainability [15].

The power sector significantly contributes to global CO_2 emissions, highlighting the urgent need for a shift to low-carbon energy sources[16]. Energy efficiency has long been crucial for mitigating greenhouse gases, but the focus now needs to be on complete decarbonization, moving away from fossil fuels[17]. Implementing energy efficiency technologies, especially in energy-intensive industries, can provide immediate reductions in energy use and emissions[18].

Despite the benefits of integrating RESs, challenges such as initial costs, technology adoption, and regulatory frameworks must be addressed to fully achieve net-zero objectives.

Smart grids enable the integration of variable renewable energy sources, essential for reducing reliance on fossil fuels[19]. They enable real-time monitoring and data acquisition, which enhances operational efficiency and reliability[20]. High interoperability among technologies is essential for seamless communication and integration within the energy system, helping to reduce long-term costs and maximize efficiency.

The integration of smart meters into the energy sector is crucial for guiding consumer behaviour toward net-zero emissions. These devices enable real-time data collection, allowing consumers to modify their energy usage in response to dynamic pricing and feedback. This capability is vital for effective demand management. Smart meters offer detailed consumption data that can drive behavioural changes, which are vital for 62% of initiatives aimed at achieving net-zero by 2050 [11]. Empirical research shows that consumer engagement levels can differ widely, depending on personalized contract terms and the quality of the information provided[21]. Advanced data mining techniques, such as neural networks, can improve the accuracy of consumption data analysis, aiding in better energy management [22]. Although smart meters offer significant potential for transforming consumer behaviour and advancing net-zero goals, addressing challenges related to data privacy and consumer engagement is essential to fully realize their benefits.

4 SUSTAINABLE PRACTICES IN UTILITIES

In India, the transition towards sustainable and consumer-centric utilities in pursuit of net-zero emissions is actively being pursued through a range of policies, initiatives, and developments.

4.1 Renewable energy integration

The National Solar Mission helps increase the use of solar energy in India. It has ambitious goals to grow the amount of solar power and support the country's renewable energy plans. The government is supporting wind energy by offering beneficial policies and incentives, such as guaranteed payments for the energy produced and tax breaks. India is also improving the power grid to manage variable renewable energy from solar and wind. This includes investing in pumped-storage hydro and battery systems[23]. The Power Grid Corporation of India is expanding its transmission network to handle the increasing amount of renewable energy. This expansion involves significant investments, with projects costing over ₹100,000 crore[24]. Policies such as exemptions from transmission charges for inter-state sales of solar and wind power, and the enforcement of renewable power purchase obligations, aim to encourage the use of renewable energy[25]. The government offers various incentives and subsidies for installing rooftop solar panels and other renewable energy systems, making it more affordable for consumers[26].

India has implemented several key initiatives to promote renewable energy as part of its strategy to achieve 500 GW of installed capacity from non-fossil fuels by 2030. These initiatives include the Scheme for Development of Solar Parks and Ultra-mega Solar Power Projects, the Central Public Sector Undertaking (CPSU) Scheme Phase-II, and the Production Linked Incentive (PLI) Scheme, also known as the National Programme on High-Efficiency Solar PV Modules. Additionally, the PM-KUSUM Scheme, Rooftop Solar Programme Phase II, Green Energy Corridors (GEC), Bio-Energy Programme, and PM-Surya Ghar further support the country's renewable energy goals. [27], [28]

4.2 Energy efficiency improvements

Perform, Achieve, and Trade (PAT) Scheme: Part of the National Mission for Enhanced Energy Efficiency (NMEEE), this scheme aims to improve energy efficiency in large energy-consuming industries.

Standards & Labelling Program: Administered by the Bureau of Energy Efficiency (BEE), this program provides energy performance labels for appliances and equipment to encourage energy savings.

4.3 Smart grid and advanced metering

Initiatives like the National Smart Grid Mission (NSGM) focus on developing smart grid technologies to enhance grid reliability, efficiency, and consumer engagement. The deployment of smart meters is being accelerated to provide real-time data, improve billing accuracy, and support demand response programs.

Decarbonization through smart metering plays a vital role in India's strategy to achieve net-zero emissions (see Fig 3). Smart meters improve energy efficiency by offering real-time consumption data, facilitating demand response programs, integrating renewable energy, and minimizing transmission losses, collectively advancing decarbonization efforts.

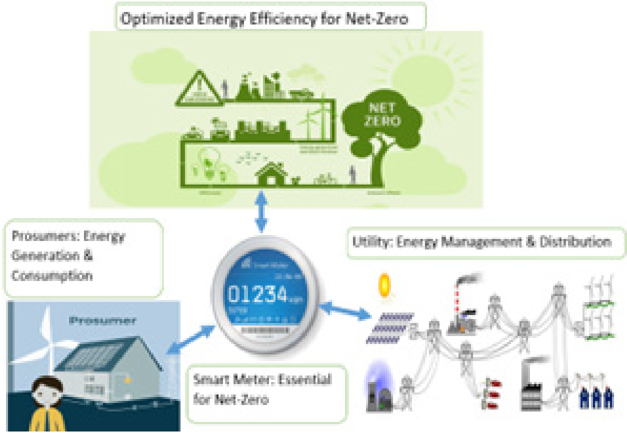


Fig 3: Key to Net-Zero: Smart Meters Linking Energy Stakeholders

India has launched several key initiatives to promote smart metering, smart grids, and solar energy in pursuit of its net-zero goals. Notable schemes include the National Smart Grid Mission (NSGM) for grid modernization and the Smart Meter National Program (SMNP) to upgrade metering systems. The Integrated Power Development Scheme (IPDS) aims to strengthen urban power distribution with smart meters and IT-enabled energy accounting. Similarly, the Deendayal Upadhyay Gram Jyoti Yojana (DDUGJY) focuses on rural electrification with smart metering and feeder separation[29].

4.4 Waste management and resource optimization

Waste management and resource optimization in utilities involve minimizing waste, recycling, adopting circular economy practices, and leveraging efficient technologies. Concerns include environmental impact, costs, regulatory compliance, and public engagement.

The Swachh Bharat Mission promotes nationwide cleanliness and solid waste management, while the Plastic Waste Management Rules target plastic reduction and recycling. Extended Producer Responsibility holds producers accountable for product lifecycle management and disposal[30].

4.5 Technological innovations (e.g., smart Grids, energy Storage)

Technological innovations, such as smart grids and energy storage, enhance utility efficiency and sustainability by optimizing energy use and integrating renewables. However, concerns include high costs, integration challenges, data security, and technology reliability, which must be addressed for successful implementation. In India, Various projects are being implemented to integrate energy storage solutions with renewable energy sources.

5 CONSUMER-CENTRIC STRATEGIES

Consumer-centric strategies play a pivotal role in helping utilities achieve net-zero emissions by engaging consumers in energy management. Demand response programs, personalized energy solutions, and customer education foster energy-efficient behaviour, while transparency and communication build trust. These approaches empower consumers to contribute to emission reductions and enhance sustainability efforts.

5.1 Demand response programs

Demand response (DR) programs are essential in aligning consumer energy use with grid demand, promoting sustainability in the transition to net-zero emissions. These programs incentivize consumers to reduce or shift energy consumption during peak times, enhancing grid reliability and integrating renewable energy sources. Various approaches are being used like Time-of-use (TOU) pricing, Critical peak pricing (CPP), Direct load control (DLC) and Incentive-based programs. Although there are certain concerns like Consumer reluctance, Technology barriers, Equity concerns which are obstacles for consumers participations in these programs.

5.2 Personalized energy solutions

Personalized energy solutions are essential for enhancing consumer engagement and supporting the shift to net-zero emissions. By tailoring energy services to individual needs and preferences, utilities can promote more efficient energy use and empower consumers to make informed decisions. Several approaches are being adopted, such as smart home technologies, personalized energy plans, energy management platforms, and AI-driven consumer behaviour insights. However, concerns remain regarding data privacy and security, accessibility and affordability, and increasing reliance on technology.

5.3 Customer engagement and education

Customer engagement and education are key pillars in driving the transition to net-zero emissions. By actively involving consumers in energy-saving initiatives and increasing their awareness, utilities can foster more sustainable energy behaviours and support long-term decarbonization goals. Various approaches include the use of digital platforms and mobile apps, targeted educational campaigns, gamification with incentives, and feedback mechanisms. However, challenges like information overload, trust and transparency issues, and the digital divide remain significant concerns.

5.4 Transparency and communication

Transparency and communication are vital for ensuring that utilities can build trust and foster consumer participation in net-zero initiatives. As utilities transition towards renewable energy, clear communication about goals, processes, and outcomes is essential for consumer engagement and long-term success. Approaches include open data and billing transparency, public reporting on sustainability goals, customer feedback channels, and proactive communication regarding policy changes. Concerns arise from issues such as lack of clarity, inconsistent communication, and ensuring equity in communication across all consumer groups.

6 CHALLENGES AND BARRIERS

The shift to net-zero emissions presents both opportunities and challenges for utilities. In India, this requires adopting renewable energy and sustainable, consumer-focused strategies. Utilities must navigate regulations and barriers, optimize energy use, and integrate advanced technologies to improve efficiency and customer engagement.

6.1 Technical constraints

Integrating renewable energy sources into existing grids poses significant challenges due to their intermittent nature. The integration of solar, wind, and hydrogen systems requires sophisticated modelling to manage their operational characteristics effectively[13]. Effective integration requires advanced grid management and energy storage technologies, which can be complex and costly [31]. Additionally, achieving high interoperability among diverse technologies complicates system integration [32], [33]. High energy demands, especially for cooling, make it challenging to achieve net-zero energy (NZE) buildings, particularly in arid regions such as few parts of India, like the northwest (e.g., Rajasthan)[34]

6.2 Financial constraints

Integrating renewable distributed generation (RDG) requires significant upgrades to existing grid infrastructures, which can be financially challenging[35]. The high initial costs for new technologies and infrastructure improvements can be particularly difficult for smaller utilities. Additionally, the delayed financial returns from these investments may discourage their adoption.

6.3 Regulatory and policy issues

Regulatory and policy frameworks are essential for guiding utilities in implementing sustainable and consumer-centric strategies as they transition to net-zero emissions. These frameworks set standards and provide support, ensuring alignment with emissions reduction goals and equitable outcomes for all stakeholders.

Utilities face significant regulatory pressures that compel them to adopt sustainable practices. These pressures stem from government mandates, investor expectations, and societal demands for accountability in sustainability efforts[36]. Achieving net-zero targets requires addressing regulatory and policy challenges, such as outdated frameworks and inconsistent enforcement[37].

Effective strategies include updating regulations to support renewable energy integration and incentivizing sustainable practices to facilitate a transition to a low-carbon economy.

Importance and Reasons of the regulatory and policy issues are Guidance and Standards, Incentives and Support, Consumer Protection, Market Efficiency and Long-term Sustainability. Addressing regulatory and policy issues is crucial for enabling utilities to implement effective, sustainable strategies and achieve net-zero targets while ensuring fair and efficient outcomes.

6.4 Consumer resistance: data privacy concerns

The integration of consumer data through smart meters enables utilities to foster proactive consumer engagement. This data can enhance energy consumption predictions and inform sustainable practices, ultimately leading to cost savings and improved resource allocation[11], [38]

Consumer resistance to net-zero strategies often stems from concerns about data privacy, particularly with the implementation of smart meters. Smart meters, which provide detailed consumption data to utilities, are instrumental in advancing sustainable energy practices by facilitating real-time monitoring and optimization of energy use. However, these benefits come with significant privacy concerns that can impact consumer acceptance and engagement.

The primary reasons are Data Security Risks, Lack of Transparency, Inadequate Privacy Protections, Perceived Surveillance and Limited Control. Addressing privacy concerns with better data protection and clear communication is key to building trust in smart meters and net-zero initiatives. Smart meters use encryption, authentication, and limit data collection to protect privacy. Regular security checks and consumer education promote transparency and trust.

6.5 Knowledge and awareness gaps

Knowledge and awareness gaps are big barriers for utilities trying to reach net-zero goals. When people don't understand sustainable practices and energy-efficient tech, it's harder for them to adopt these solutions and get involved. Boosting education and outreach is key.

The main reasons for these gaps are a lack of education, poor information sharing, complex technology, inconsistent communication, and cultural differences. To overcome these issues, we need to work together on various fronts to create a sustainable and consumer-friendly path to net-zero energy. Utilities must deal with complex regulations, financial issues, and find ways to engage people effectively while sticking to their sustainability goals.

Table 1 outlines consumer concerns and mitigation strategies, illustrating how smart meters address issues like privacy, billing accuracy, and installation costs. It also highlights current initiatives and innovative solutions such as AI-driven maintenance and peer-to-peer energy trading.

Table 1: Consumer concerns and mitigation strategies

Key Concerns	Mitigation Strategies	Existing Initiatives in Place	Innovative Solutions
Accuracy and fairness in Billing	1. Ensure increased accuracy with reliable smart meter technology. 2. Offer compensation/ rebates for substandard power quality.	1. Incentive programs for consumers opting for smart meters. 2. Address accuracy concerns by clarifying that smart meters are generally more precise than traditional meters. 3. Consumer complaint forums, SLAs ensuring power quality, Compensation mechanisms in some regions	1. User-friendly interfaces for easy monitoring of energy usage and bills. 2. Dynamic billing based on power quality. 3. AI-driven predictive maintenance for preventing low voltage issues. 4. Third-Party Verifications: Giving consumers an independent verification of their billing integrity.
Complexity and Usability	Provide clear guides and support for using smart meter technology.	Consumer feedback mechanisms to address concerns and improve services.	1. Intuitive mobile apps that simplify data interpretation, user engagement through Amazon Alexa, Google Assistant. 2. Gamified User Experience: Energy-Saving Challenges, Social Sharing Features

Costs	Communicate potential long-term savings to justify upfront costs.	Collaboration with local governments to subsidize	1. Consumption-Based Financing, such as pay-as-you-save models for installations. 2. Incentivisation on DR during peak hours/ non solar hours 3. Peer-to-Peer (P2P) Energy Trading for Income Generation 4. Using smart meter data for Proactive Maintenance for Longer Equipment Life
Trust Concerns Regarding New Technology	Build trust through transparency and consistent communication.	1. Community workshops and outreach to explain the benefits of smart metering. 2. Grace periods and clear warning (SMS, Email, Web, Auto Pay Reminders) systems before remote disconnections.	1. Community-based initiatives to promote collective responsibility for energy savings. 2. Flexible payment plans to avoid sudden disconnections. 3. Publicly Recognize Energy-Conscious Consumers 4. Proactive Customer Support: Use data from smart meters to proactively address potential issues
Barriers to Widespread Household Adoption of Smart Meters and Rooftop Solar	Promoting the adoption through various government schemes and initiatives	1. Revamped Distribution Sector Scheme (RDSS) 2. National Smart Grid Mission (NSGM) 3. Smart Meter National Programme (SMNP) 4. PM Surya Ghar Yojna 5. Social Media Awareness Campaigns 6. Consumer Education Workshops	1. Incentivized energy challenges 2. Integration with smart appliances 3. Educational campaigns and gamification of energy saving 4. Virtual energy audits 5. Virtual Net Metering 6. Provide anonymized data for public sharing to identify patterns, trends, and insights that can lead to innovations in energy management, grid optimization, and consumer behaviour.

7 FUTURE DIRECTIONS

As utilities strive to achieve net-zero emissions, identifying and leveraging future directions is essential for the successful transformation of the energy sector. This section outlines key areas of focus Fig 4 that will shape the future of sustainable and consumer-centric utility strategies. By exploring emerging technologies, refining policy and regulatory frameworks, and enhancing consumer participation, stakeholders can navigate the complexities of the transition towards a sustainable and low-carbon energy system. The following subsections provide a detailed examination of these critical components, offering insights into the innovations, policies, and strategies that will drive progress in the pursuit of net-zero goals.

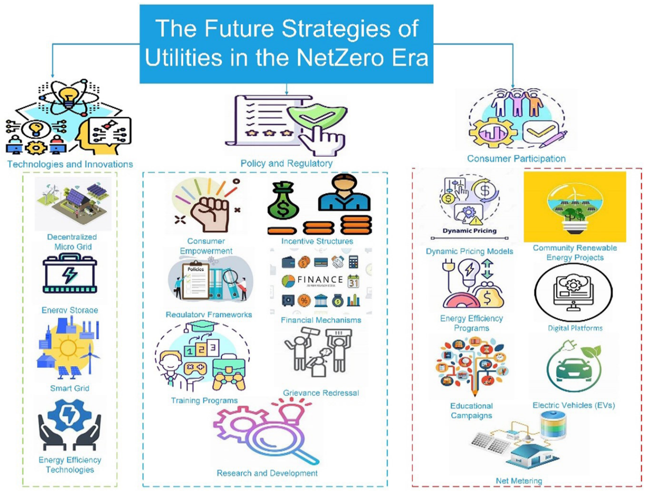


Fig 4: Future Strategies of Utilities in Net-Zero Era

7.1 Emerging technologies and innovations

Advancements such as next-generation energy storage, smart grid systems, and hydrogen fuel cells are pivotal for integrating renewable energy and enhancing grid efficiency, thus supporting the transition to net-zero utilities.

I. Decentralized energy systems: Microgrids and Distributed Generation: Advancing microgrids and distributed generation in rural and remote areas can improve energy access and reliability while reducing transmission losses.

II. Advanced energy storage: Battery Storage Solutions: Investing in advanced batteries is crucial for storing surplus renewable energy and ensuring grid stability, addressing the intermittency of renewable sources.

III. Digital transformation: Smart Grids: Implementing smart grids enhances grid management and operational efficiency, facilitating the integration of renewable energy and real-time system monitoring.

IV. Energy efficiency technologies: Adoption of cutting-edge energy efficiency technologies, such as advanced building management systems and industrial process improvements, contributes to reduced energy consumption and lower operational costs.

7.2 Policy and regulatory recommendations

Effective policies should incentivize renewable energy adoption, streamline regulations for emerging technologies, and promote cross-sectoral alignment to facilitate a smooth and equitable transition to sustainable utility practices.

I. Consumer empowerment: Prosumers: Encouraging consumers to generate and sell their own renewable energy fosters a decentralized energy system and active market participation.

II. Incentive structures: Subsidies and Tax Benefits: Offering financial incentives for renewable energy projects, efficient appliances, and electric vehicles can reduce barriers and promote adoption.

III. Regulatory frameworks:

a. Net metering policies: Enhancing net metering regulations ensures fair compensation for renewable energy generation, encouraging investment.

b. Renewable purchase obligations (RPOs): Mandating utilities to source a portion of their energy from renewables supports sector growth.

IV. Financial Mechanisms:

a. Green bonds: Green bonds can finance renewable energy projects, aiding sustainability goals.

b. Priority sector lending: Including renewables in priority sector lending improves access to finance.

V. Capacity Building:

a. Training programs: Training for utility staff and consumers on renewable technologies and efficiency supports effective technology deployment.

VI. Consumer Protection:

a. Transparent billing: Clear billing practices provide detailed information on energy use and costs, enhancing trust.

b. Grievance redressal: Robust grievance mechanisms address consumer complaints effectively.

VII. Research and Development:

a. Innovation hubs: Research centres focused on renewable technologies drive advancements and support new solutions.

These strategies are essential for developing a sustainable and consumer-centric energy system aligned with net-zero goals.

7.3 Strategies for enhanced consumer participation

Engaging consumers through education, personalized energy solutions, and transparent communication will drive adoption of sustainable practices, while demand response programs and incentives will enhance active participation in achieving net-zero objectives.

I. Dynamic pricing models: Implementing time-of-day tariffs to incentivize electricity use during off-peak hours, aiding in demand balancing and renewable energy integration.

II. Community renewable energy projects: Promoting solar parks and community solar initiatives, allowing consumers to invest in and benefit from shared solar power.

III. Energy efficiency programs: Expanding the Ujala scheme to include a wider range of energy-efficient appliances, beyond just LED bulbs.

IV. Green financing options: Including renewable energy projects under priority sector lending to facilitate easier access to loans for solar installations.

V. Enhanced digital platforms: Deploying smart meters nationwide to offer real-time energy consumption data, helping consumers manage their usage more effectively.

VI. Educational campaigns: Conducting awareness drives through social media, TV, and community events to promote the benefits of renewable energy and efficiency.

VII. Net metering and feed-in tariffs: Strengthening policies and incentives for rooftop solar installations to encourage adoption by households and businesses.

VIII. Integration of electric vehicles (EVs): Expanding the FAME India scheme to provide additional incentives for EV purchases and charging infrastructure development.

8 CONCLUSION

This paper has examined sustainable and consumer-centric strategies essential for utilities to achieve net-zero emissions. The key findings underscore the critical role of integrating renewable energy, advancing energy efficiency, and leveraging smart grid technologies in the transition to a sustainable energy system.

The study highlights that achieving net-zero objectives requires a multifaceted approach, including the deployment of emerging technologies such as advanced energy storage and hydrogen fuel cells. Effective policy frameworks are necessary to incentivize clean energy adoption and address regulatory barriers. Consumer engagement strategies, including personalized solutions and transparent communication, are vital for fostering active participation and driving behavioural change.

For utilities, the transition involves substantial investments in technology and infrastructure, necessitating a strategic focus on innovation and efficiency. Policymakers must develop supportive regulatory frameworks that encourage sustainable practices and facilitate the integration of new technologies. Aligning energy policies with broader environmental and economic goals will be crucial for a successful transition.

Future research should explore the long-term impacts of emerging technologies on grid stability and efficiency, as well as the effectiveness of various policy measures in different regulatory environments. Additionally, investigating strategies to enhance consumer engagement and participation in sustainable practices will provide valuable insights into achieving net-zero targets. Further studies should also address the economic implications of transitioning to net-zero and develop models to predict and mitigate potential challenges.

9 REFERENCES

[1] "COP26: Together for our planet | United Nations." Accessed: Sep. 12, 2024. [Online]. Available: https://www.un.org/en/climatechange/cop26

[2] A. Das, V. Saini, K. Parikh, J. Parikh, P. Ghosh, and M. Tot, "Pathways to net zero emissions for the Indian power sector," Energy Strategy Reviews, vol. 45, p. 101042, Jan. 2023, doi: 10.1016/j.esr.2022.101042.

[3] S. Bhattacharya, R. Banerjee, V. Ramadesigan, A. Liebman, and R. Dargaville, "Pathways to a Decarbonised Power Sector in India," in 2023 Second International Conference On Smart Technologies For Smart Nation (SmartTechCon), Aug. 2023, pp. 759–764. doi: 10.1109/SmartTechCon57526.2023.10391588.

[4] J. E. T. Bistline and G. J. Blanford, "The role of the power sector in net-zero energy systems," Energy and Climate Change, vol. 2, p. 100045, Dec. 2021, doi: 10.1016/j.egycc.2021.100045.

[5] M. A. Rahmanta et al., "Towards a Net Zero-Emission Electricity Generation System by Optimizing Renewable Energy Sources and Nuclear Power Plant," Energies, vol. 17, no. 8, Art. no. 8, Jan. 2024, doi: 10.3390/en17081958.

[6] D. Palchak, I. Chernyakhovskiy, and M. Joshi, "Power Sector Decarbonization in South Asia: Pathways for Research, Modeling, and Implementation," National Renewable Energy Lab. (NREL), Golden, CO (United States), NREL/TP-6A40-81944, Jan. 2022. doi: 10.2172/1843207.

[7] "India: Transforming to a net-zero emissions energy system." Accessed: Sep. 12, 2024. [Online]. Available: https://www.shell.in/energy-and-innovation/new-sketch-india-transforming-to-a-net-zero-emissions-energy-system.html

[8] S. Durga, M. Evans, L. Clarke, and R. Banerjee, "Developing new pathways for energy and environmental decision-making in India: a review," Environ. Res. Lett., vol. 17, no. 6, p. 063004, May 2022, doi: 10.1088/1748-9326/ac6f13.

[9] A. J. Apostoli and W. A. Gough, "India's Energy-Climate Dilemma: The Pursuit for Renewable Energy Guided by Existing Climate Change Policies," Journal of Earth Science & Climatic

Change, vol. 7, no. 7, Art. no. 7, Jul. 2016, doi: 10.4172/2157-7617.1000362.

[10] C. Piselli, G. Salvadori, L. Diciotti, F. Fantozzi, and A. L. Pisello, "Assessing users' willingness-to-engagement towards Net Zero Energy communities in Italy," Renewable and Sustainable Energy Reviews, vol. 152, p. 111627, Dec. 2021, doi: 10.1016/j.rser.2021.111627.

[11] L. Liu, M. Workman, and S. Hayes, "Net Zero and the potential of consumer data - United Kingdom energy sector case study: The need for cross-sectoral best data practice principles," Energy Policy, vol. 163, p. 112803, Apr. 2022, doi: 10.1016/j.enpol.2022.112803.

[12] N. Rossetto, "Beyond Individual Active Customers: Citizen and Renewable Energy Communities in the European Union," IEEE Power and Energy Magazine, vol. 21, no. 4, pp. 36–44, Jul. 2023, doi: 10.1109/MPE.2023.3269541.

[13] M. S. S. Danish et al., "Techno-Economic Modeling of Diverse Renewable Energy Sources Integration: Achieving Net-Zero CO2 Emissions," IEEJ Transactions on Electrical and Electronic Engineering, vol. 19, no. 7, pp. 1168–1182, 2024, doi: 10.1002/tee.24065.

[14] S. Patra, M. Bahloul, R. Trivedi, and S. Khadem, "Smart bi-directional inverter control and PV-ESS integration for net zero energy residential buildings," pp. 380–385, Jan. 2022, doi: 10.1049/icp.2023.0023.

[15] P. Muthuraju, M. Moghimi, S. Stegen, J. Lu, and P. Kaparaju, "Integration of Renewable Energies to Convert University Commercial Buildings to Net-Zero Energy Buildings," in Sustainability in Energy and Buildings 2018, P. Kaparaju, R. J. Howlett, J. Littlewood, C. Ekanyake, and L. Vlacic, Eds., Cham: Springer International Publishing, 2019, pp. 95–105. doi: 10.1007/978-3-030-04293-6_10.

[16] E. Clémençon-Charles and K. Baranek, "Looking Beyond Power Generation to Achieve Electricity Sector Net-Zero Goals," Climate and Energy, vol. 39, no. 7, pp. 20–23, 2023, doi: 10.1002/gas.22330.

[17] J. Rosenow and N. Eyre, "Reinventing energy efficiency for net zero," Energy Research & Social Science, vol. 90, p. 102602, Aug. 2022, doi: 10.1016/j.erss.2022.102602.

[18] S. Sundaramoorthy, D. Kamath, S. Nimbalkar, C. Price, T. Wenning, and J. Cresko, "Energy Efficiency as a Foundational Technology Pillar for Industrial Decarbonization," Sustainability, vol. 15, no. 12, Art. no. 12, Jan. 2023, doi: 10.3390/su15129487.

[19] R. Anto and R. Singh, "Smart Grid Technologies and Consumer Engagement a Review," in Proceedings from the International Conference on Hydro and Renewable Energy, B.-M. Hodge and S. K. Prajapati, Eds., Singapore: Springer Nature, 2024, pp. 233–240. doi: 10.1007/978-981-99-6616-5_25.

[20] J. Yang, "Comprehensive Analysis of Key Technologies for Smart Grid," Highlights in Science, Engineering and Technology, vol. 76, pp. 467–476, Dec. 2023, doi: 10.54097/53y8c604.

[21] J. Batalla-Bejerano, E. Trujillo-Baute, and M. Villa-Arrieta, "Smart meters and consumer behaviour: Insights from the empirical literature," Energy Policy, vol. 144, p. 111610, Sep. 2020, doi: 10.1016/j.enpol.2020.111610.

[22] J. Li, L. Kong, C. Cheng, and J. Dong, "Research on key technologies of net metering for smart grid AMI and data mining of user electricity consumption," in 2022 International Conference on Electronics and Devices, Computational Science (ICEDCS), Sep. 2022, pp. 95–99. doi: 10.1109/ICEDCS57360.2022.00028.

[23] "Renewables Integration in India – Analysis," IEA. Accessed: Sep. 12, 2024. [Online]. Available: https://www.iea.org/reports/renewables-integration-in-india

[24] "How Powergrid Is Catching Up With The Renewable Energy Transition In India," Forbes India. Accessed: Sep. 12, 2024. [Online]. Available: https://www.forbesindia.com/article/take-one-big-story-of-the-day/how-powergrid-is-catching-up-with-the-renewable-energy-transition-in-india/94120/1

[25] R. Verma, "India's energy transition: Challenges and opportunities for a sustainable future," The Times of India. Accessed: Sep. 12, 2024. [Online]. Available: https://timesofindia.indiatimes.com/blogs/voices/indias-energy-transition-challenges-and-opportunities-for-a-sustainable-future/

[26] NITI Aayog, "Report on India's Renewable Electricity Roadmap 2030," Power Ministry, India, vol. 69, no. 1, pp. 207–221, 2014.

[27] "Major ongoing Renewable Energy Schemes and Programmes." Accessed: Sep. 12, 2024. [Online]. Available: https://pib.gov.in/Pressreleaseshare.aspx?PRID=1983766

[28] "Cabinet approves PM-Surya Ghar: Muft Bijli Yojana for installing rooftop solar in One Crore households." Accessed: Sep. 12, 2024. [Online]. Available: https://www.pmindia.gov.in/en/news_updates/

cabinet-approves-pm-surya-ghar-muft-bijli-yojana-for-installing-rooftop-solar-in-one-crore-households/

[29] "Decentralized renewable energy can accelerate India's path to Net Zero by 2050, ET EnergyWorld." Accessed: Sep. 12, 2024. [Online]. Available: https://energy.economictimes.indiatimes.com/news/renewable/decentralized-renewable-energy-can-accelerate-indias-path-to-net-zero-by-2050/108705379

[30] P. Randhawa, F. Marshall, P. K. Kushwaha, and P. Desai, "Pathways for Sustainable Urban Waste Management and Reduced Environmental Health Risks in India: Winners, Losers, and Alternatives to Waste to Energy in Delhi," Front. Sustain. Cities, vol. 2, May 2020, doi: 10.3389/frsc.2020.00014.

[31] A. Castillo and D. F. Gayme, "Grid-scale energy storage applications in renewable energy integration: A survey," Energy Conversion and Management, vol. 87, pp. 885–894, Nov. 2014, doi: 10.1016/j.enconman.2014.07.063.

[32] I. Alotaibi, M. A. Abido, M. Khalid, and A. V. Savkin, "A Comprehensive Review of Recent Advances in Smart Grids: A Sustainable Future with Renewable Energy Resources," Energies, vol. 13, no. 23, Art. no. 23, Jan. 2020, doi: 10.3390/en13236269.

[33] M. Khalid, "Smart grids and renewable energy systems: Perspectives and grid integration challenges," Energy Strategy Reviews, vol. 51, p. 101299, Jan. 2024, doi: 10.1016/j.esr.2024.101299.

[34] E. M. H. Ismaeil and A. E. E. Sobaih, "Heuristic Approach for Net-Zero Energy Residential Buildings in Arid Region Using Dual Renewable Energy Sources," Buildings, vol. 13, no. 3, Art. no. 3, Mar. 2023, doi: 10.3390/buildings13030796.

[35] Q. Hassan et al., "Enhancing smart grid integrated renewable distributed generation capacities: Implications for sustainable energy transformation," Sustainable Energy Technologies and Assessments, vol. 66, p. 103793, Jun. 2024, doi: 10.1016/j.seta.2024.103793.

[36] "Sustainability | Free Full-Text | How Is the Utilities Sector Contributing to Building a Sustainable Future? A Systematic Literature Review of Sustainability Practices." Accessed: Sep. 12, 2024. [Online]. Available: https://www.mdpi.com/2071-1050/16/1/374

[37] J. Hardy and C. Mazur, "Enabling Conditions for Consumer-Centric Business Models in the United Kingdom Energy Market," Front. Energy Res., vol. 8, Sep. 2020, doi: 10.3389/fenrg.2020.528415.

[38] H. N. Durmus Senyapar and A. Aksoz, "Empowering Sustainability: A Consumer-Centric Analysis Based on Advanced Electricity Consumption Predictions," Sustainability, vol. 16, no. 7, Art. no. 7, Jan. 2024, doi: 10.3390/su16072958.

10 ACKNOWLEDGEMENTS

The authors wish to acknowledge the guidance and support provided by Indian Institute of Information Technology Kota. Further, authors their gratitude to their own organization and its management for kind support. The views expressed in this paper are of authors and not necessarily that of the organizations they represent.

BIO-DATA

SANDEEP KUMAR BENIWAL
Genus Power Infrastructures Ltd

Date of Birth:	1 July 1984
Qualification:	MTech, MBA, B.E
Designation:	Assistant General Manager
Present Organization:	Genus Power Infrastructures Ltd, Jaipur, India
Field of Expertise:	Smart Grid, AMI, Smart Metering, Embedded Systems, Linux Device Drivers, Artificial Intelligence, Machine Learning and Wireless Innovations
Mobile:	+91 93582 34555
Email:	sandeep.beniwal@genus.in

BRIEF PROFILE

Sandeep Kumar Beniwal, M.Tech (MNIT, Jaipur), and B.E.(Rajasthan University), currently holds the position of Assistant General Manager-Technical at Genus Power Infrastructures Ltd., Jaipur, Additionally, research scholar at IIIT Kota. He has over 19 years of experience in Smart Grid, AMI, Smart Metering, Embedded Systems, Linux Device Drivers, and Wireless Innovations. His research interests primarily focus on Wireless Communication Technologies, Artificial Intelligence, and Machine Learning in Smart grid applications.

COMPREHENSIVE SECURITY FRAMEWORK FOR AMI SYSTEMS: ADDRESSING REGULATORY AND COMPLIANCE CHALLENGES

Dr Sumedha Ganjoo | Ankesh Kumar
Secure Meters Limited

ABSTRACT

Prime Minister Narendra Modi has initiated the Smart Meter National Programme (SMNP), aimed at replacing India's 250 million conventional meters with advanced smart alternatives. Advanced Metering Infrastructure (AMI) systems facilitate two-way communication between utilities and consumers, significantly improving efficiency, billing accuracy, and customer service. However, this digital transformation also amplifies the data load on AMI Service Providers (AMISPs), involving vast amounts of consumer data. This surge in data introduces substantial security risks, including unauthorised access, cyber-attacks, and operational disruptions, compromising the integrity, confidentiality, and availability of AMI systems.

This paper begins by exploring the critical aspects of digitalisation within the power sector, highlighting the transformative role and impact of smart metering technologies. It examines the current regulatory landscape, identifying gaps and inconsistencies that pose challenges to effective cybersecurity implementation. The analysis emphasises the need for harmonised regulations and standards across different jurisdictions to ensure a unified approach to AMI security.

To address these challenges, this paper proposes a comprehensive security framework for AMI systems, focusing on advanced security measures and stringent compliance strategies to enhance the resilience and security of these systems. Key components of the proposed framework include robust encryption protocols, real-time monitoring systems, strict access control mechanisms, etc. By implementing these strategies, the research aims to fortify the AMI ecosystem, ensuring trust and reliability in the smart metering industry.

Keywords: AMI systems, smart metering, regulatory challenges, cybersecurity, data protection, utility security standards, energy sector digitalisation, security framework.

INTRODUCTION

Advanced Metering Infrastructure (AMI) represents a pivotal advancement in the energy sector, enabling utilities to enhance operational efficiency, improve billing accuracy, and facilitate real-time energy management. AMI systems consist of smart meters, head-end systems (HES) and MDM that work together to collect, transmit, and analyse energy consumption data. These systems support utilities in balancing power supply and demand, detecting outages, and providing detailed energy usage information to consumers. The Government of India has set an ambitious target to install 250 million smart meters to replace conventional meters by March 2025, thus propelling the transition towards a more efficient and resilient power grid.

However, integrating AMI systems within the existing electricity grid introduces significant cybersecurity challenges. AMI operates as an Information and Communication Technology (ICT) network within a broader infrastructure of legacy electrical and electro-mechanical machines. This integration exposes the grid to cyber vulnerabilities that can threaten the confidentiality, integrity, availability, and accountability of the power system. Given the critical nature of the energy sector, ensuring the security and resilience of AMI systems is paramount to maintaining the stability and reliability of the electricity supply.

The regulatory framework for securing AMI systems is comprehensive, encompassing a variety of national and international standards and guidelines. Despite these guidelines and standards, utilities often face challenges in achieving and maintaining compliance with cybersecurity regulations and standards. These challenges include the technical complexity of AMI systems, financial constraints, and the need for continuous monitoring and updates to address evolving cyber threats. Additionally, the contractual arrangements between utilities and AMI service providers (AMISPs) vary widely, leading to disparities in compliance measures and security provisions.

This paper aims to explore the regulatory and compliance challenges associated with securing AMI systems. It examines the current regulatory landscape, identifies key security risks and vulnerabilities, and proposes a comprehensive compliance framework to enhance the cybersecurity posture of AMI systems. By addressing these challenges, utilities can protect their infrastructure, ensure the privacy and security of consumer data, and support the broader goals of operational efficiency and sustainability in the energy sector.

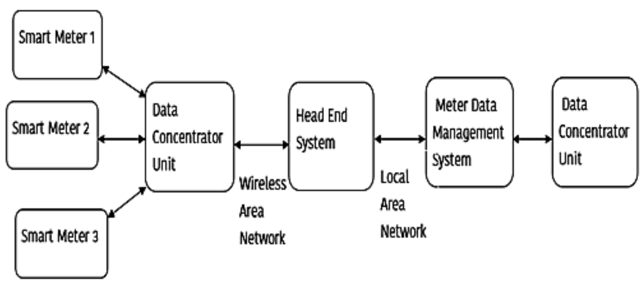


Fig 1: AMI system

2. Regulatory landscape for AMI security

The regulatory landscape for securing AMI systems is multifaceted, involving national and international standards designed to ensure the confidentiality, integrity, and availability of energy data. As AMI systems become integral to modern utility infrastructure, the importance of a robust regulatory framework cannot be overstated. This section examines the regulatory requirements and guidelines that govern AMI security, focusing on both the Indian and global contexts.

2.1. Regulatory landscape in Indiatech

In India, the regulatory framework for AMI security is grounded in several key regulations and guidelines. The Information Technology Act of 2000, serves as the foundational legal framework for cybersecurity, mandating the protection of electronic data and prescribing penalties for cyber offences. This act has been essential in establishing a baseline for cybersecurity across various sectors, including the energy sector.

The Central Electricity Authority (CEA) and the Indian Computer Emergency Response Team (CERT-In) are critical in operationalising cybersecurity within the power sector. The CEA has issued specific guidelines for AMI, outlining the technical and operational requirements to secure smart meters and related infrastructure. These guidelines emphasise the importance of securing data transmission and storage, enforcing access controls, and conducting regular security audits to detect and mitigate potential vulnerabilities.

The National Critical Information Infrastructure Protection Centre (NCIIPC) is another key institution, tasked with protecting critical information infrastructure in India. NCIIPC works closely with CERT-In and sectoral CERTs to provide incident response and support to utilities, ensuring a coordinated approach to managing cyber threats.

Furthermore, the standard bidding document (SBD) for AMI service providers, notified by REC Limited, specifies the security-related compliance requirements for stakeholders involved in AMI deployment. This document ensures that all contracts between utilities and AMI service providers incorporate comprehensive cybersecurity provisions, including data retention policies, system security measures, and disaster recovery plans.

The regulatory framework is further strengthened by the National Cyber Security Policy (NCSP) 2013, drafted by the Ministry of Electronics and Information Technology (MeitY), which aims to build a secure and resilient cyberspace for citizens, businesses, and government. This policy outlines strategies for protecting critical information infrastructure, promoting research and development in cybersecurity, and enhancing awareness and education.

The Electricity Act of 2003 mandates the Central Electricity Regulatory Commission (CERC) and State Electricity Regulatory Commissions (SERCs) to develop and enforce standards for the safe and secure operation of the electricity grid. The act also emphasises the need to identify and protect critical cyber assets within the power sector.

The Indian Electricity Grid Code (IEGC), issued by CERC, requires utilities to identify critical cyber assets and take necessary measures to protect them, ensuring reliable grid operation. It mandates utilities to follow stringent cybersecurity protocols and conduct regular security audits.

The Revamped Distribution Sector Scheme (RDSS), launched in 2021, aims to convert all non-agricultural electricity meters to smart meters by March 2025. It includes provisions for financial assistance to DisComs, contingent upon their adherence to standardised cybersecurity practices as outlined in the SBD.

2.2. Global regulatory landscape

Globally, several frameworks and standards guide the security practices for AMI systems. The ISO / IEC 27001 standard provides a comprehensive framework for information security management, enabling utilities to protect their AMI data effectively. This standard emphasises on information security management, comprehensive risk management and continuous improvement, ensuring that organisations can stand against evolving cyber threats.

The National Institute of Standards and Technology (NIST) issues NIST 800-53 Cybersecurity Framework, which is widely adopted by utilities globally. This framework offers best practices for managing cybersecurity risks, focusing on five core functions: identify, protect, detect, respond, and recover. The NIST framework helps utilities establish a robust cybersecurity posture, capable of addressing current and future threats.

In the European Union, the General Data Protection Regulation (GDPR) mandates stringent data protection measures, ensuring the privacy and security of consumer data. Utilities operating within the EU must comply with GDPR requirements, which include securing personal data, ensuring data accuracy, and obtaining explicit consent from consumers for data processing activities. Additionally, the Network and Information Systems Directive (NISD) requires member states to identify and mitigate cybersecurity risks in critical infrastructure sectors, including energy.

In the United States, the Department of Energy's Office of Cybersecurity, Energy Security, and Emergency Response (CESER) oversees cybersecurity preparedness in the energy sector. CESER supports various initiatives, such as the Cybersecurity Capability Maturity Model (C2M2) and the Cybersecurity Risk Information Sharing Program (CRISP), which provide utilities with tools and resources to enhance their cybersecurity capabilities. These programs emphasise the importance of information sharing and collaboration among utilities to effectively manage cyber threats.

3. Compliance challenges

Ensuring compliance with cybersecurity standards in the deployment and operation of Advanced Metering Infrastructure (AMI) systems presents numerous challenges. These challenges stem from the technical complexity of AMI systems, the evolving nature of cyber threats, and the need for continuous monitoring and updates. This section delves into the specific compliance challenges faced by utilities and AMI service providers (AMISPs), drawing insights from the attached document.

3.1. Technical complexity

AMI systems integrate various components, including smart meters, MDM, HES and communication networks, each with its own set of vulnerabilities. Ensuring comprehensive security across all these components requires a deep understanding of both the operational technology and the associated cyber risks.

Utilities often struggle with the technical expertise needed to implement and maintain robust security measures. The rapid pace of technological advancement further complicates this, as new vulnerabilities emerge with regular updates and / or integrations.

3.2. Resource limitations

Financial constraints are a significant barrier to achieving compliance with cybersecurity standards. Many utilities, especially those operating in regions with tight budgets, find it challenging to allocate sufficient funds for cybersecurity initiatives. This includes investments in advanced security technologies, hiring skilled cybersecurity professionals, and conducting regular security audits. As highlighted in the document, utilities in India, such as those in Rajasthan and Assam, exhibit gaps in system availability and accountability measures due to resource limitations.

3.3. Variability in contractual obligations

The variability in contractual obligations across different states and utilities creates inconsistencies in compliance measures. For instance, that utilities in Haryana have comprehensive security and data retention policies, while others lack stringent measures. This inconsistency can lead to unequal levels of security across the power grid, exposing weaker links to potential cyber-attacks. Harmonising contractual obligations to ensure a consistent baseline of security requirements is crucial for enhancing the overall resilience of AMI systems.

3.4. Information asymmetry

There is often a significant information asymmetry between utilities and AMISPs. AMISPs typically have greater visibility into the security status of the systems they manage, while utilities may lack the technical capacity to fully understand and act on security advisories. This gap can hinder the utilities' ability to ensure compliance and respond effectively to cyber threats. It is essential to ensure that utilities are equipped with the necessary knowledge and tools to assess and improve their cybersecurity posture.

3.5. Evolving regulatory landscape

The regulatory landscape for cybersecurity is continuously evolving to address new and emerging threats. Utilities must stay abreast of these changes and adapt their compliance strategies accordingly. However, this can be challenging, especially for smaller utilities with limited regulatory expertise. The need for continuous monitoring, updates, and adaptation to new regulations adds an additional layer of complexity to compliance efforts.

The compliance challenges in AMI systems are complicated, involving technical complexity, resource limitations, variability in contractual obligations, information asymmetry, and an evolving regulatory landscape. Addressing these challenges is crucial for ensuring the security and reliability of AMI systems in the power sector.

4. Security risks and threats

The deployment and operation of AMI systems introduce several security risks and threats that can significantly impact the confidentiality, integrity, and availability of energy data. These risks are inherent due to the digitalisation and interconnected nature of AMI systems, which combine smart meters, HES, MDM, and communication networks. Based on the attached document, this section outlines the key security risks and threats associated with AMI systems.

4.1. Unauthorised access and data breaches

One of the primary security risks in AMI systems is unauthorised access to sensitive data. Smart meters collect detailed information about consumers such as personal information, energy consumption data, which, if accessed by malicious actors, can lead to data privacy breaches and unauthorised manipulation of billing information, undermining the trust and reputation in AMI systems . Unauthorised access can occur through various means, including weak access control mechanisms, poor authentication processes, and vulnerabilities in the communication network.

4.2. Cyber attacks

AMI systems are attractive targets towards cyber-attacks due to their critical role in energy management. Cyber-attacks can take various forms, including denial-of-service (DoS) attacks, malware infections, and phishing attacks aimed at compromising the system's integrity and availability. For instance, denial-of-service attacks can overwhelm the communication network, disrupting data transmission between smart meters and the utility's head-end system (HES). Malware infections can corrupt data and disrupt system operations, leading to inaccurate billing and potential service outages.

4.3. Data tampering and manipulation

Data integrity is crucial for the accurate operation of AMI systems. However, data tampering and manipulation pose significant threats. Malicious actors can intercept and alter data during transmission, leading to false consumption readings and inaccurate billing. This can result in financial losses for both utilities and consumers. Furthermore, data tampering will mislead utilities about the actual demand and supply conditions, affecting their ability to manage the power grid effectively.

4.4. Operational disruptions

The integration of AMI systems with legacy electrical and electro-mechanical machines can create operational vulnerabilities. Cyber-attacks targeting these systems can cause significant disruptions, including power outages and service interruptions. For example, an unauthorised remote disconnection signal could lead to widespread outages, as evidenced by the incident in Uttar Pradesh, where nearly 1,58,000 households experienced a power outage due to a technical glitch. Such operational disruptions can have severe consequences for grid stability and customer satisfaction.

4.5. Privacy concerns

The detailed consumption data collected by smart meters can reveal sensitive information about consumers' habits and lifestyles. Unauthorised access to this data can lead to privacy breaches and potential misuse. Privacy concerns are heightened by the fact that AMI systems involve the continuous collection and transmission of data, increasing the risk of unauthorised exposure. Ensuring the confidentiality of consumer data is, therefore, a critical aspect of AMI security.

4.6. Insider threats

Insider threats are a significant risk in AMI systems, given the system access to utility employees and AMI service providers. Insiders with malicious intent or those who are negligent can cause significant damage by altering data, disrupting operations, or exposing sensitive information. Addressing insider threats requires robust access control mechanisms, regular monitoring, continuous security awareness trainings and thorough background checks for personnel with access to critical systems.

5. Case study

Case study: Cyber intrusions in the Indian power sector

Between 2020 and 2021, several cyber intrusion attempts targeted the Indian power sector, highlighting the critical need for robust cybersecurity measures in AMI systems and other critical infrastructure. Notably, these attacks were linked to advanced persistent threat (APT) groups, showcasing the sophisticated nature of cyber threats faced by the energy sector.

BACKGROUND

In October 2020, a major power outage occurred in Mumbai, affecting millions of residents. Investigations revealed the presence of malware in the systems of the Maharashtra State Electricity Transmission Company Limited (MSETCL). This incident was part of a broader campaign targeting multiple power sector entities in India, including power generation, transmission, and distribution companies.

ANALYSIS

The analysis of these cyber intrusions brought out several vulnerabilities and security challenges:

Sophisticated malware: The malware used in these attacks was designed to disrupt operations and exfiltrate sensitive data. This demonstrates the advanced capabilities of APT groups and the need for robust malware detection and prevention mechanisms.

System interconnectivity risks: The interconnected nature of the power grid means that a compromise in one part of the system can have cascading effects. Ensuring comprehensive security across all interconnected systems is crucial.

Need for enhanced monitoring: The intrusions went undetected for a significant period, indicating a need for improved monitoring and threat detection capabilities. Implementing real-time monitoring and anomaly detection systems can help identify and respond to threats promptly.

In response to these incidents, the Indian government and regulatory bodies have taken steps to enhance the cybersecurity posture of the power sector. This includes mandating regular security audits, strengthening incident response protocols, and improving coordination between various cybersecurity agencies and power sector entities.

6. Proposed comprehensive security framework for AMI systems in India

Stage 1: Harmonisation of regulatory and compliance requirements

Objective: Establish uniform security standards across all AMI implementations to ensure consistent protection measures.

Standardised Bidding Documents (SBDs): Develop and mandate the use of standardised bidding documents that incorporate comprehensive security requirements for all AMI projects. These documents should cover data retention, system security, disaster recovery, and compliance measures.

Collaborative regulation: Engage with state and central regulatory bodies, such as the Central Electricity Authority (CEA) and the Indian Computer Emergency Response Team (CERT-In), to ensure consistent application and enforcement of security standards across all states.

Stage 2: Advanced security measures

Objective: Implement advanced security measures to protect AMI systems from sophisticated cyber threats.

Encrypted and secure communication: Ensure end-to-end encryption of data transmitted between smart meters, data concentrators, and head-end systems. Utilise secure communication protocols to prevent data interception and tampering.

Access control and authentication: Implement stringent access control mechanisms, including multi-factor authentication (MFA) and role-based access controls (RBAC), to prevent unauthorised access to AMI systems and data.

Real-time monitoring and anomaly detection: Deploy real-time monitoring systems to detect and respond to security incidents promptly. Use anomaly detection algorithms to identify unusual patterns of activity that may indicate a cyber-attack.

Regular updates in the system and software being used: The system and software used in AMI should be updated regularly with the security patches released by different OEMs.

Payment gateway security: Incorporate robust security protocols for payment gateways used for billing and transaction purposes. Implement PCI DSS compliance, end-to-end encryption, tokenisation, and MFA to protect sensitive financial data and personal information.

Stage 3: Regular security audits and assessments

Objective: Conduct regular security audits and assessments to identify vulnerabilities and ensure compliance with regulatory standards.

Third-party audits: Engage certified third-party auditors to perform annual security audits for AMI systems, including assessments of hardware, software, and network components.

Continuous vulnerability assessments: Implement continuous vulnerability assessment programs to identify and remediate security weaknesses in real-time. Utilise automated tools to scan for vulnerabilities and ensure timely patch management.

Stage 4: Incident response and recovery planning

Objective: Minimise the impact of security breaches and ensure quick restoration of services through effective incident response and recovery planning.

Incident Response Teams (IRTs): Establish dedicated incident response teams within utilities and AMISPs to coordinate responses to cybersecurity incidents. Ensure these teams are trained in handling various types of cyber-attacks.

Crisis management plans: Develop and regularly update cyber crisis management plans that outline procedures for responding to and recovering from cyber incidents. Include guidelines for communication, coordination, and escalation during incidents.

Disaster recovery mechanisms: Implement robust disaster recovery mechanisms, including data backup and redundancy, to ensure business continuity in the event of a cyber-attack.

Stage 5: Capacity building and technical support

Objective: Build technical capacity and provide ongoing support to utilities for effective implementation and maintenance of AMI security measures.

Training programmes: Develop comprehensive training programmes for utility staff and AMISPs on cybersecurity best practices, regulatory requirements, and incident response procedures.

Technical assistance: Provide technical assistance through central agencies such as CEA and CERT-In, including real-time analytical support and the development of local cybersecurity expertise.

Resource allocation: Ensure adequate allocation of resources for cybersecurity initiatives, including funding for advanced security technologies and skilled personnel.

Stage 6: Enhanced accountability and transparency

Objective: Ensure accountability and transparency in AMI operations and cybersecurity practices to build trust and reliability.

Information disclosure requirements: Mandate the disclosure of relevant security information by AMISPs and utilities, including security incident reports, audit findings, compliance status, and data breaches.

Penalties for non-compliance: Implement strict penalties for non-compliance with security standards and contractual obligations. Hold both utilities and AMISPs accountable for lapses in cybersecurity.

Public reporting: Encourage public reporting of cybersecurity performance metrics and incident statistics to promote transparency and accountability.

Stage 7: Fostering collaboration and information sharing

Objective: Enhance collaboration and information sharing among stakeholders for effective cybersecurity management.

Sectoral CERTs: Strengthen the role of sectoral CERTs in the power sector by enhancing their capabilities for threat intelligence sharing and incident coordination.

Industry partnerships: Foster partnerships between utilities, AMISPs, regulatory bodies, and cybersecurity firms to share best practices, threat intelligence, and resources.

International cooperation: Engage with international cybersecurity organisations and forums to stay informed about global trends, emerging threats, and advanced security technologies.

Stage 8: Implementation of the Digital Personal Data Protection Act 2023

Objective: Ensure compliance with the Digital Personal Data Protection Act 2023 to safeguard consumer data and privacy.

Data protection policies: Develop and enforce data protection policies that comply with the DPDPA. These policies should cover data collection, processing, storage, and sharing practices, ensuring that personal data is handled securely and transparently.

Consent management: Implement robust mechanisms for obtaining and managing consumer consent for data processing activities. Ensure that consumers are informed about how their data will be used and that they can withdraw consent anytime.

Data minimisation: Adopt data minimisation principles to ensure that only necessary data is collected and processed. Avoid excessive data collection and ensure that data retention periods align with regulatory requirements.

Data subject rights: Establish procedures to uphold the rights of data subjects as outlined in the DPDPA, including the right to access, correct, delete, and transfer personal data. Provide consumers with easy-to-use interfaces to exercise these rights.

Data breach notification: Implement protocols for detecting, reporting, and responding to data breaches. Ensure timely notification to regulatory authorities and affected individuals in case of a data breach, as mandated by the DPDPA.

Data Protection Impact Assessments (DPIAs): Conduct regular DPIAs to identify and mitigate risks associated with data processing activities. Assess the impact of new technologies, projects, and processes on data protection and take appropriate measures to address identified risks.

7. CONCLUSION

The transition to Advanced Metering Infrastructure (AMI) systems within India's power sector is a foundational step toward realising a modern, efficient, and resilient energy ecosystem. AMI technology brings substantial benefits, including improved billing accuracy, enhanced operational efficiency, and real-time energy management capabilities. However, as this digital transformation progresses, the volume and sensitivity of data managed by AMI systems introduce a range of cybersecurity and privacy risks that must be addressed proactively.

This paper has explored the current regulatory landscape, identifying key challenges related to compliance, technical complexity, and the evolving nature of cyber threats. These challenges, if left unaddressed, can lead to vulnerabilities that threaten the confidentiality, integrity, and availability of AMI systems. Therefore, the proposed security framework emphasises a holistic approach to safeguard AMI systems, encompassing the harmonisation of regulatory requirements, implementation of advanced security measures, regular security audits, and robust incident response mechanisms. By adopting these strategies, utilities can enhance their cybersecurity resilience and foster a safer digital environment for both utilities and consumers.

The framework also underscores the importance of collaboration and capacity-building among stakeholders, including utilities, AMI service providers (AMISPs), regulatory bodies, and cybersecurity experts. Building a culture of accountability and transparency will be vital to ensure compliance with both national and international cybersecurity standards, such as the ISO / IEC 27001, NIST cybersecurity framework, and the GDPR. Additionally, incorporating the principles of the Digital Personal Data Protection Act 2023 within AMI operations is essential for securing consumer data and maintaining public trust.

WAY FORWARD

As India moves towards its ambitious goal of deploying 250 million smart meters by 2025, there are critical next steps to solidify a secure and resilient AMI infrastructure. The following recommendations provide a roadmap for continued progress in cybersecurity and regulatory compliance:

Strengthen regulatory oversight and harmonisation: There is a pressing need for consistent cybersecurity standards across states and regions. The development of standardised regulatory documents, such as a universally accepted Standard Bidding Document (SBD), will aid in establishing a uniform approach to AMI security requirements.

Invest in advanced security technologies: As cyber threats evolve, security measures in place must advance as well. Utilities should prioritise investments in cutting-edge technologies such as end-to-end encryption, multi-factor authentication, and real-time threat detection systems. Ensuring these systems are frequently updated with the latest security patches is crucial for ongoing protection.

Enhance training and technical capacity: Continuous training programmes should be developed to equip utility staff with the skills needed to implement and maintain robust cybersecurity measures. This will also involve fostering partnerships with national cybersecurity organisations, such as the Central Electricity Authority (CEA) and CERT-In, to provide technical support and access to cybersecurity expertise.

Develop a culture of accountability and transparency: Utilities and AMISPs must be held accountable for maintaining rigorous cybersecurity standards. Implementing information disclosure requirements, establishing penalties for non-compliance, and promoting public reporting of cybersecurity performance metrics can drive improvements and encourage a proactive security culture.

Promote industry collaboration and information sharing: Enhanced collaboration between utilities, regulatory bodies, and the cybersecurity community is essential. The establishment of sector-specific CERTs in the power sector, along with partnerships with international cybersecurity forums will enable stakeholders to share best practices, threat intelligence, and resources effectively.

Align with consumer protection laws: As the digital footprint of consumers expands, it is imperative to prioritise data privacy and protection. Compliance with the Digital Personal Data Protection Act 2023 will not only meet regulatory requirements but also strengthen consumer trust in AMI systems. This includes clear data protection policies, robust consent management practices, and transparent data breach notification procedures.

By implementing these strategies, India's power sector can build a secure, resilient, and trustworthy AMI ecosystem. In doing so, the nation can ensure a stable energy supply, improve operational efficiencies, and foster sustainable growth in the energy sector. The framework presented in this paper offers a scalable, future-proof solution that aligns with global best practices and prepares India to confront the cybersecurity challenges of tomorrow. As the energy sector continues to evolve, safeguarding digital infrastructure will be paramount to achieving long-term sustainability and enabling an empowered, digitally connected society.

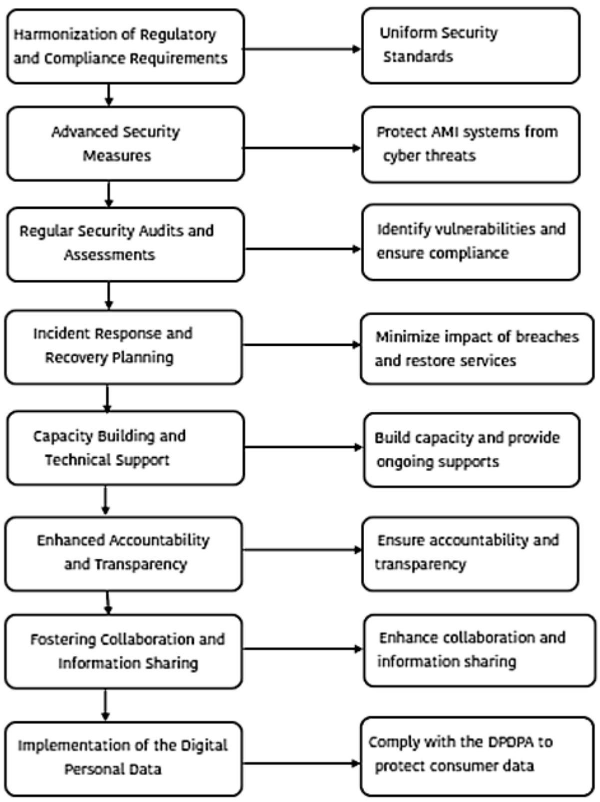


Fig 2: Framework overview

8. REFERENCES

Information Technology Act, 2000. Government of India. Available at: https://www.indiacode.nic.in/handle/123456789/1999?locale=en

Central Electricity Authority (CEA). "Cyber Security Guidelines for Power Sector." Available at: http://www.cea.nic.in/reports/others/god/dpd/guidelines_cyber_security.pdf

Indian Computer Emergency Response Team (CERT-In). "Guidelines for Protection of Critical Information Infrastructure." Available at: https://www.cert-in.org.in/

National Critical Information Infrastructure Protection Centre (NCIIPC). "Guidelines for Protection of Critical Information Infrastructure." Available at: https://nciipc.gov.in/

Ministry of Electronics and Information Technology (MeitY). "National Cyber Security Policy (NCSP) 2013." Available at: https://www.meity.gov.in/writereaddata/files/downloads/National_cyber_security_policy-2013(1).pdf

Central Electricity Regulatory Commission (CERC). "Indian Electricity Grid Code (IEGC)." Available at: http://www.cercind.gov.in/

Revamped Distribution Sector Scheme (RDSS), 2021. Government of India. Available at: https://www.pfcindia.com/Home/RDSS

ISO/IEC 27001. "Information Security Management." International Organization for Standardization. Available at: https://www.iso.org/isoiec-27001-information-security.html

National Institute of Standards and Technology (NIST). "Cybersecurity Framework." Available at: https://www.nist.gov/cyberframework

General Data Protection Regulation (GDPR). European Union. Available at: https://gdpr.eu/

Department of Energy (DOE). "Office of Cybersecurity, Energy Security, and Emergency Response (CESER)." United States. Available at: https://www.energy.gov/ceser/office-cybersecurity-energy-security-and-emergency-response.

Cybersecurity Capability Maturity Model (C2M2)." Department of Energy. Available at: https://www.energy.gov/ceser/cybersecurity-capability-maturity-model-c2m2

Cybersecurity Risk Information Sharing Program (CRISP)." Department of Energy. Available at: https://www.energy.gov/ceser/cybersecurity-risk-information-sharing-program-crisp

India Today confirmed Maharashtra cyber report: Malware caused outage via Trojan Horses, installed by unverified sources. https://www.indiatoday.in/india/story/maharashtra-cyber-cell-mumbai-power-outrage-1774522-2021-03-01

ieema
your link to electricity

BIO-DATA

DR SUMEDHA GANJOO
Secure Meters Limited

Date of Birth:	March 22, 1990
Qualification:	Ph.D. Data Privacy
Designation:	Global Data Privacy Assurance Manager
Present Organization:	Secure Meters Limited
Field of Expertise:	Data Privacy
Mobile:	+91 85889 11282
Email:	sumedha.ganjoo@securemeters.com

BRIEF PROFILE

Dr. Sumedha Ganjoo is the Global Data Privacy Assurance Manager at Secure Meters Ltd., where she oversees the development and execution of robust data privacy frameworks that safeguard the company's digital assets and ensure compliance with global regulations. Holding a Ph.D. in Data Privacy, she has extensive expertise in identifying privacy risks, implementing strategic policies, and maintaining alignment with ever-evolving legal requirements. Dr. Ganjoo is highly regarded for her ability to navigate complex regulatory environments, providing key insights that elevate the company's privacy standards and practices. Her leadership fosters a strong data protection culture across all levels of the organization, reinforcing Secure Meters' commitment to compliance and trustworthiness.

In addition to her operational role, Dr. Ganjoo is a published author with numerous articles in journals and newspapers, reflecting her passion for data privacy and thought leadership in the field. Her proactive approach ensures that Secure Meters stays ahead of regulatory changes while building trust with stakeholders. Through her strategic efforts, she continuously enhances the organization's data protection practices, positioning Secure Meters as a leader in privacy compliance.

BIO-DATA

ANKESH KUMAR
Secure Meters Limited

Date of Birth:	July 24, 2000
Qualification:	B.Tech CSE
Designation:	Cyber security executive
Present Organization:	Secure Meters Limited
Field of Expertise:	Vulnerability Assessment and Penetration Testing
Mobile:	+91 62837 59906
Email:	ankesh.kumar@securemeters.com

BRIEF PROFILE

Ankesh Kumar holds a B.Tech in Computer Science and Engineering (CSE) and is a skilled Cyber Security Executive specializing in Vulnerability Assessment, Penetration Testing (VAPT), and Red Teaming at Secure Meters Ltd. With a strong technical background, Ankesh plays a crucial role in identifying security vulnerabilities and safeguarding the organization's digital infrastructure against evolving cyber threats. His expertise includes conducting comprehensive assessments of IT systems, networks, and applications, enabling the implementation of effective security measures that strengthen the company's overall security posture. His proactive approach, keen attention to detail, and continuous drive for improvement make him an essential member of the company's Information Security (InfoSec) team. Ankesh's commitment to maintaining the highest standards of cyber resilience ensures the protection of critical assets and contributes significantly to the organization's success.

QUALITY ASSURANCE AND TESTING OF CYBER SECURITY REQUIREMENTS FOR AN ADVANCED METERING INFRASTRUCTURE

Florian Becker | Marcel Schönknecht
ZERA GmbH, Germany

ABSTRACT

The security of Advanced Metering Infrastructures (AMI) in smart metering and smart grids is critical to protecting against cyberattacks that could cause widespread power outages. This paper explores the threats to AMIs, and highlights notable cyberattacks on energy infrastructure, illustrating the vulnerabilities in critical infrastructure. The paper argues for the necessity of robust cyber security measures, emphasizing the differences between security tests and functional tests. It discusses the importance of negative tests for each component within the AMI. Practical examples of security tests, for both Device Language Message Specification (DLMS) and Transport Layer Security (TLS) connections, are provided to demonstrate effective strategies for mitigating cyber threats. The findings underscore the need for continuous verification of security measures to maintain the integrity and reliability of smart grids amid an evolving threat landscape.

1 INTRODUCTION

Cyber security is essential to the protection of smart grids because it protects critical infrastructure from cyberattacks that could result in widespread power outages and disruptions. Ensuring the integrity and confidentiality of data within smart grids prevents unauthorized access and manipulation, safeguarding both operational efficiency and consumer privacy. Additionally, robust cyber security enhances the resilience and reliability of smart grids, ensuring a stable and continuous electricity supply even in the face of ever evolving cyber threats.

In 2021, the Indian Ministry of Power addressed this need by issuing guidelines on cyber security for Advanced Metering Infrastructure Service Providers (AMISP). These guidelines mandate several types of testing, including Factory Acceptance Tests (FAT), Field Installation and Integration Tests (FIIT), and Site Acceptance Tests (SAT) [1].

Although AMISPs are legally obligated to conduct these tests, it is considered best practice for utility companies to take additional responsibility by regularly ensuring that their infrastructure is in good operational condition, rather than relying solely on third party providers.

2 THREATS TO ADVANCED METERING INFRASTRUCTURES

2.1 Controllable loads and unintended load shedding

Controllable loads refer to electrical devices and systems whose power consumption can be adjusted remotely to balance supply and demand on the power grid. Common examples include smart appliances, heating, ventilation, and air conditioning (HVAC) systems, electric vehicle chargers, and industrial equipment. By managing these loads, grid operators can enhance grid stability, optimize energy usage, and facilitate the integration of renewable energy sources. For instance, during periods of high demand or low supply, controllable loads can be temporarily reduced or shifted to off-peak times, thereby preventing outages, and reducing the need for expensive peaking power plants. Additionally, controllable loads can respond to real-time price signals, encouraging more efficient energy consumption patterns and lowering overall electricity costs [2], [3].

However, this flexibility also introduces significant security risks. If malicious actors gain unauthorized access to the control systems, they could disrupt the balance of supply and demand, leading to instability or even large-scale blackouts. Cyberattacks on these systems could be used to create targeted outages, sabotage industrial processes, or disrupt the balance of supply and demand.

2.2 Control of active smart grid based on false data

Adjustable local transformers, designed to maintain voltage stability in grids with decentralized energy generation, are particularly vulnerable to data injection attacks. These transformers rely on real-time data to ensure optimal performance and efficiency [4]. If an attacker injects false data indicating that voltage levels are too high or too low, these transformers may adjust incorrectly, possibly leading to disruptions, bodily injuries, or property damage due to local voltage range violations.

2.3 Non-technical losses and other fraudulent behavior

Cyberattacks aimed at manipulating smart meters to falsify billing data represent a significant threat in the digitalization of metering. By exploiting vulnerabilities in the meter software or communication protocols, consumers can illegally reduce the reported electricity consumption, thereby lowering their bills.

Additionally, consumers may be compensated for reducing their power consumption or curtailing their systems in the interests of grid stability (as discussed in section 2.1). This obviously creates an incentive to receive the compensation without carrying out the grid-friendly action (e.g., preventing a wallbox from charging an electric vehicle (EV) later or slower by preventing the grid operator from communicating with a wallbox through a Denial of Service (DoS) attack).

While such attacks may not offer significant financial rewards for individual perpetrators, widespread exploitation could cause serious harm to the system. Therefore, smart grid infrastructures must have basic resilience to prevent these forms of fraud from becoming prevalent issues.

3 EXAMPLES FOR CYBERATTACKS ON POWER INFRASTRUCTURE

3.1 2013 New York dam attack

In 2013, Iranian hackers successfully breached the computer systems controlling the Bowman Avenue Dam in Rye Brook, New York. This cyberattack exposed vulnerabilities in U.S. critical infrastructure, raising significant concerns about the security of similar systems nationwide. The hackers gained access to the dam's operational controls, allowing them to gather sensitive information about its status and functions. Fortunately, the dam was offline for maintenance at the time, preventing the attackers from manipulating the floodgate, which could have caused property damage or safety risks.

This attack was part of a broader campaign by Iranian cyber actors targeting U.S. critical infrastructure. The attackers exploited known security weaknesses in the dam's Supervisory Control and Data Acquisition (SCADA) systems, highlighting the susceptibility of outdated and poorly secured systems to cyber intrusions [5].

3.2 2015 attack on the Ukrainian power grid

On December 23, 2015, Ukraine experienced a landmark cyberattack on its power grid - the first publicly reported incident where hackers successfully disrupted a nation's electricity supply. The attack targeted three regional utility companies and left around 230,000 people without power for several hours. The attackers had infiltrated the systems months earlier via spear phishing emails, which contained malicious attachments that infected the computers with the "BlackEnergy" malware. This malware granted the hackers remote access to the utility company's systems, allowing them to meticulously plan and execute the disruption on December 23, 2015.

By manipulating SCADA systems, the attackers were able to shut down substations and cause widespread power outages. The attack was multi-layered, not only manipulating the control of the electricity grid, but also employing other tactics to maximize the damage and delay the recovery efforts. For example, the hackers simultaneously launched a telephone denial-of-service attack on the electricity suppliers' customer service centers. This flooded the phone lines and prevented affected customers from reporting the outages and seeking assistance, adding to the confusion. Additionally, the attackers deployed the "KillDisk" malware to wipe the affected systems and disable recovery processes, further complicating the restoration of power.

This coordinated and sophisticated attack points to a state-sponsored effort, especially considering the context of the ongoing Russian aggressions against Ukraine [6].

The attack highlighted the vulnerability of critical infrastructure to cyber warfare, serving as a wake-up call to governments around the world about the potential impact of such attacks on civilian life.

A year later, in December 2016, hackers followed up with another attack, employing the so-called "Industroyer" virus, causing a brief outage in Kyiv [7].

3.3 Ransomware attacks on Indian utilities

In 2019, criminals targeted the power utility systems of Telangana and Andhra Pradesh in India compromising SCADA systems crucial for real-time monitoring and control of the power grid. The infection occurred unintentionally through an infected USB stick, and while it did not result in power outages, the incident revealed vulnerabilities in the critical infrastructure of the region [8].

This incident serves as a reminder that even scattergun attacks can expose and exploit weaknesses, emphasizing the importance of securing critical systems from a wide range of potential cyber threats, both well-targeted and non-specific.

4 SPECIAL CHARACTERISTICS OF SECURITY TESTS

4.1 Insufficiency of positive testing

Positive testing aims to verify that a system correctly implements a specific requirement without errors. A negative test checks whether the system responds correctly to an incorrect input – regardless of whether these inputs arise from errors or malicious actions. While positive tests can confirm the correct operation of a system – under expected conditions, they provide no insight into the security of a system. Cybersecurity tests are predominantly based on negative tests, as they aim to verify that a certain function or data is not available to unauthorized actors.

Designing negative tests requires greater care than positive tests to ensure that failures occur for the right reason. Each test should only contain exactly one specific "error". This is crucial because, unlike with positive tests, where all components must work together to achieve success, in negative tests, a single error can cause a process to abort before other components are evaluated. If multiple errors are introduced simultaneously, it becomes difficult to determine which error caused the failure, making it impossible to draw meaningful conclusions about system vulnerabilities

4.2 Insufficiency of end-to-end testing

End-to-end (E2E) tests play an essential role in validating the overall functionality and performance of software systems by simulating real-world user scenarios from start to finish. However, they are inadequate for comprehensive cyber security testing for several reasons.

E2E tests primarily focus on normal operational scenarios and do not account for the wide range of potential attack vectors. They lack adversarial testing elements, which simulate malicious behaviors, such as unauthorized access attempts or data tampering. Since E2E tests mostly cover expected behavior, they are largely positive tests, especially for intermediate systems.

Furthermore, E2E tests, by definition, only interact with the ends of a system. However, if the data or instructions pass through intermediate systems, the security of these systems must also be verified. An attack on any of these intermediate systems may be sufficient to cause the whole system to be compromised. Any chain of components is only as strong as its weakest link and E2E tests alone are insufficient to uncover weaknesses in intermediate systems.

5 EXPERIENCES FROM OTHER MARKETS

5.1 Unreliability of software version numbers and hashes

In Europe, several instances have been reported where meters provided misleading or false information regarding their version. This issue arises because version numbers and even hashes were not automatically generated. As a result, the meter's software can be changed, but if the hard-coded version number and hash value is not updated, the meter will continue to present the outdated information as if the software would have never been changed. The inability to verify the actual version and hash makes this information inherently unreliable.

While this issue is not entirely security-related, it is particularly important in that context, because most malfunctions will not be immediately noticeable in the field, whereas a missing feature would be obvious. This is because the missing feature would become apparent when someone tries to use it, but a security vulnerability will only be noticed during a cyberattack - when it is already too late. Therefore, the behavior must be continuously verified by repeating all tests and not only comparing version numbers and hash codes.

5.2 Standardization of test procedures for certification of German smart metering devices

In Germany, the early standardization efforts by the federal government no formal and precise test specifications were published [9]. For these standards, long-lasting certification processes of multiple years have been common practice.

For the newer regulation, increasingly precise test specifications [10], [11] have been developed, of which the latest is automatically executable, leading to quicker feedback for developers of the devices to be certified, thus reducing the time needed for certification.

6 PRACTICAL EXAMPLES OF CYBER SECURITY TESTS

The exact test setup highly depends on the implementation used. The general structure depends on which specific AMI testing scenario is used. Commonly, there are three different scenarios for AMI testing depending on what stations are involved, illustrated in Fig-1:

1. meter and Head End System (HES)/MDMS,
2. meter, data concentrator, and HES/MDMS, or
3. HES/MDMS and test facilities or other third-party systems.

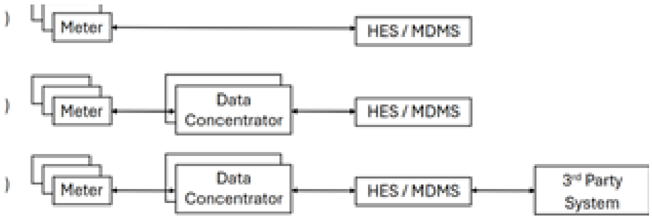


Fig-1: Different AMI Topologies

In the first scenario, the meter is supposed to communicate directly with the HES/MDMS. When testing in this environment, test equipment needs to either impersonate the remote station (so the HES/MDMS for the meter and vice versa) or get or send data or commands via the HES/MDMS.

In the second scenario, multiple meters communicate with a data concentrator, which then communicates with the HES/MDMS. When taking the first approach mentioned above - impersonation all remote stations - there is an increased implementation effort needed. The second approach to get or send data or commands via the HES/MDMS now decreases the effort for the testing equipment, because only one interface needs implementation.

While the first and second scenario contain fieldbus communication – often DLMS – the third scenario is not well standardized. Typically, for HES or MDMS applications a Representational State Transfer (REST) or Simple Object Access Protocol (SOAP) interface will be used. These protocols are then often used using the Hyper Text Transfer Protocol Secure (HTTPS), which utilizes TLS. Generally, TLS tests do not require an implementation of the used application layer protocol, as the tested behavior precedes its usage.

The E2E approach is obviously simpler and less dependent on the specific test setup, thus it is preferable for functional positive tests. This subject was also emphasized in Metering India 2022 [12]. For security tests, on the other hand, the more complex but also more detailed approach must be used for the reasons explained in chapter 4.1. They need to be conducted with every protocol used along the chain of components, e.g. DMLS between the meter and data concentrator, and TLS between the data concentrator and the HES/ MDMS.

6.1 Attempted access with unauthorized DLMS roles

Authentication verifies the identity of a user or system, while authorization determines the access level granted to an authenticated entity. Security tests must ensure that the device under test (DUT) correctly verifies whether an authenticated user is authorized to read or write specific data or perform a specific action. Each combination of role and data field or action should be tested.

This test will generally require implementing of the relevant DLMS companion specification, which defines the interface classes used in the connection. In India, these are commonly outlined in [13].

6.2 Attempted access with illegal DLMS security parameters

These tests verify that the DUT checks the passwords and keys used in the DLMS connections by attempting to connect with incorrect credentials.

The DLMS standard defines three possible cipher suites [14]. However, Indian regulations prohibit the usage of the standard suites and require a custom suite [13]. A test should ensure that the used DLMS implementation rejects connections with the standard cipher suites.

Additionally, Message Authentication Codes (MAC) should be tested to ensure the DUT correctly verifies the integrity of transmitted messages. By sending a message with an incorrect MAC value, the DUT should reject or ignore the message.

6.3 Unsafe TLS parameters in HES/MDMS connections

Despite the lack of standards governing communication with HES and MDMS, securing these systems is critical, as a compromised HES or MDMS will lead to all connected meters being vulnerable. Thus, these systems must also be protected.

In a TLS connection, cryptographic algorithms and parameters are negotiated between the client and the server through the handshake protocol [15]. A simplified version, where some parts are omitted for brevity, of this handshake is illustrated in Fig-2.

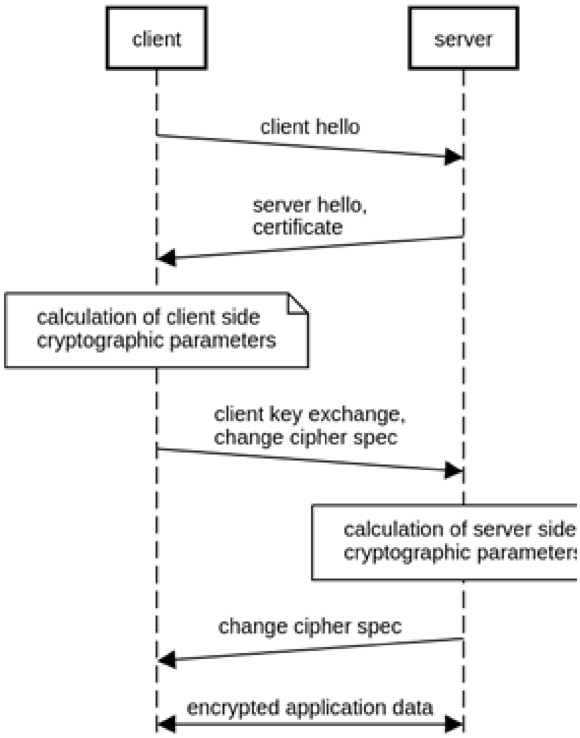


Fig-2: Sequence diagram for a simplified TLS handshake

The client sends its very first message, called the client hello. In that message, the client indicates to the server which TLS versions and cipher suites it supports. Then the server answers with a message called server hello, where it selects a version and cipher suite from the list presented in the client hello. Furthermore, the server sends its certificate. If the client also needs to authenticate themselves with a certificate, it will now send that, otherwise the handshake just continues, and the server does not authenticate the client based on TLS (however, there could be a password or token required on the upper layer protocol). Then, the client sends some cryptographic values, either random or calculated based on the server certificate, from which the server can calculate the secret used for the actual encryption. After the server has done that, client and server can now communicate securely using the parameters they just negotiated.

Currently, only TLS versions 1.2 and 1.3 are considered secure. A common test for TLS servers would be to try to establish a connection offering only deprecated versions of TLS in the client hello, or even the predecessor Secure Sockets Layer (SSL). The analogous client test case would be to check what versions are offered in the client hello.

A cipher suite is a standardized set of cryptographic algorithms used during a TLS handshake to establish a secure connection, including key exchange, authentication, encryption, and MACs. As certain algorithms became unsecure, some cipher suites became outdated and should not be used anymore. For clients, there should be a test that the client hello only contains secure cipher suites. For servers, there should be tests which assert that they abort connections when only insecure cipher suites are given in the client hello.

A certificate is a public key and meta information about that key, signed by a certificate authority (CA). Clients must always verify the certificate presented by the server. Certificates can be flawed in many ways, all of which must lead to the termination of the connection:

1 corrupted certificate: the data structure of the certificate is malformed, and therefore unreadable,

2 the hash value used for the signature is wrong but correctly signed,

3 the hash value used for the signature is correct but wrongly signed,

4 the certificate is self-signed or

5 issued by an unknown CA.

If mutually certificate-based authentication is used, servers must request and ensure that the client sends a certificate, and then conduct all verifications mentioned above as well.

In some cases, specific TLS extensions are required for secure operation. E.g., the encrypt-than-MAC-Extension is required whenever the connection uses cipher block chaining (CBC)-based cipher suites.

Even when using third-party TLS libraries, these tests are essential, as misconfigurations can still lead to critical vulnerabilities. Proper testing ensures the secure operation of the whole system.

7 CONCLUSIONS

Security testing is not only a regulatory requirement but also a critical technical necessity to safeguard the operation of energy infrastructure. This sector remains a high-value target for a broad spectrum of malicious actors, ranging from opportunistic fraudsters and extortionists to sophisticated state-sponsored groups, as demonstrated by numerous past attacks.

Continuous acceptance testing is essential to ensure that devices are free from outdated or improperly modified software. Traditional testing methods, such as pure positive testing and E2E testing, are insufficient for identifying security vulnerabilities. A more comprehensive security strategy is needed, which includes a diverse set of tests specifically tailored to the AMI topology, with a focus on robust assessments of DLMS and TLS protocols.

Regulatory bodies must establish clear, precise test specifications ahead of time, as this can significantly expedite the certification process. Streamlining certification enables faster deployment of smart meters, data concentrators, and other critical devices, ultimately improving grid security and resilience.

Moreover, incorporating negative test cases and comprehensive E2E testing of the entire smart metering ecosystem is essential for ensuring the system's ability to withstand real-world cyber threats. Effective cybersecurity requires more than just technical measures - it demands fostering a proactive culture of security within the energy sector. Security must be embedded from the initial design phase, becoming an integral part of the system's development or deployment, not an afterthought.

By embracing this proactive approach, the energy industry can better protect its critical infrastructure from cyberattacks and ensure a safer, more secure energy future.

8 REFERENCES

[1] "CEA (Cyber Security in Power Sector) Guidelines." 2021. [Online]. Available: https://cea.nic.in/wp-content/uploads/notification/2021/10/Guidelines_on_Cyber_Security_in_Power_Sector_2021-2.pdf

[2] Z. Ziadi, S. Taira, M. Oshiro, and T. Funabashi, "Optimal Power Scheduling for Smart Grids Considering Controllable Loads and High Penetration of Photovoltaic Generation," *IEEE Trans Smart Grid*, vol. 5, no. 5, pp. 2350–2359, Sep. 2014, doi: 10.1109/tsg.2014.2323969.

[3] Y. Dong, X. Xie, W. Shi, B. Zhou, and Q. Jiang, "Demand-Response-Based Distributed Preventive Control to Improve Short-Term Voltage Stability," *IEEE Trans Smart Grid*, vol. 9, no. 5, pp. 4785–4795, Sep. 2018, doi: 10.1109/tsg.2017.2670618.

[4] M. Juamperez, G. Yang, and S. B. Kjær, "Voltage regulation in LV grids by coordinated volt-var control strategies," *Journal of Modern Power Systems and Clean Energy*, vol. 2, no. 4, pp. 319–328, Sep. 2014, doi: 10.1007/s40565-014-0072-0.

[5] M. Thompson, "Iranian Cyber Attack on New York Dam Shows Future of War — time.com." Mar. 2016. Accessed: Jun. 27, 2024. [Online]. Available: https://time.com/4270728/iran-cyber-attack-dam-fbi/

[6] "Analysis of the CyberAttack on the Ukrainian Power Grid," Mar. 2016, [Online]. Available: https://www.sherpain.net/SW_upload_file/SW_qna/a615bde86d160330091226.pdf

[7] P. Kozak, I. Klaban, and T. Šlajs, "Industroyer cyber-attacks on Ukraine's critical infrastructure," in *2023 International Conference on Military Technologies (ICMT)*, IEEE, May 2023. doi: 10.1109/icmt58149.2023.10171308.

[8] "7 Biggest Ransomware Attacks In India," CCoE. Accessed: Jul. 05, 2024. [Online]. Available: https://ccoe.dsci.in/blog/7-biggest-ransomware-attacks-in-india

[9] "Protection Profile for the Gateway of a Smart Metering System (Smart Meter Gateway PP)." Mar. 2014. [Online]. Available: https://www.bsi.bund.de/SharedDocs/Downloads/DE/BSI/Zertifizierung/Reporte/ReportePP/pp0073b_pdf.pdf?__blob=publicationFile&v=1

[10] "TS-03109-1: Testspezifikation zur Technischen Richtlinie TR-03109-1 (German)." Jan. 2024. [Online]. Available: https://www.bsi.bund.de/SharedDocs/Downloads/DE/BSI/Publikationen/TechnischeRichtlinien/TR03109/TR-03109-1_Testspezifikation.pdf?__blob=publicationFile&v=2

[11] "TS-03109-5: Testspezifikation zur Technischen Richtlinie TR-03109-5 (German)." Jun. 2024. [Online]. Available: https://www.bsi.bund.de/SharedDocs/Downloads/DE/BSI/Publikationen/TechnischeRichtlinien/TR03109/TR-03109-5_Testspezifikation.pdf?__blob=publicationFile&v=2

[12] M. Schönknecht, F. Becker, and F. Gonzalez, "Advanced Smart Meter Testing: Test-System with Integrated AMI Interface," in *Metering India, 9th Edition: Resilient Utilities & Empowered Consumers*, New Delhi, Nov. 2022, pp. 134–143.

[13] "IS15959: Data Exchange for Electricity Meter Reading, Tariff and Load Control – Companion Specification," New Delhi, IND, Sep. 2011.

[14] "IEC 62056-5-3:2023: Electricity metering data exchange - The DLMS®/COSEM suite - Part 5-3: DLMS®/COSEM application layer," Geneva, CH, Sep. 2023.

[15] E. Rescorla and T. Dierks, "The Transport Layer Security (TLS) Protocol Version 1.2," no. 5246. in Request for Comments. RFC Editor, Aug. 2008. doi: 10.17487/RFC5246.

BIO-DATA

FLORIAN BECKER
ZERA GmbH

Date of Birth:	05.12.1994
Qualification:	B.Sc. Energy Informatics
Designation:	Software Developer
Present Organization:	ZERA GmbH
Field of Expertise:	Standardization and testing of communication protocols of smart meters and other energy systems for interoperability, interchangeability, conformance, and cyber security
Mobile:	+49 2244 9277 246
Email:	f.becker@zera.de

BRIEF PROFILE

Florian Becker is a software developer at ZERA, Königswinter, Germany. He graduated Ruhr West University of Applied Sciences in Bottrop, Germany in 2018 and has since specialised on the testing of communication protocols of smart meters and other energy systems for interoperability, interchangeability, conformance, and cyber security, e.g., as a consulting technical expert for the German Federal Office for Information Security for the QA and test development for the relevant German regulation.

ieema
your link to electricity

BIO-DATA

MARCEL SCHÖNKNECHT
ZERA GmbH

Date of Birth:	22.04.1987
Qualification:	M. Sc. Informatics
Designation:	Director Development
Present Organization:	ZERA GmbH
Field of Expertise:	7 Years of experience in Smart Meter Testing Specialist for interfaces between Smart Meter test system and Head End System. End to End Testing Smart Meter Infrastructure
Mobile:	+49 2244 9277-164
Email:	m.schoenknecht@zera.de

BRIEF PROFILE

Marcel Schönknecht is Head of Development at ZERA Königswinter, Germany. He graduated Ruhr West University of Applied Sciences in Bottrop, Germany in 2016 and has since specialised on Smart Meter testing. The integration of HES with the ZERA test systems to perform End to End tests is one of his knowledge areas.

Marcel was invited as a speaker at Metering India 2022 & 2019.

ARCHITECTURE & SYSTEMS APPROACH IMPERATIVES FOR SUSTAINABLE DIGITAL TRANSFORMATION OF DISCOMS

N. Kishor Narang
Technology Philanthropist

ABSTRACT

The Electricity Infrastructure is undergoing a paradigm shift in wake of changing societal imperatives and onslaught of disruptive digital technologies. The complexity of Distribution utility architecture has also exponentially grown to meet new technical requirements and consumer expectations about Automation to Sustainability demanding a fresh approach in design of utility infrastructure and business processes. This paper proposes applying a system thinking to this evolving utility paradigm and developing a unified digital architecture for sustainable digital transformation of distribution utilities that can facilitate a seamless integration of all the business processes with diverse technical systems/ solutions coming from different energy sectors and relevant ecosystems like Cities, Buildings and Homes in resilient & cyber secure manner.

INTRODUCTION

The new paradigm of Smart Grid, Smart Home, Smart Building, Smart Manufacturing, Smart City already complicated by the ‘Internet of Things’ & Internet of ‘Everything’ made further complex by the 5G, Artificial Intelligence, Big Data, Machine Learning, Blockchain, Quantum Computing, Digital Twin, Metaverse and ever-evolving Cyber-threat landscape demand a fresh perspective in Critical/Civic Infrastructure Design.

The recent evolution of disruptive technologies and digitalization compounded by the Covid 19, changing geopolitical situations, and increasing cyber-attacks from not-so-friendly nations; bring a whole new set of challenges for the Security and Security Evaluation Methodologies for complex nature & architectures of Critical Infrastructures of any nation leveraging the IT & Communication Networks evolving to meet these rising needs of the Society.

On one hand, we have the highly protected Networks for the ‘Critical Information Infrastructures’; on the other hand, these very ‘highly protected networks’ need to give access to the consumers (and increasing the vulnerability surface attack area exponentially) for Consumer Engagement and Participation in these Smart (Digital) Infrastructures to meet the true drivers of setting them up. These large Smart Networks are actually highly complex ‘Systems of Systems’ and “Networks of Networks’, and thus create fresh challenges in architecting approaches that need to develop Comprehensive & Granular and yet Flexible & Scalable Architectures to ensure making the Infrastructure Sustainable, Resilient & Future Proof. Distribution Utilities are one of the principal constituents of such an evolving paradigm in the Critical Infrastructure.

CONTEXT

Electricity is the cornerstone for economic development and social wellbeing, serving as the golden thread across all SDGs. The Electricity Infrastructure is also undergoing a technological metamorphosis to cope up with global imperatives like Climate Crisis, Net Zero, Energy Security, Renewable Energies, Smart Grids, Energy Efficiency, Electric Mobility etc. demanding a fresh thinking and approach to transform the electricity infrastructure across the globe into a sustainable and resilient lifeline of the society.

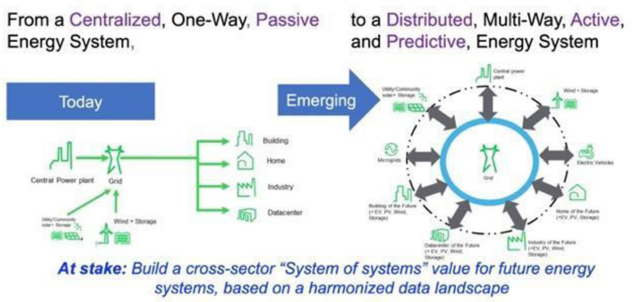


Figure 1. Shifting paradigms in Energy Systems

In wake of such transformational imperatives, it would be prudent to understand the current challenges that Distribution utilities have to contend with:

- Generation is still centralized and still primarily fossil fuels based though share of clean generation sources is on the rise.
- Energy security concerns due to geo-political uncertainty, gas crisis. Access to Energy/clean energy for certain countries further aggravated.
- Pledges to fight climate change impose new ways of to run utility operations, including decarbonizing and digitalizing the utility infrastructure and operations together to improve operational efficiency, increasing the capital spending and fiscal constraints.
- Traditional utility 'control & command' architectures are designed to work with bulk generation connected to transmission networks, loads connected through distribution networks to bulk supply, and TSOs forecasts system load, schedules generation to balance load (via some sort of market). Internal utility operations are still siloed, composed of large number of sub-systems managing core operations, metering, energy market participation, and customer engagement roles.
- Distribution Utilities are struggling to integrate diverse heterogenous technologies and solutions into a homogenous framework for improving coordination and operational efficiency and seamless Data sharing.
- Standardization is not uniformly spread across utility operations - Semantic & Syntactic interoperability within a distribution utility is a challenge due to heterogeneity of Communication protocols and Data Models. A case in point is Data Models- Control & Automation systems are largely based on IEC 61850 series, with enterprise level integration based on CIM. Metering based on COSEM, and new data models and system interfaces are being developed to integrate DER sources, EVs, batteries etc.
- Cyber risks and data privacy emerge as systems-wide concern rather than limited to products and sub-systems. Managing these concerns across integrated energy sectors, with different legal jurisdictions become a complex task.

THE RATIONALE – UTILITY AS A SYSTEM OF SYSTEMS

The relationship between Digital Infrastructure and Electricity Utilities needs to be understood in this context: "In an electricity utility Generation, Transmission, Distribution, Renewable & Grid Scale Storage integration, Electric Vehicles Charging Infrastructure integration, Advance Metering Infrastructure and other key services need to be managed in concert to support smooth operation of the utility while providing for a clean, economically viable, resilient and safe Electricity supply to all the consumers to enable & empower them to lead a sustainable, resilient and vibrant life.

Hence, the perspective in Infrastructure Design for any utility has undergone a paradigm shift with advent of convergence and networking technologies, solutions for information, communication, security, and surveillance, which are beginning to have a profound impact on the way we look at the Utility Design (be it distribution or transmission) and complete Energy value chain.

Utilities are intricate composite environments and the manner in which utilities are today operated, financed, regulated, and planned are extremely complex to say the least. Utility operations are multi-dimensional and comprise of multiple stakeholders whose dependencies and inter-dependencies affect and ultimately determine the utility's infrastructure and operational environment.

The hugely complex nature of a utility infrastructure project creates a very real risk that oversights in the planning phase can cause the sub-optimization of sub-systems, which can severely impair the overall success of the project.

The various departments mostly overlook these dependencies and interdependencies though known, in their efforts and focus of providing their services and of being answerable only for the services they provide. Part of the answer to making utilities 'smarter' is a more all-embracing coordinated management of resources and infrastructure, a collaborative approach to a cleaner greener environment, and harmonized governance that result in a better quality of service to its consumers.

There is also a recursive cycle to the data in a utility. Information that is generated is information that is consumed which in turn adds to the information generated which becomes information used again.

DIGITAL TRANSFORMATION

Electricity utilities now find themselves making three classes of transformations:

- Improvement of Infrastructure, also called the Strong Grid.
- Addition of the digital layer, which is the essence of the Smart Grid.
- Business process transformation, necessary to capitalize on the investments in smart technology.

The transformation is aptly called as the Digital Transformation, however digital transformation of utilities or the electricity infrastructure is NOT about integration of IT(Information Technologies) & OT (Operational Technologies) only, as is generally considered; rather, it has evolved into a much larger, complex and comprehensive paradigm where Network Technologies (NT), Internet of Things (IoT) and Artificial Intelligence (AI) also play individually and collectively an equal if not more crucial role to enable the structured scalable digital transformation of the Electricity Infrastructure.

The genesis of Digital Transformation in any paradigm, domain, or ecosystem can be summarized as - 'Sustainability' the True Destination; 'Resilience' the Core Characteristic; 'Smart' merely the Accelerator; and 'Standards' the Chromosomes of Digital Infrastructure.

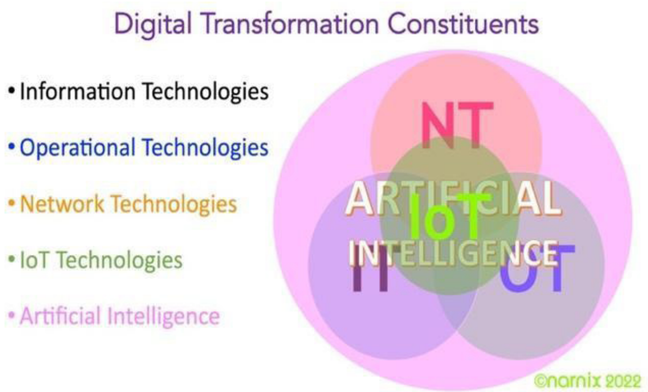


Figure 2. . Digital Transformation Constituents

Digital Transformation is NOT a Technology, rather it's a complex paradigm with domain specific implications. We are living in an ephemeral world.

SYSTEMS APPROACH

The multiplicity of technologies and their convergence in many new and emerging markets, however particularly those involving large-scale infrastructure demand a top-down approach to standardization, starting at the system or system-architecture rather than at the product level. A systems level approach in design and standardization is likely to not only enable newer and better services, but also allow far greater synergies and cost-effective deployments, reducing the lifecycle (total) cost of ownership of any Infrastructure, be it the smart grid, a home, a building or even a city, with attendant environmental benefits, including carbon reductions. Therefore, the Systems Engineering principles can help define and strengthen the systems approach throughout the technical community to ensure that highly complex market sectors can be properly addressed and supported. Further, design and standardization in such cases needs to be inclusive, top down and bottom up; a new hybrid model with a comprehensive approach is needed.

Electric Utilities are mainly self-evolving utilities with thousands of individual needs and capabilities to be handled systemically. Such systemic problem can be comprehensively solved only with systems approach. In the case of 'new generation' Utilities, systems approach should be a holistic & iterative discovery process that helps with first defining the right problem in complex situations and then with finding elegant, well-designed, and working solutions. It should be used not only in design of technical solutions, but also architecting systems with many various additional aspects (human, economic, social, etc.).

ARCHITECTING PRACTICES

International Standard - ISO/IEC/ IEEE 42010: 2022 (Systems and Software Engineering - Architecture Description) is a perfect foundation for architecting digitally coordinated systems with following few simplifications:

- Architecture Views and Models are members of Architecture Description, and they can be elements of the System-of-Interest.
- No correspondence rules – Model-Kinds and Models are more practical.
- Stakeholders and their concerns are Models.
- Architecture Description may contain an Architecture Viewpoint without its Views, and Model-Kind without Models.
- An Architecture Viewpoint may be used to prepare more than one View.
- A Model-Kind may be used to prepare more than one Model.

REFERENCE ARCHITECTURE

One of the essential characteristics of a matured industrialized domain is its Reference Architecture (as a template for Solution Architectures which realizes a predefined set of requirements). An important driving factor for Reference Architecture is to improve the effectiveness of creating products, product lines and product portfolios by:

- Managing Synergy,
- Providing Guidance, e.g. Architecture Principles and Best Practices,
- Providing an Architecture baseline and an Architecture blueprint, and
- Capturing and sharing (Architectural) Patterns.
- An ideal Reference Architecture as a basis for systemic Digital Transformation of any domain or enterprise, will bring the following capabilities:
- Ability to use the best world-wide knowledge, practices, and solutions.
- Ability to deploy ready-to-use digital solutions which can be calibrated to unique needs of each utility and each relevant ecosystem.
- Ability to collaborate in the evolution of domain solutions & thus develop homogenous ecosystem.
- Ability to coordinate the evolution of domain solutions.
- Ability to evolve with its own pace and priorities, and under regulators-led governance, and
- Ability to consider various economic, cultural, legal, and other specific needs of consumers, businesses, and civic administrations.

FOUR LEVELS OF ARCHITECTING

If the future solutions are rather complex, then it is recommended to use the following four levels of architecting:

Reference Model is an abstract framework for understanding concepts and relationships between them in a particular problem space.

Reference Architecture is a template for potential solution architectures, which realizes a predefined set of requirements.

Note: Reference Architecture uses its Reference Model (as the next higher level of abstraction) and provides a common (architectural) vision, a modularization and the logic behind the architectural decisions taken.

Solution Architecture is architecture of the future system.

Note: A Solution Architecture (also known as a blueprint) can be a tailored version of a particular Reference Architecture (which is the next higher level of abstraction).

Implementation is a realization of the future system.

The dependencies between these 4 levels are shown in illustration below:

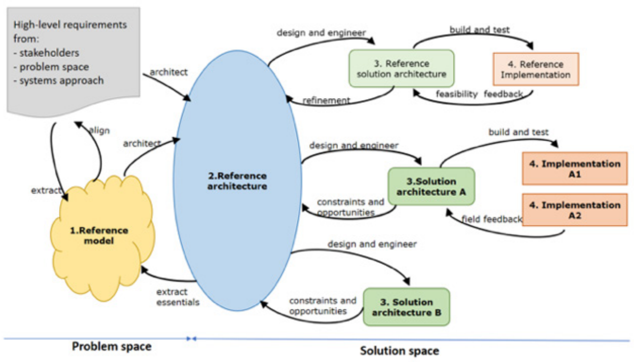


Figure 3. Levels of Architecting

The presence of some "loops" of this illustration confirms the complexity of architecting. For example, there is no guarantee that the original high-level requirements have a high-quality content, e.g. based on a prefect terminology; thus collecting of important concepts in the reference model may necessitate some modifications in the high-level requirements to align their terminology.

UTILITIES NEED ENTERPRISE ARCHITECTURE

Any complex system e.g. a utility needs to be carefully designed, using a systematic approach, to describe in detail its structure, all the processes needed to fulfil the purposes of the utility and all the subsystems within it (AMI, SCADA DMS, DA, FMS etc.) and how its design meets the different functional requirements of its users.

This is needed at the design & deployment phase to ensure that the utility is properly designed to enable it to fulfil all the requirements of its purpose. However, it is also needed to support the on-going management of that utility and to support the design of any alterations and upgrades needed to meet any change in requirements or to benefit from new technologies to fulfil existing requirements.

The aims and strategy, business structures and business processes of an enterprise and the software applications and communications infrastructures that support them, also need to be carefully described and reviewed. Only in this way is it possible to ensure that its business structures and processes can effectively support the delivery of its strategies and outcomes and to allow these to change and adjust to changing requirements and opportunities.

Enterprise Architecture is the definition and description of an enterprise from the combined viewpoints of its strategy, business structure, business processes, information systems and technology, both in terms of how it is at present, and of how it needs to be in the future.

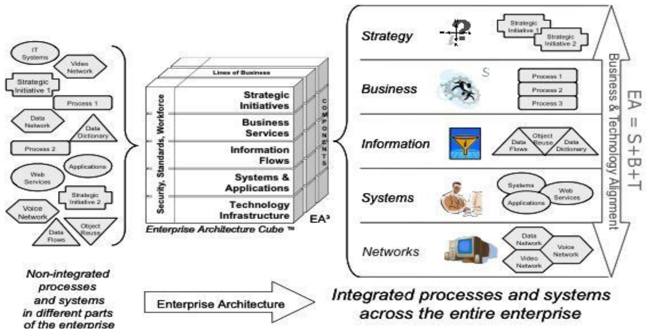


Figure 4. Architecture management & transition

EA defines how business and Information systems alignment should be achieved.

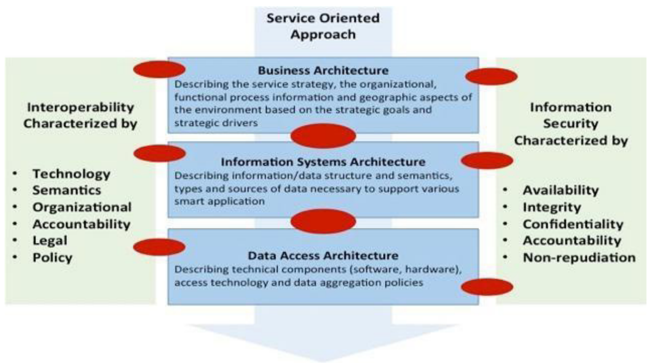


Figure 5. Service Oriented Approach to Enterprise Architecture

It is where business capability (financial and market goals) and technology capability (products, vendors, and functionality) are tied together with organizational capability (people or process) to drive an ongoing strategy or desired outcome. SOA is recognized as a methodology optimized in applications architecture or Service architecture, with a view to deliver one of the domains within EA namely the applications architecture.

'SGAM' TO 'UNIFIED DIGITAL UTILITY REFERENCE ARCHITECTURE' (UDURA)

To develop the much-needed Unified Digital Utility Reference Architecture, we don't need to start afresh. The 'Smart Grid Architecture Model' (SGAM) - IEC SRD 63200:2021 provides a robust foundation, that when combined with the Systems Approach, Architecture Principles and Enterprise Architecture Frameworks helps develop the comprehensive blueprint (Reference Architecture) for any Electricity Utility, be it Generation, Transmission or Distribution.

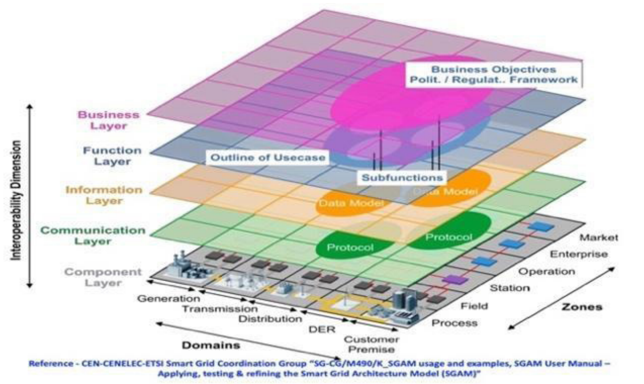


Figure 6. SGAM - Smart Grid Architecture Model

The several critical methodologies and practices for achieving the top level of maturity in developing Reference Architecture in any complex domain are assembled in the 'Smart Cities Reference Architecture Methodology' (SCRAM) – IEC SRD 63188:2022.

- Each utility develops its own solutions individually, although there are quite a many common parts.
- Many architectures with many methodologies for various aspects and products are available for specific elements and technologies, however they are not compatible.
- A common Unified Digital Utility Reference Architecture (UDURA) with many viewpoints based on the same methodology needs to be developed and accepted as an International Standard.
- The common Reference Architecture is the foundation for a common platform and common solutions which are developed collaboratively and incrementally by technology, software & solution companies, and utilities.
- Each utility has its own customized implementation of the common platform and, potentially, many common solutions developed in close coordination amongst them.

Mapping the Information Flow stack in the digital infrastructure in any technical solution of the utilities shows that different utility applications need changes as part of the solution requirements to derive value from different infrastructure pillars, but the ICT (and IoT) backbone remains the same. This implies that across diverse infrastructures and/or technical solutions utilities can leverage one common ICT Backbone (Infrastructure).

The evolved Comprehensively Unified ICT Architecture can be modelled as a "Classic Saucer Champagne Glass" with a wide Flat Bottom Base depicting the multitude of Field Devices & sensors etc. The Saucer Shaped Bowl on the Top depicting being filled with an ever-increasing spectrum of Utility Applications and Consumers Services.

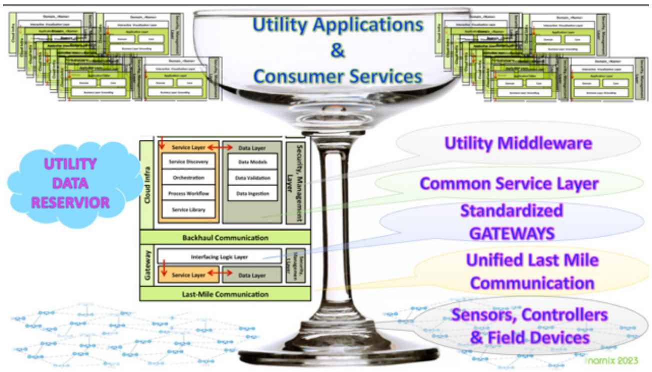


Figure 7. Classic Saucer Champagne Glass Architecture Model

The Long Stem depicts all the Common Layers viz.: the Unified Last Mile Communication, Common Standardized Gateways (Application or Solution Agnostic), Common Service Layer representing the Common Service Functions in the Gateways, as well as, in the Cloud… and the Utility Middleware & Utility Data Reservoir in the Cloud.

It is the "Long Stem" of the "Champagne Glass Model" instead of the famous Short & Narrow Neck in the "Hourglass Model" that brings the comprehensive harmonization, standardization & interoperability in the Architecture leading to optimization in operational efficiency & Life Cycle Cost of the ICT Infrastructure in any Utility.

This Architecture Model, beyond reducing significantly, the CAPEX, OPEX & Carbon Footprint of the Digital Infrastructure, enables a unified & well architected Infrastructure that can be comprehensively Resilient & Cyber Secure.

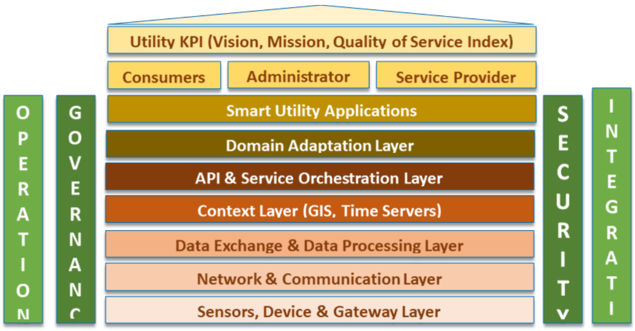


Figure 8. Simplified Unified Architecture of Digital Utility

An intuitive and adaptive cyber posture defined by zero latency networks and quantum leaps will be needed across diverse solutions within the utility infrastructure and business processes. A systemic architectural approach to Cyber Immunity at every layer will create networks that are inherently secure and self-learning. AI-induced digital intuition is one of the pillars of cyber-Security strategy that will allow intelligent adaption. The ability of AI systems to out-innovate malicious attacks by mimicking various aspects of human immunity will be the line of defence to attain cyber resilience based on both supervised and unsupervised machine learning.

The diverse utility systems could be designed to make the right decisions with the context-based data, pre-empt attacks on the basis of initial indicators of compromise or attack, and take intuitive remediated measures, allowing any digital infrastructure to be comprehensively Resilient.

COMBINING SIMILARITY AND DIVERSITY

The key feature of the UDURA needs to be a built-in capability to combine similarity and diversity. In other words, each utility may start from a standard solution and decompose it into smaller elements to adjust them to utility's particular needs. All of these can be done without compromising the quality characteristics of the solution.

The UDURA (Unified Digital Utilities Reference Architecture) will allow building the smart utilities faster, more effective, more resilient, and more sustainable. Each utility can adopt the UDURA and customize & calibrate it to its needs leveraging the comprehensive Digital Utility Implementation Manual (DUIM) that shall complement the UDURA.

CONCLUSION :

The Architectural & Systems Approach proposed in the paper if adopted by the Electricity Utilities including but NOT limited to Distribution Utilities, can drive comprehensive De-carbonization and Digitalization together, meeting current and future socio-techno-economic imperatives of the ecosystem stakeholders.

FUTURE WORK

To develop the discussed 'Unified Digital Utility Reference Architecture' (UDURA) followed by a Granular for 'Unified Digital Distribution Utilities Reference Architecture' (UDDURA) with all its system components.

REFERENCES

[1] EC SRD 63200:2021 - Definition of extended SGAM smart energy grid reference architecture mode

[2] IEC SRD 63188:2022 - Smart Cities Reference Architecture Methodology

[3] Pre-standardisation Study Report - Technical Requirements Analysis of Unified, Secure & Resilient ICT Framework for Smart Infrastructure

BIO-DATA

N. KISHOR NARANG
Technology Philanthropist

Date of Birth	28 September 1957
Qualification	P.D.EE AMIE
Designation	Principal Design Strategist & Architect
Present Organization	Narnix Technolabs Pvt. Ltd.
Field of Expertise	System Design Architect (Electronics, ICT & Digital Infrastructure)
Landline /Mobile No.	+91 9810163990
Email	kishor@narnix.com

BRIEF PROFILE

Kishor is Technology Advisor, Mentor, Design Strategist & Architect in Electrical, Electronics & ICT with over 47 years of professional experience in education, research, design and advisory running an Independent Design House – NARNIX since 1981. Over 37 years of hardcore Research and Design Development Experience in Solutions, Systems, Products, Hardware, Software & Firmware (Embedded Software) across diverse technology & application domains, and over 10 years of Strategic Advisory Experience to different segments of business & industry. Leading multiple National & Global Standardization Initiatives & Projects at BIS, TSDSI, IEEE, IEC, ISO, ITU and IETF.

For the last 15 years, been deeply involved in standardization in the electrical, electronics, communications, information technology, digital infrastructure and cyber security domains with a focus on identifying gaps in standards to bring harmonization through system standards and standardized interfaces to ensure end-to-end Interoperability. Recent work includes advocacy and standardization in cross cutting societal Ethical imperatives – Sustainability (focus on Decarbonization in every domain), Safety of the Mankind and the Environment in use of disruptive digital technologies (including but NOT limited to Artificial Intelligence).

Mentoring many Deep Tech & Disruptive Tech Startups in the domains of e-mobility, drones, robotics, automotive like Electric Vehicles, Autonomous Vehicles, Drones, Robotics & AI; Strategic Electronics like Defence, Aerospace, AR/VR/XR etc.

ADDITIONAL PAPERS

INDIGENOUS IMPLEMENTATION OF ADVANCED METERING INFRASTRUCTURE

Neethu K V | Davidson C | Jiju K | Sherin John | Indhu T R | Mahesh T | Arun Gopi | Aby Joseph
Centre for Development of Advanced Computing, Kerala State Electricity Board Ltd

ABSTRACT

This paper is based on the implementation experience of indigenously developed Advanced Metering Infrastructure (AMI) solutions for electricity utilities. The pilot deployment was done with the support of Kerala State Electricity Board Limited (KSEBL), and the project was funded by the National Mission on Power Electronics Technology (NaMPET) under the Ministry of Electronics and Information Technology (MeitY), Government of India. Through this paper, the authors are trying to share some of the challenges in AMI deployment and their possible solutions.

1 INTRODUCTION

Advanced Metering Infrastructure (AMI) and Smart Meters are one of important technologies essential for next generation smart grid and utility business. AMI needs to be viewed in a larger canvas rather than limiting to electric energy metering alone. The total business size of smart metering is estimating as approximately three lakh crore including water, gas etc. The benefit from AMI in electricity alone is estimated as around one lakh crore in a year. AMI is not only a utility automation solution but also a strategic technology business. The AMI data needs to be handled very carefully and in a secure manner. Nowadays, some of the metering deployments are done with the support of foreign technology, which may cause long-term dependability for the utilities.

AMI refers to a comprehensive platform including smart meters (SM), data communication, data storage, Data Concentrator Units (DCU), and Head End Systems (HES), including Meter Data Acquisition System (MDAS) and Meter Data Management System (MDMS). AMI has features like bidirectional secure communication, bidirectional energy flow measurements, remote firmware upgrades, load management, interoperability, etc.

Since the power sector is a very strategic area of concern for the government, the government has a plan to indigenize the major technologies to reduce foreign dependability and enslavement. As per the Atmanirbhar initiative, the Government of India is funding the indigenization of these types of technologies, and AMI is one of them.

Under various schemes of the Government of India, CDAC has developed indigenous solutions for AMI, which include technologies for single-phase and three-phase smart energy meters, meter protocol testing software, meter data acquisition software, etc. KSEBL has also a plan for supporting Indigenous technology development to reduce dependability.

2 CHALLENGES

A new technology implementation is always a challenging process; if it is very related to mass consumers, then its complexity will be very high. Some of the challenges that the project team has faced during the execution of the project are as follows:

- Identifying meter deployment sites and convincing customers about this smart meter technology
- Establishing the heterogeneous communication interface with meters
- Storing the data of heterogeneous meters in a structured database
- Finalization of requirement specification
- Creating and securing API which is for interfacing existing billing software with MDAS
- Applying cyber security and other security features in the MDAS

3 NAVIGATING CHALLENGES: SOLUTIONS AND STRATEGIES IN DEPLOYMENT

To address the challenges encountered during deployment, a range of strategies was considered. Each strategy underwent a careful evaluation to effectively tackle specific obstacles.

a. Smart Meter Deployment Site Selection:

Proper selection of the site for deploying the smart meter and convincing consumers are vital parts of the deployment process. It's crucial to consider deploying the meters in various geological and demographical conditions to test the efficiency of the communication process under different circumstances. So, the project team selected consumers who come from different geographical areas, different power usage patterns, etc. in the same KSEBL section.

Getting consent from the selected consumers was a tricky job. It is common for consumers to feel confused about the new system. People are often resistant to change because they are comfortable with the current system and fear the unknown. To address these confusions, the smart meter is connected in series with the existing meter.

Data for KSEB billing purposes is collected from the old meter, while data for testing purposes is gathered from the smart meter. This method was helpful for the utility's internal validation of the system and to convince consumers as well.

Fig-1: Smart meter deployments at the site

b. Establishing heterogeneous communication Interface with Meters:

Meters have to be deployed in different geographical and demographical conditions. The initial phase of the deployment was cellular communication. So, last-mile connectivity is a challenge. But the project also envisages the development of communication infrastructure using RF and optical technology.

The project team has developed DCUs and different types of communication modules like LoRa, Wi-Fi, etc. and made a common interface for the NIC so as to enable easy migration of communication methods. That is, the same meter can interface with LoRa NIC and Wi-Fi NIC by replacing the NIC and without changing the software or hardware in the meter. The LoRa NIC is developed with the support of ProChip Technologies, a startup from Kerala.

Fig-2: Prototype of DCU

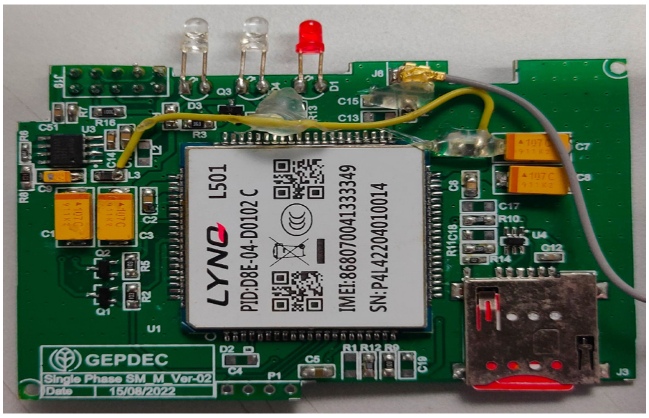


Fig-3: 4G NIC

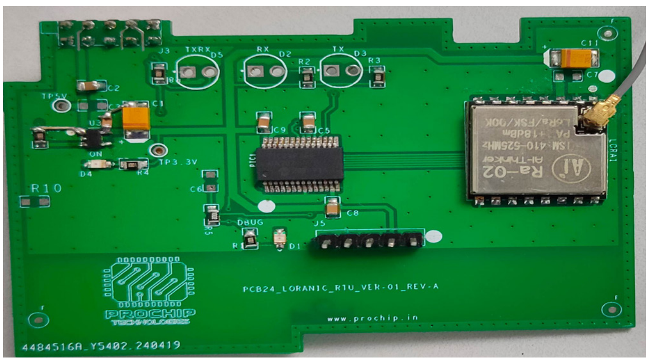


Fig-4: LoRa NIC

c. **Storing the data of heterogeneous meters in a structured database:**

Even though all the meters are following the same standard, the structure of different meters is different. It may vary from meter to meter and from manufacturer to manufacturer. Data structures for the same category can vary across different manufacturers, and the data from different variants of the same manufacturer's meter can also differ. The project team formulated a comprehensive method and algorithm to mitigate this issue. By using this method, MDAS will collect data from different meters and store it in a structured database for future use.

d. **Finalization of Requirement Specification:**

The first step in this was the finalization of smart-meter standards. Even India has a common standard for smart meters, but each utility has its own custom requirements. It may be in the display parameter, tamper conditions, current and voltage ratings, etc. To avoid conflict with the utility's existing system, smart meters are customized to comply with the existing static meter features. After the customization, the meters underwent accuracy and tamper testing at utility testing labs.

The basic requirement of MDAS is that it can communicate with different varieties of meters. As per Indian Standard (IS), the meters are communicated via TCP/IP socket, and the application layer protocol follows IEC62056 (DLMS). So, the MDAS has to be designed in such a way that it can handle multiple-meter communication, and the system should have applications for encoding and decoding DLMS frames. And the other features like meter registration, deletion, update, storing profile data, handling MDM's requests, the facility for configuring the meter remotely, remote firmware update, etc. The MDAS also should have communication facilities that are connected through DCUs. For easy access to MDAS from anywhere, it was decided to have a web-based Graphical User Interphase (GUI), and the development platform was the Laravel PHP framework with MySQL as the database.

The MDAS named as Smart Electrical Energy Measurement and Analysis (SEEMA) and the modules of SEEMA were customized based on the requirements of KSEB. The entire project was divided into several modules, each assigned to different team members.

User Module

The user module includes user registration, user login, user listing, and user profile management. Within the login section, users encounter a login page and undergo an authentication process. This section is the most important and high-risk page, as the system's primary security depends on it. Initially, only the username, password, and role fields were used to submit and check authentication. Later, to enhance security, a captcha check was also implemented. For users without accounts, a signup option facilitates user registration.

To restrict unauthorized registrations and logins, there is an activation process in place for newly registered users. Only after undergoing activation, which is done by the responsible official, can a user log in and use their account. All the registered users are listed under the users list menu. From there, the responsible person can assign roles to each user. Here, administrators can allocate roles to individual users, each role dictating specific privileges regarding application menus.

These role-based privileges play a crucial role in safeguarding data and application menus against unauthorized access.

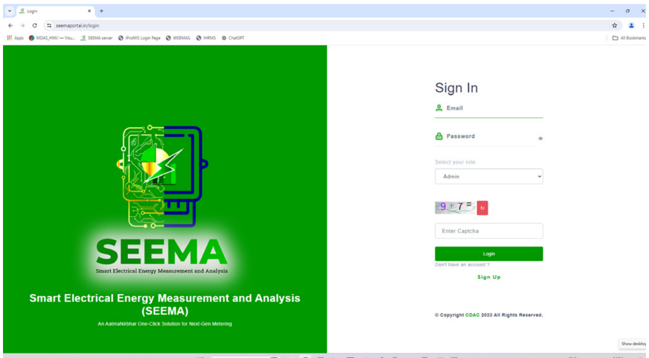


Fig-5: SEEMA login page

After successfully logging in, the user will reach the dashboard, where deployed meters are represented as icons on a map along with some data. If the user clicks on a meter icon, detailed information such as the meter UID, RTC (Real-Time Clock), kWh, and kVAh will be displayed.

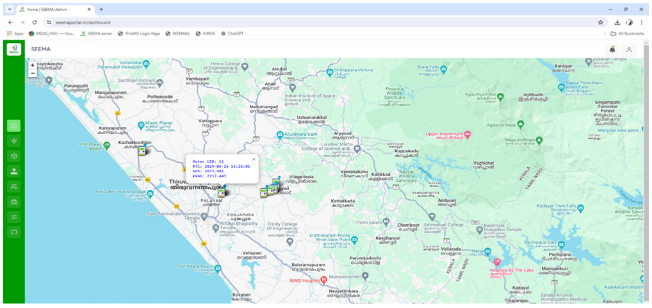


Fig-6: SEEMA dashboard

Meters Module

All meters used by the utility must be registered in the database before installation. For that purpose, there is a meter registration menu available. During registration, the association linked to each meter can also be added. The association includes client details like Meter Reader (MR), Utility Settings (US), Firmware Upgrade (FU), etc. as per IS, and their security mechanisms, properties, and keys.

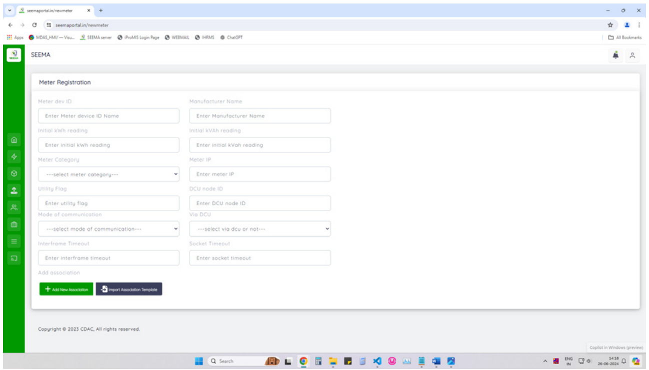


Fig-7: Meter registration page

All the registered meter details are listed under the meters list menu. From there, registered meter details can be edited, and the reconnection-disconnection (RC-DC) process can also be performed. Here is an option to configure profile tables after a successful firmware upgrade. All these are very crucial processes that require careful attention.

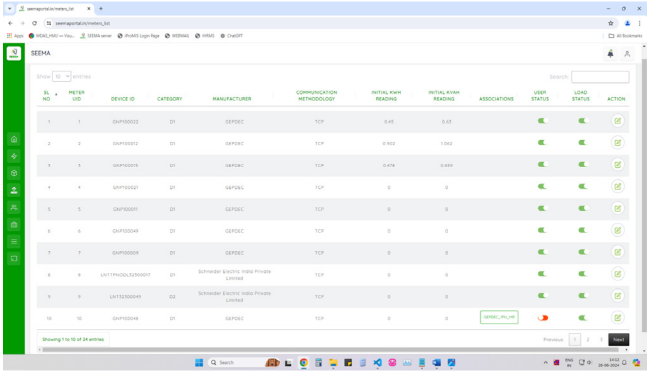


Fig-8: Meters list

Programmable Parameters Module:

Many programmable parameters, such as the real-time clock, demand integration period, profile capture period, tariff zones, etc., can be set to any desired value as per standard.

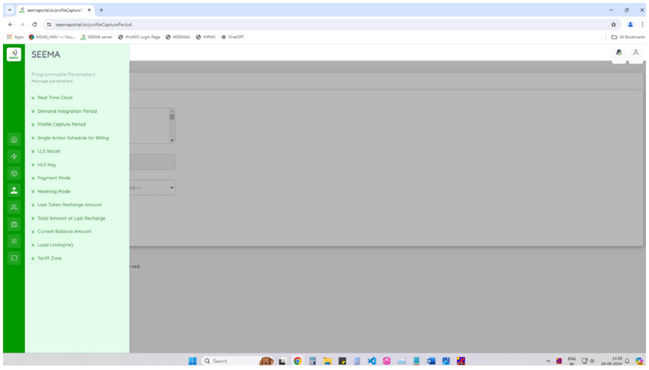


Fig-9: Programmable parameters submenu

These settings will reflect on the smart meter, causing it to behave according to the set values. These values can also be read and verified.

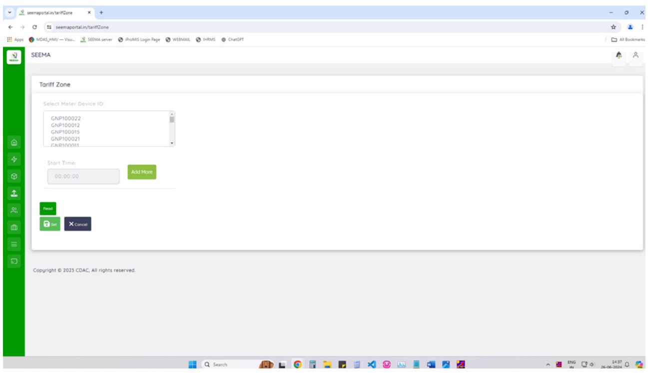


Fig-10: Tariff Zone Read and Set Form

Fig-10 shows the Tariff Zone get and set form, which allows users to view previously set tariff zones and to set new time periods for additional tariff zones.

Events Module

There are different events that may occur in a smart meter, such as current events, voltage events, power events, transaction events, non-roll-over events, control events, and other events. During the occurrence of each event, data like real-time details and other event-specific information are stored in a database table. These details can be viewed in the events menu on the SEEMA portal, represented in tabular form. All the event data from the meter is periodically downloaded by different services running in MDAS.

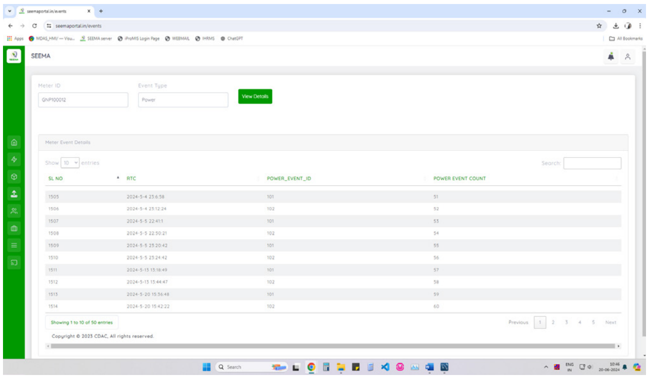


Fig-11: Power event table of a particular meter

Profiles Module

Different profiles, like block load, daily load, billing, instantaneous, etc., are downloaded periodically and stored in corresponding tables in the database. Tabular representations of block load, daily loads, nameplate details, and instantaneous parameters are also available in this menu for detailed analysis. There is an option to view these data in a graph plot as well. By analyzing these graphs and data, the utility can formulate various load management methods.

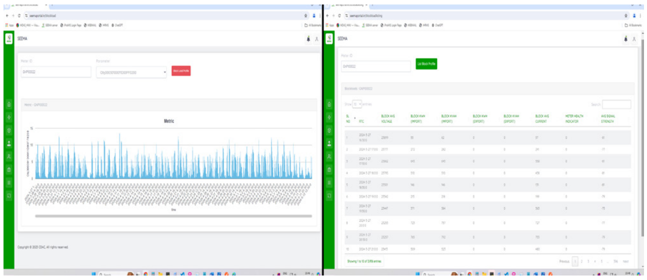


Fig-12: Graphical and Tabular Representation of Block Load Profile

e. Creating and Securing API for Billing Software Integration with MDAS:

API stands for Application Programming Interface. As the name says, it acts as an interface between two applications to communicate with each other and exchange data, features, and functionality. In the development of SEEMA software, API creation is one of the most challenging parts. As per the client's requirement, they need to access several pieces of data from SEEMA to integrate with their application. To secure this process, API authentication is required. API authentication is crucial for ensuring that only authorized users and applications can access and interact with the API. It plays a significant role in protecting sensitive data, preventing misuse, and maintaining the integrity and security of the application.

In SEEMA, JWT token authentication is used for the API authentication process. JSON Web Token (JWT) authentication is a method of securely transmitting information between parties as a JavaScript Object Notation (JSON) object. This information is digitally signed, so it can be verified and trusted. JWT token is used to authenticate and authorize users in web applications and APIs. JWTs consist of three components: a header, a payload, and a signature. They are used to encode claims, which can be used to verify the user's identity and ensure that they have the proper permissions.

According to the KSEB's requirements, the project team created different APIs for their billing software integration with MDAS.

Login API

API authentication process starts from Login API. Users need to sign in using a username and password. Then the authentication server verifies the credentials and issues a JSON Web Token (JWT) signed using a private key. The client will use the JWT to access protected resources by passing the JWT in the HTTP Authorization header. The resource server then verifies the authenticity of the token using the public key.

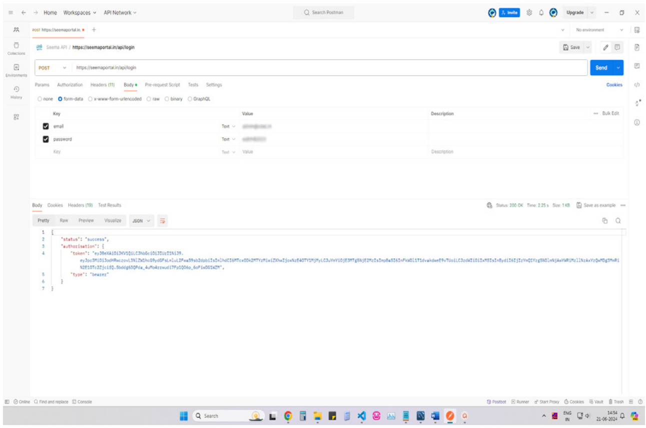


Fig-13: Login API response

Roles API

Different roles are assigned to each user by the utility company. These roles determine the privileges of the user within the application. To retrieve the list of roles, the Roles API is used. No data needs to be passed as a parameter, but the JWT token must be included in the HTTP authorization header.

Meter Details API

This API is used to integrate with MDM to retrieve the details of a specific meter. The unique ID of the meter should be passed as a parameter, and the JWT token should be included in the HTTP authorization header.

Meter ID API

To retrieve the unique IDs (UIDs) and device IDs of all registered meters, this API is used. The JWT token must be included in the HTTP header, and no parameters are required.

Billing API

This is the most essential API requirement from the KSEBL. They need to obtain the billing data for a specific meter over a particular period to create bills. The meter's unique ID (UID), along with the start and end dates and times, are provided as parameters. The JWT token must be included in the HTTP header to access the billing data. Using the retrieved data, KSEB can generate bills for each customer through their billing software.

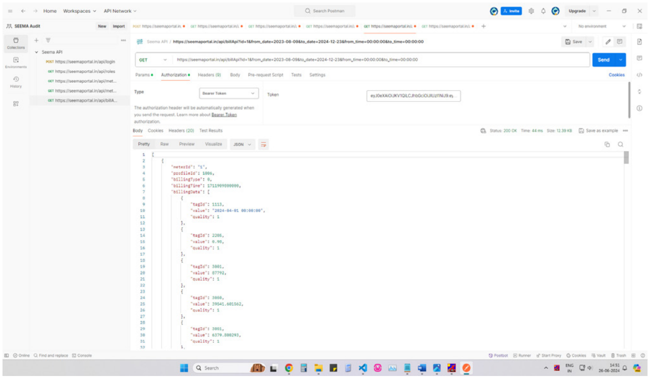


Fig-14: Billing API response

f. Applying cyber security and other security features in the MDAS.

The total process flow of MDAS development follows Secure Development Life Cycle. The steps of SDL are mentioned below.

- Security Requirement
- Architecture Design & Review
- Threat Modelling
- Implementation & Code Review
- Security & Penetration Testing
- Deployment
- Maintenance & Upgrade

This is done with the support of cyber security team of CDAC. The developed MDAS UI is undergone cyber security testing. After multiple iterations and modifications, the system is now compliance with OWASP Top 10 2017 standard.

प्रगत संगणन विकास केंद्र
CENTRE FOR DEVELOPMENT OF ADVANCED COMPUTING
(A Scientific Society of Ministry of Communications and Information Technology, Government of India)
Plot No. 6 & 7, Hardware Park, Sy No. 1/1, Srisailam Highway, PahadiShareef Via Keshavagiri (Post), Hyderabad – 501510
Email: cswan@cdac.in **Website:** www.cdac.in
Cert-In Empanelled Organization

ID # CDAC/22/ISS-WA-0393/06/24/2121

Audit Certificate

Application Name	Website of Seema Portal
Test URL	https://seemaportal.in/
Test dates	**Stage 1:** 14.09.2023 to 29.09.2023 **Final Stage:** 11.06.2024
Conclusion	The Web Application has been undergone security testing as per OWASP and SANS Standard. Website may be considered safe for hosting and deployment with below recommendations followed.
Production URL	https://www.seemaportal.in

Recommendations

1. Website may be considered safe for hosting with read only permissions and authenticated by trusted users.
2. The production server should have operating system and web server hardening done and ensure security patches regularly.
3. Entire website should be continued to host over valid HTTPS.
4. Audit Trails, Sanitized logging and regular monitoring of the logs is recommended which are to be maintained for at least one year.

Note:

- The certification is valid till no changes are done on the application's dynamic content or one year from the date of issue whichever is earlier.
- The Certificate is generated based on the enclosed report with reference number, CDAC/22/ISS-WA-RP-0393/06/24/2121.
- The Production URL is mentioned for reference purpose only. No testing has been carried out on Production URL.

Date of Issue: 21.06.2024

for Centre for development of Advanced Computing, Hyderabad

This certificate can be verified at: https://cdac.in/verify-sth

Fig-15: Cyber Security Certificate

4 CONCLUSIONS

The indigenous development and implementation of the Advanced Metering Infrastructure (AMI) is a challenging process. It requires patience, expertise in multiple domains, and the coordination and cooperation of different entities like utilities, consumers, network service providers, etc. So, it is better to do a smart meter rollout in a phased manner instead of a mass rollout. Each phase should start with a small pilot, because since the AMI is a multi-domain expertise-required activity, the challenges may vary from time to time and region to region. The deployment is for long-term sustainability; it is better to have more credible indigenous components to avoid dependency for updates and future upgrades.

5 ACKNOWLEDGEMENTS

The Authors are thankful to the management of CDAC, KSEBL & MeitY for providing an opportunity to carry out the work and to publish this paper.

6 REFERENCES

[1] Sreedevi V S, Prakash Prasannan, Jiju K, Indu Lekshmi J I "Development of Indigenous Smart Energy Meter adhering Indian Standards for Smart Grid",2020 IEEE international Conference on Power Electronics, Smart Grid and Renewable Energy, Kerala, India

[2] Thanh Son Huynh, Duc Tung Tran, Quoc Hung Vu, and Luong Anh Tuan Nguyen "Design and Implementation of Web Application Based on MVC Laravel Architecture", EJECE, European Journal of Electrical Engineering and Computer Science ISSN: 2736-5751DOI

[3] Salman Ahmed, Qamar Mahmood "An authentication-based scheme for applications using JSON web token", 2019 22nd International Multitopic Conference (INMIC).

BIO-DATA

JIJU K
Centre For Development of Advanced Computing, Trivandrum

Date of Birth:	30-05-1985
Qualification:	Bachelor of Technology
Designation:	Scientist E
Present Organization:	Centre For Development of Advanced Computing, Trivandrum
Field of Expertise:	Electronic and embedded system design, software development, measurement monitoring and communication
Mobile:	+91 98958 22667
Email:	jijuk@cdac.in

BRIEF PROFILE

Jiju K is an Applied Electronics and Instrumentation Engineer with over 17 years of experience. He is currently employed in the Power Electronics Group (PEG) at the Centre for Development of Advanced Computing (CDAC) in Trivandrum. His expertise includes Smart Metering (SM), Advanced Metering Infrastructure (AMI), Embedded System Design, Power Electronics, Renewable Energy, and biomedical applications.

He has been involved in the entire product lifecycle—from conceptualization through research, proto model development, engineering, documentation, and supporting manufacturing by industries in India. His contributions to research and development have earned him several awards.

He has published numerous papers and journals and holds multiple patents and copyrights. Jiju K is an active member of the technical committee of the Bureau of Indian Standards (BIS) for SM and AMI standards. He is also a member of the technical committee of the Public Sector Restructuring and Internal Audit Board and Kerala State Electronics Development Corporation Ltd. for a Smart Meter manufacturing project. Additionally, he is engaged in technical committees of the Energy Management Centre and the Kerala Development and Innovation Strategic Council.

BIO-DATA

NEETHU K V
Centre For Development of Advanced Computing, Trivandrum

Date of Birth:	12-07-1994
Qualification:	Bachelor of Technology
Designation:	Project Associate
Present Organization:	Centre for Development of Advanced Computing, Thiruvananthapuram
Field of Expertise:	Software development, Back-end Development, Front-end Integration, PHP Development, Laravel Framework Proficiency, Application Programming Interface (API) Management, Practical Proficiency in HTML/CSS, C Programming
Mobile:	+91 95262 68216
Email:	neethu.kv@cdac.in

BRIEF PROFILE

Neethu K V is a skilled Computer Science Engineer with over two years of experience, currently working at the Centre for Development of Advanced Computing (CDAC) in Trivandrum. She specializes in software development, particularly in PHP, MySQL, and frameworks like Laravel and CodeIgniter.

At CDAC, she played a key role in developing and implementing the Advanced Metering Infrastructure (AMI), including meter data acquisition software and client software integration through API management. She also helped organize a workshop on the “Development of DLMS/COSEM Testing Tool for Smart Energy Meters” at CPRI, Bengaluru. Additionally, she holds a copyright for the “Firmware Upgrade Service” in the SEEMA (Smart Electrical Energy Measurement and Analysis) Web Application.

IMPACT OF BLOCKCHAIN TECHNOLOGY IN POWER SECTOR VALUE CHAIN IN INDIA

Aftab Alam
Damodar Valley Corporation

ABSTRACT

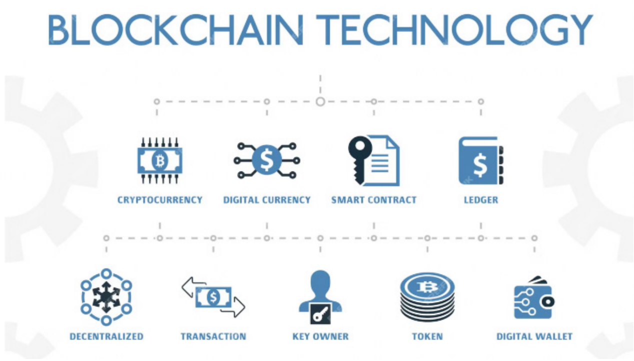
Blockchain is an emerging technology that allows for the decentralized sharing of transactional data across a vast peer-to-peer network, allowing non-trusting users to interact verifiably and without the need for an intermediary. In this paper, we go over the fundamentals of blockchain technology as well as its types, applications, and operation. The security, privacy, and consensus procedures of this technology are likewise significant and cause for concern, as they lie behind this inventive technique. This research highlights how efficient power trading, carbon trading, renewable energy certificates (RECs) with the implementation of Blockchain technology.

Hence, this research will show the impact of blockchain technology in power sector value chain in India.

INTRODUCTION

Blockchain is an important concept of Bitcoin. It was proposed by Satoshi Nakamoto in "Bitcoin: A Peer-to-Peer Electronic Cash system" in 2008. A blockchain is a distributed ledger that duplicates and distributes transactions across the network of computers participating in the blockchain. Blockchain technology is a structure that stores transactional records, also known as the block, of the public in several databases, known as the "chain" in a network connected through peer-to-peer nodes. Typically, this storage is referred to as a 'digital ledger. 'Every transaction in this ledger is authorized by the digital signature of the owner, which authenticates the transaction and safeguards it from tampering. Hence, Blockchain is a method of recording information that makes it impossible or difficult for the system to be changed, hacked, or manipulated.

Blockchains or distributed ledgers are an emerging technology that has drawn interest from energy supply firms, start-ups, technology developers, financial institutions, national governments. Blockchains promise transparent, tamper-proof, and secure systems that can enable business solutions, especially when combine with smart contracts.



Blockchain originates from the core support technology of the digital cryptocurrency system represented by Bitcoin. The essence is a decentralized database based on a distributed network. It has also the characteristics of autonomy, openness, security, anonymity, etc. In recent years, it has become a hot topic of research and discussion in united nations and many governments. The integration of blockchain technology with various industry is accelerating. The energy industry as a traditional heavy industry, is confronted with new challenges caused by the development of distributed energy and information technology. Therefore, the blockchain also has a deep and practical application in the field of Power sector.

Core technology of the blockchain are as follows:

a) Data storage structure

A blockchain is a series of blocks that stored complete transaction records. All the data are stored in blocks permanently and all these blocks are sequentially connected in chronological order.

b) Distributed ledger

Distributed ledger technology (DLT) is based on decentralized mechanism in which data sharing, synchronization and replication in a network of multiple network nodes, multiple physical addresses can be performed. As unlike in conventional or old distributed data storage systems which was generally controlled by a central node.

c) Network protocol

In blockchain technology, network protocols generally approve P2P protocol to ensure that each individual in the same network is equal to each other without any special nodes and it is decentralized in nature. Due to its decentralized in nature, it is tampered proof and resistant to attacks.

d) Encryption algorithm

Blockchain technology which makes extensive use of modern technology of highly secured information and cryptography which includes symmetric encryption, hash algorithms, asymmetric encryption, digital signatures, digital certificates, etc. It utilises all these encryption and algorithms so that the privacy protection ability is to be achieved to full extent.

e) Consensus mechanism

Consensus mechanism adopts consensus algorithm in which each node in the network initiates a proposal and how other nodes reach agreement on this proposal. So, consensus mechanism decides how others untrusted nodes in the distributed network come to an agreement to attach a new block in the network.

Types of consensus algorithms are as follows: -

- Proof of Work (PoW)

PoW consensus mechanism uses permission-less or public blockchain networks. In PoW algorithm, miner compiles all the records of transactions from different nodes and verify them whether it is from a valid node or not. Each and every miner builds the block of transactions that they receive, so all the miners will have a blockchain ledger replica with them. Therefore, a specific consensus algorithm in which a miner needs to solve a puzzle to mine a block, is known as PoW consensus algorithm.

- Proof of stake (PoS)

One of the demerits of PoW is that it requires high computational power. In PoS consensus algorithm, a node is chosen for the new block conception based on its stake, i.e. it will have high coinage. So, one can understand that larger the coin owns by a node, the easier it will understand and solve the riddle. This in turn will be led to decrease the computational power and therefore, reduces the power consumption.

- Proof of capacity (PoC)

In PoW, multiple nodes simultaneously decipher the computational riddles intensively to mine a block. In this process of computational puzzles solving led to high consumption of electrical energy. Actually, what happen in PoW algorithm, the miner keeps on changing the value which will satisfy the difficulty level set by the network. In PoC, all the participating nodes have large space to store high number of solutions that has better probability to mine a block. So, energy consumption is reduced considerably in PoC due to high disk space to store solutions.

- Proof of authority (PoA)

PoA is modified version of PoS algorithm. PoA requires special permission to make some changes in the blockchain. Example, one or more members have special key which is required to generate all the blocks.

f) Smart contract

Smart contract is a computer-based protocol which is designed to initiate, validate and execute a contract in an informational manner. It accepts the transactions or allow the trusted transactions without the intermediaries/third party.

Unlike in a traditional contract, there is an agreement between two or more parties to do or not to do something in exchange for something and also parties have to trust each other and follow the agreement rules and regulations & fulfil their obligations.

As in case of smart contract, they have to agree or disagree with each other to do or not to do, but they need no longer trust each other because the smart contract is not only defined by the algorithms but also enforced by this encrypted algorithm which is executed automatically and are not contrary to each other.

The initiation and execution of smart contracts follow the steps as –

- Building of smart contracts: All the participants in the blockchain participate for the conception of the smart contracts.
- Storage of smart contracts: smart contracts stretch out to each node through P2P network and stored in the blockchain.
- Execution of smart contract: smart contract goes through the status of the automation regularly to validate the transactions that has to be as per the notified conditions and automatically execute and inform the network users following consensus algorithms.

Blockchains can be classified into three major categories, each with different characteristics and benefits. The architecture of a blockchain is heavily dependent on the access rights provided to the network participants. The three different types of blockchains are as follows: -

a. Public blockchains

Public blockchains also referred as permissionless blockchains. In the public blockchains, all the people in the network have the access to join. Bitcoin and Ethereum are public blockchains. Public blockchains allow participants of random unknown network without initial check of trustworthiness. These permissionless blockchains historically rely on Proof of Work (PoW) consensus mechanism, in which every miner can validate new data blocks.

b. Private blockchains

Private blockchains are kind of permissioned blockchains in which only restricted users are allowed to have access to the blockchain network. This private blockchains work on Proof of Authority mechanism (PoA) in which single node generates new data blocks.

c. Consortium blockchains

In a consortium blockchain, there is compromise between public and private blockchain in which only verified participants can validate blocks. Multiple corporations and companies form alliance or come together and form a consortium. In this type of blockchain, all the members which form consortium can read the distributed ledger, but writing or editing in the ledger is only permitted to an authorized node.

Table showing blockchain characteristics:

	Public	Private	Consortium
Access	Permissionless	Permissioned	Shared Perm.
Personal information	Pseudonymity	Known	Known
Device authentication	Not required	Required	Conditional
Consensus mechanism	PoW, PoS	PoS, PoA, PBFT	PoW,PoS, PoA
Security	Decentralized control	Single point of failure	Various
Transaction speed	Low (PoW)	Rather High	Higher than public
Energy consumption	High (PoW	Rather Low	Rather low
System costs	High	Rather low	Medium to low
Individual costs	Low	Rather high	Various

Blockchain technology as a current, trendy, and promising phenomenon brings crucial changes. This dissertation paper deals with the utilisation of blockchain in the energy sector. The implementation of this technology in the energy sector is providing to be beneficial.

We can summarize the current energy trends and goals into “4D”. This 4D stands for decentralization, decarbonization, diversification, and digitalization.

The basic process with blockchains is transacted as follows. In the beginning the user initiate a new transaction to be included in the blockchain. The created transaction is distributed within the network for authentication and audit. The moment this type of transaction is authorized by the nodes based on pre-determined and well-established set of rules and frameworks, this job can be transferred to the chain as a new block. So all this transaction history are stored in a separate nodes to ensure the safety of the entire system.

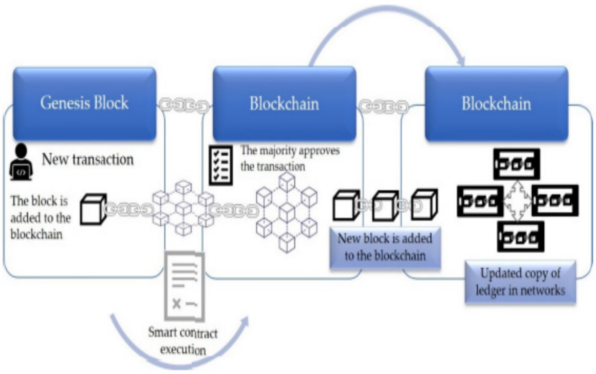


Figure showing basic steps in Blockchains.

REVIEW OF LITERATURE

Next, we focus on blockchain solutions for the energy industry and inform the state of the art by thoroughly reviewing the literature and current business cases. To our knowledge, energy systems are undergoing rapid changes to accommodate the increasing volumes of embedded renewable generation, such as solar, wind, hydro power including pump storage, biomass generation, geothermal, tidal energy. Renewable energy resources (RES) have undergone huge development in recent years, enabled by privatisation, unbundling of energy sector, and boosted by financial and energy policy initiatives.

Blockchain has a lot of potential which can redefine the digital trust and eliminate intermediaries that form a new management paradigm that can alter traditional ways. Blockchain has currently seen growing recognition as an innovative solution to address not only India's but global challenges of climate change mitigation and lack of electricity. Blockchain permit create smart contract, microgrid applications, ancillary service, energy storage systems, smart charging scheme of electric vehicles and demand side management.

Energy sector policy makers and utility companies have asserted that blockchains could possibly offer solutions to challenges in the power industry, as it has potential to improve the efficiency of current energy practices and processes, can accelerate the development of IoT platforms and digital applications and provide innovation in peer-to-peer energy trading and decentralised generation. In addition, they report that blockchain technologies have the potential to significantly improve current practices of generation, transmission, and distribution companies by improving internal processes, customer services and costs.

Blockchain technologies can be applied to a variety of use cases related to the operations and business processes of power companies. Existing literature explains the potential applications and aspects of business models that might be affected, as below: -

- Billing
- Sales and marketing
- Trading and markets
- Automation
- Smart grid applications
- Grid management
- Security and identity management
- Sharing of resources
- Competition
- Transparency
- Green certificates and carbon trading
- Electric e-mobility

A conventional and centralized electricity markets is made up of a close or monopolized integration where the generators have control of the energy production, supplying their energy to the transmission utilities to further transmit power to the distributors who are responsible for supplying the energy to the end-user as shown in below figure (1). Within this process, all the economic transactions are handled entirely by a banking system. Over the past decades, this methodology has been operational. However, it has not been modernised in response to the new challenges such as new users or small prosumers who want to enter the electricity market.

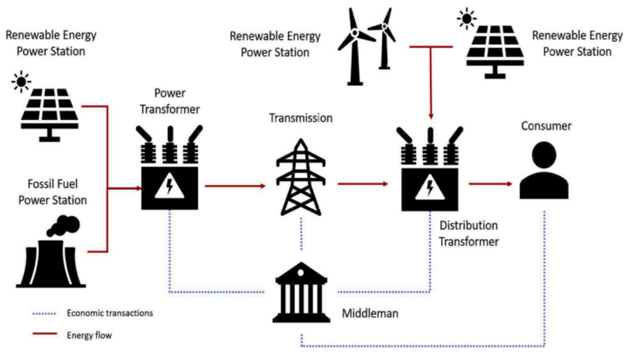
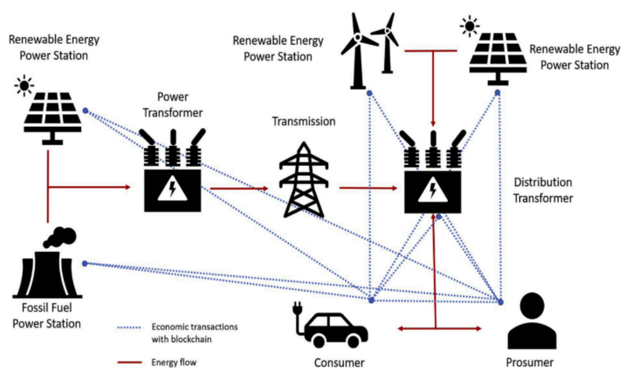


Figure (1) showing present scenario conventional electricity market.

A new approach is proposed in below figure (2) that responds to the decentralization of the new model. This new approach is expected to be made up of all entities that participate in the current model. However, the first change is that it gives way to new members to actively participate like prosumers and develop smart grids, micro grids, smart contracts, smart purchases, and energy for renewable energy and electric mobility. One of the significant changes is that economic transactions through banking entities are expected to be replaced by cryptocurrency-based transactions through blockchain, giving the freedom to make exchanges and smart contracts.

The activities of entire power sector value chain i.e., generation, transmission, and distribution will carry out their energy transactions of purchase and sale of energy actively through blockchain integrated into a system of smart contracts, where a constant supply of electricity and banking transactions will be available. However, it also provides a space for the negotiation of prosumers who want to sell their surplus energy in a spot market, including neighbours, users of electric vehicles, or the local distribution company. This model is intended to be fully inclusive for each of the participants.



This figure (2) showing Propose Approach using Blockchain for the electricity market.

As this blockchain technology has attracted considerable attention in the energy sector, where blockchain has benefacted to the emerging concept known as Internet of Energy (IoE) which allows transparent, decentralized energy prosumer networks. This blockchain technology has great applications which have been manifested in several sector of this power industry such as electric e-mobility, energy democratization, P2P energy trading platforms, demand response mechanisms, smart metering, smart grid applications and grid management, automation of green certificates issuance and carbon trading, etc. In a nutshell, it has three main applications in power industry which are as follows: -

- Decentralized energy trading and energy supply
- Effective, automated control of energy and storage flows through smart contracts.
- Secure records of all the business activities in the power industry.

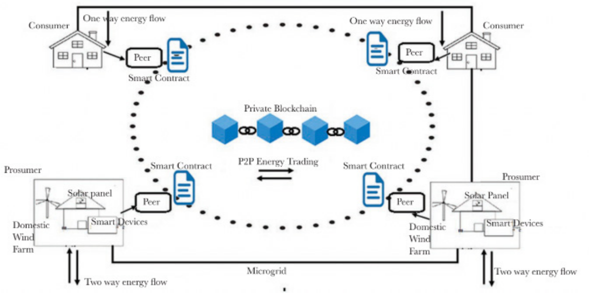
The list of areas where blockchain technology has been manifested as its application as: -

- Smart metering, billing, and security
- Decentralised energy trading
- Cryptocurrencies, energy tokens and in-vestments
- Green certificates and carbon trading
- Smart grid management
- IoT, automation and asset management
- Electric transportation
- Circular economy

Let see how blockchain technology will help in different of power sector one by one in brief: -

a. Energy trading – P2P platforms and energy democratization:

As it is having been mentioned earlier that decentralization is one of the important features of blockchain technology. This decentralization can facilitate in efficient trading, and storage activities particularly in case of solar generation where energy prosumers are more active in the energy market, by forming local energy communities so called crowds. So, this crowd energy idea seems to be very helpful in case of direct peer to peer energy transactions, traceability and provenance of energy, and smart contracts and so on. It has helped energy companies in reducing transaction costs and trading volumes significantly, which draws attention of small sized prosumers to help to involve in the energy markets. Prosumers oriented energy markets are more favourable for the flexibility of the grid. So, such enhancement and improvement cause well enhanced competition and known as energy democratization.



b. Cryptocurrencies and energy tokens:

The mainstream of initial know-how about blockchain links distributed ledger technology with the cryptocurrencies, such as Bitcoin. Hence, Blockchain technology is one of the most important acknowledged applications, these cryptocurrencies are new emerging concept in today's era. They act as an incentive for low carbon energy generation, transmission, distribution, trading, and utilisation of energy; hence cryptocurrencies can serve as a reward for sustainable practices in the power industry and therefore, can enhance clean energy investments. In current scenario, many companies are applying cryptocurrencies to attract new investors and will act as additional financing options, for example, Initial Coin Offering (ICO). Currently, there are several examples of inventing new cryptocurrencies and energy tokens with an objective of fostering IoT, sustainable, affordable, security (i.e. energy trilogy), and clean energy investments such as Solar coin, Eco coin, Evergreen coin, etc.

c. Enabling Iot and asset management:

Fast growing and increasing number of smart devices, such as smart meter, smart grid, etc. which bring numerous benefits to all the sectors of power sector value chain. Innovative digital support can help to optimise the performance of power sector and data & resource analytics can help to reduce the input costs.

IoT solutions are associated with hardware and software smart automation technologies, such as smart sensors, smart meters, cloud connectivity, etc. which help to reduce the maintenance and management costs for better output and productivity. Therefore, it is very important to say that blockchain technology really support these IoT based solutions to improve grid stability, & its management, real-time coordination and maintaining the energy supply and demand.

d. Smart metering and smart grid management:

Smart meters and smart contracts have been manifested as numerous benefits for the power sectors while administered through blockchain technology. Blockchain help to automate the billing procedures through smart meters in more effectively and efficiently. It also provides transparent and tracks the usability of energy particularly, clean energy tracking, which enhances the competition in the energy markets and causes social awareness about the environmental aspects of energy.

Other aspects of blockchain technology which concerns on hazardous incidents such as power outage and energy wastage can be tackled by utilisation of smart contracts while during the formation of smart grid.

So, this block chain technology helps to improve opportunity with the help of automation and decentralized grid management through smart grids.

Green certificates and carbon trading – automation:

Green certificates, also known as REC (Renewable energy certificates) which are traded currently through IEX platform for those companies' creating pollution from conventional sources of generation of electricity, like thermal, gas, diesel, lignite, etc. With the evolution of blockchain technology, green certificates and carbon can be traded. In-fact, it is very useful for small scale energy producers, which are excluded from this carbon trading procedures.

Blockchains can initiate automatic issuance of REC and generate transparent markets and reduce the transaction costs by preventing double spending.

e. Electric transportation:

EVs are nowadays very prominently seen in the transport industry. As we know that currently 11-12% carbon emissions are contributed by transport industry. So electric vehicle or electric e-mobility is most important solution to mitigate adverse impacts of global climate change and it will address this problem in more environmentally friendly. The decentralized nature of current scenario transport industry makes blockchain more favourable. EV charging and shared charging infrastructure are most important key areas where blockchain utilisation is most. Blockchains help EV owners about the entire power source selection and charging prices more transparently. Also, blockchain wallets can be implemented for payment methods at charging stations. Due to blockchains unique capability of delivering one kind of validation and communication platform, it is very suitable for cross border mobility. Blockchains facilitate market-oriented mechanism for management optimization and EV charging coordination. Charging station operators will optimise the easiness of use of electric vehicles owners with the help of blockchain technology, and infrastructure management, security level of the system along with the promotion of the shared energy concept. So blockchain in a way is very useful for transport industry in fuel usage reduction significantly and thereby reducing GHG emissions.

g) Circular economy:

Blockchain helps to promote circular economy practices, which include reducing materials and wastes, reusing of products and recycling. So, this transparency and traceability quality helps to reduce the operating costs and wastage are minimised. It also helps to incentivize new behaviours by verifying social sustainability claims, tokenizing sustainable purchases, and creating new systems for pricing and trading. This feature of transparency nature of the blockchain assists in achieving sustainable practices more and prevent contractors in violation of human rights, child labour, inhuman working conditions, corruption, etc.

Therefore, the concept of the circular economy is considered as a social tool for coordination, by its ability to join and coordinate various distributed databases, where these all could be updated instantaneously and available to all network agencies or participants. This can also change the concept of value creation and value appropriation by creating a decentralized convention of value creation and circulation. So, this fundamental concept of distributed ledger technology or blockchain technology helps to achieve the objective of circular economy principles through its attributes of decentralization, distributiveness, safety or tamper-protection, in addition to these all, it also favours smart contracts and tokenization.

NEED OF THE RESEARCH

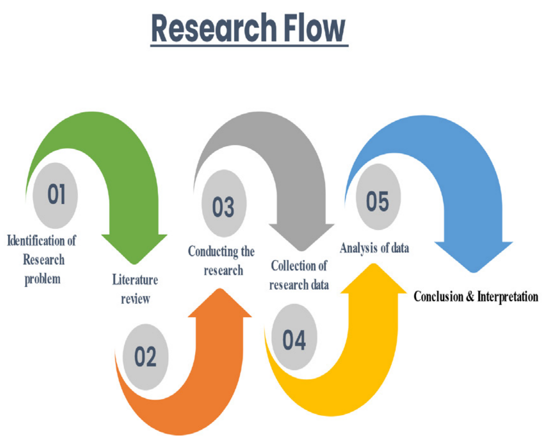
Power is an important part of country's infrastructure that determines its economic development. The rate of increase in power demand is generally higher than the rate of increase in GDP. According to studies, the power supply must grow at a rate of around 12% per year to achieve an annual GDP growth rate of 8%.

But currently Indian power sector is facing with some highlighted issues as follows: -

- Poor performance of SEBs as of now total regulatory assets (RA) as per Government data is Rs 88,720 crore as of June 30,2023. However, many believe that this may just be the tip of the iceberg as the government data logs only the amount recognised by state regulators, and not the claimed amount by Discoms. The actual amount could be over Rs 1 lakh crore.

- Inefficiency of Regulators in formulating policy and framework due to lack of transparency of all the activities i.e., technical, operational, financial, etc. carried out in the entire power sector value chain.

RESEARCH DESIGN



Type of research: The proposed research is descriptive research. The objective of this descriptive which is qualitative in nature helps to show the impact of Blockchain technology in Power sector value chain in India.

Research tool: A questionnaire developed for collecting data on the research problem from various research papers, journals, etc.

The questionnaire then addresses the following: -

- High Regulatory Assets
- Inefficiency of Policy framework
- Cyber security threat
- Promoting sustainable activities like investment in RESs, Trading of RECs and carbon credits, EV charging, etc.
- Promotion of electricity wholesale markets and grid operation.

Data Collection: Qualitative data from various research papers, journals, conferences and case studies used for the purpose of study.

RESULTS AND DISCUSSION

There are many areas and purposes within power sector where blockchain technology is currently being applied. Some, for instances incorporate blockchain for P2P energy trading for eliminating intermediaries to reduce cost, while others use it to set out monetise environmental resources and conservation by promoting trading of RECs and carbon credits. Some of used cases where blockchain technology are currently incorporated in various companies are as follows: -

Company	Blockchain application	Operational where and since
Alliander	P2P energy trading	Netherland since 2017
Bankymoon	Prepaid enabled smart meters to collect payment	South Africa since 2015
Conjoule	P2P power trading	Germany since 2016
Greeneum	P2P energy trading platform that incentivise renewable based generation through green tokens	UK, Israel, Germany, USA since mid 2018
Sun Exchange	P2P funding of solar PV installations	South Africa since 2015
WePower	P2P trading of renewable energy and fund raising for renewable projects	Lithuania and Spain in 2018
SolarCoin Foundation	Solar energy installations, it awards crypto-coins to registered and validated solar energy producers. 1 coin equals 1MWh of solar energy	Used by European countries since 2014
Electron	Automated energy supplier switching platform with an objective of P2P energy trading and grid balancing	UK since 2016

List of summaries of blockchain based projects and start-ups in the electricity sector: -

#	Project or company	Type	Country	Platform	Consensus mechanism	Application	Year Founded
1	Bankymoon	Startup	South Africa	Ethereum	PoW	Metering and billing	2015
2	CarbonX	Startup	Canada	Ethereum	PoW	Trading of RECs and carbon credits	2017
3	DAO IPCI	Private project (non-profit)	Russia	Ethereum	PoW	Trading of RECs and carbon credits	2016
4	Electron	Startup	UK	EWC	PoW, PoAu	Grid operation	2015
5	Energy Blockchain Labs	Company	China	Hyperledger	PBFT	Trading of RECs and carbon credits	2016
6	EW Origin	DApp running on EWC	Germany	EWC	PoAu	Trading of RECs and carbon credits	2018
7	Fujitsu	Patent by company and utility	Japan	NA	NA	Grid operation	2018
8	Green Energy Wallet	Startup	Germany	NA	NA	Grid operation	2017
9	Grid Singulaity	Startup	Austria	EWC	PoAu	P2P energy trading	2016
10	Grid+	Startup	US	Ethereum	PoW	Retail markets	2017
11	ImpactPPA	Startup	US	Ethereum	PoW	Investment in RESs	2017
12	LO3 Energy	Startup	US	Tendermint	PBFT	P2P energy trading	2016
13	Lo3&eMotorWerks	Pilot by companies	US	Tendermint	PBFT	P2P energy trading	2018
14	Local-e	Startup	US	Ethereum	PoW	Investment in RESs	2017
15	Ponton (EnerChain)	Pilot by a company	Germany	Tendermint	PBFT	Wholesale markets	May 2016 -Mar 2018
16	Ponton (GridChain)	Pilot by a company	Germany	Tendermint	PBFT	Grid operation	2016
17	Ponton (New 4.0)	Pilot by a company	Germany	Tendermint	PBFT	Wholesale markets	2017
18	Poseidon	Startup	Switzerland	Stellar [160]	Federated Byzantine Agreement	Trading of RECs and carbon credits	2017
19	Power Ledger	Startup	Australia	Ethereum	PoAu	P2P energy trading, Grid operation, Trading of RECs and carbon credits	2016
20	Prosume	Startup	Switzerland	NA	NA	P2P energy trading, Grid operation, Investment in RESs, Metering and billing	2016
21	Pylon	Startup	Spain	Pylon Coin CORE	Proof of Capacity	Metering and billing	2017
22	Quertierstrom	Pilot project	Switzerland	Tendermint	PBFT	P2P energy trading	Jan 2019 – Jan 2020
23	Restart Energy	Company	Romania	NA	NA	Retail Markets, P2P energy trading	2015
24	Share&Charge	Startup	Germany	Ethereum/ EWC	PoW/ PoAu	EV charging	2016
25	Share&Charge and eMotorWerks	Startup	US	Ethereum/ EWC	PoW/ PoAu	EV charging	2017
26	Share&Charge and Oxygen Initiative	Startup	US	Ethereum/ EWC	PoW/ PoAu	EV charging	2017
27	SolarCoin	Startup	Andorra	SolarCoin (LiteCoin & Vericoin-based)	Proof of Stake Time	Investment in RESs	2014
28	SP group	Platform from utility	Singapore	EWC	PoAu	Trading of RECs and carbon credits	2018
29	Spectral (Jouliette)	Startup	Netherlands	MultiChain	PoW	P2P energy trading	2017
30	SunContract	Startup	Slovenia	NA	NA	P2P energy trading	2016
31	Sun Exchange	Startup	South Africa	Ethereum	PoW	Investment in RESs	2015
32	TenneT	Pilot by utility	Netherlands	Hyperledger	PBFT	Grid operation	2017
33	ToBlockChain	Startup	Netherlands	NA	NA	P2P energy trading	2016
34	WePower	Startup	Gibraltar	Ethereum	PoW	Investment in RESs	2017

Therefore, blockchain technology has wide range of application and are effective and efficient. It has been incorporated by many countries in the field of power sector in carrying out activities as show in above tables like P2P energy trading, wholesale markets, metering, billing and retails markets, trading of RECs and carbon credits, EV charging, Enhancing cyber security, investment in RESs, Grid operation and management. Research studies and efforts put up by many companies in various countries regarding blockchain incorporation showed promising potential in the field of electricity sector and the value that it has provided gives a competitive edge for many companies. It was found that blockchain technology could generate several advantages like –

- Better grid operation and management
- Decentralized electricity markets
- Increasing the role of small prosumers
- Smart contracts
- Enhancement of transparency
- Security from cyber-attacks and malicious behaviour
- Building of trust between participants
- Elimination of intermediaries to minimize cost
- Better participation of Distributed Energy Resources (DERs) in the electricity markets

The main challenges that blockchain technology will going to face regarding its positioning within power sector are as follows: -

- Infrastructure problems
- Regulation
- Scalability
- Economical challenge
- Technology and training

CONCLUSIONS

This paper presents an overview of the basic elements of blockchain technology and its application and implementation by many industries and institution in various fields, but here we are concerned about its impact in electricity sector domain. Blockchain technology has gained quite tremendous momentum in recent years due to a lot of investment is being carried out by many industries and institutions.

Various research studies and pilot projects by institutions and industries has clearly indicate that this blockchain technology can be incorporated in power sector in India due to its various applications and benefits in various domains of electricity sector.

In summary, looking at the trends within the power sector in India, we suggest that the impacts expected from blockchain technology have already begun to manifest and seems to be grounded, although large number of research is further going on to find out the solution in eliminating the main barriers of scalability issues and large-scale adoption of blockchain technology.

BIBLIOGRAPHY

- Almero De Villers and Paul Cuffe, (Member, IEEE), “A Three-Tier Framework for understanding disruption Trajectories for Blockchain in the Electricity Industry” IEEE Access, publication on 26 March 2020.
- M. Aybar-Mejía, D. Rosario-Weeks, D. Mariano-Hern´andez, M. Domínguez-Garabitos, “An approach for applying blockchain technology in centralized electricity markets”: The Electricity Journal 34 (2021) 106918, www.elsevier.com/locate/tej
- Pornpit Wongthongtham, Daniel Marrable, Bilal Abu-Salih, Xin Liu, Greg Morrison, “Blockchain-enabled Peer-to-Peer energy trading”, contents list available at ScienceDirect Computers and Electrical Engineering 94 (2021) 107299, www.elsevier.com/locate/compeleceng
- Anna Borkovcová, Miloslava Cˇerná and Marcela Sokolová, “Blockchain in the Energy Sector—Systematic Review”, Sustainability 2022, 14, 14793, https://doi.org/10.3390/su142214793
- Merlinda Andoni, Valentin Robu, David Flynn, Simone Abram, Dale Geach, David Jenkins, Peter McCallum, Andrew Peacock, “Blockchain technology in the energy sector: A systematic review of challenges and opportunities”, Renewable and Sustainable Energy Reviews 100 (2019) 143–174, www.elsevier.com/locate/rser
- Morsy Nour, Jose Pablo Chaves Avila, and Alvaro Sanchez Miralles, ICAI School of Engineering, Institute for Research in Technology, Comillas Pontifificial University, 28015 Madrid, Spain, “Review of Blockchain Potential Applications in the Electricity Sector and Challenges for Large Scale Adoption”, IEEE Access- Received March 16, 2022, accepted April 23, 2022, date of publication April 29, 2022, date of current version May 6, 2022, Digital Object Identifier 10.1109/ACCESS.2022.3171227
- Yu-Chung Tsao, Vo-Van Thanh, Qiuwei Wu, “Sustainable microgrid design considering blockchain technology for real time price-based demand response programs”, Electrical Power and Energy Systems 125 (2021) 106418, Contents lists available at ScienceDirect Electrical Power and Energy Systems journal homepage: www.elsevier.com/locate/ijepes.
- Moein Choobineh, Ali Arab, Amin Khodaei, Aleksi Paaso, Electrical and Computer Engineering, University of Denver, CO 80210, USA, “Energy innovations through blockchain: challenges, opportunities, and the road ahead” , The Electricity Journal journal homepage: www.elsevier.com/locate/tej
- Qiang Wang, Min Su, School of Economic and Management, China University of Petroleum (East China), Qingdao, Shandong 266580, People’s Republic of China, “Integrating blockchain technology into the energy sector from theory of blockchain to research and application of energy blockchain”, Computer Science Review journal homepage: www.elsevier.com/locate/cosrev
- Simon Albrecht, Dirk Neumann, and Stefan Reichert from University of Freiburg, Jan Schmid and Jens Struker from Fresenius

University, Gilbert Fridgen from University of Bayreuth, “Dynamics of Blockchain Implementation- A case study from the energy sector”, Proceedings of the 51st Hawaii International Conference on System Sciences 2018.

- Manish Kumar Thukral, Manipal University Jaipur, Electrical Engineering Department, Jaipur, India, “Emergence of blockchain-technology application in peer-to-peer electrical-energy trading: a review”, Clean Energy, 2021, 104–123 doi: 10.1093/ce/zkaa033, Homepage: https://academic.oup.com/ce
- Tonghe Wang, Haochen Hua Zhiqian Wei, Junwei Cao, Department of Automation, Tsinghua University, Beijing 100084, China, “Challenges of blockchain in new generation energy systems and future outlooks”, International Journal of Electrical Power and Energy Systems, journal homepage: www.elsevier.com/locate/ijepes
- Adetomike Adeyemi, Mingyu Yan, Mohammad Shahidehpour, Cristina Botero, Alba Valbuena Guerra, Niroj Gurung, Liuxi (Calvin) Zhang, Aleksi Paaso, “Blockchain technology applications in power distribution systems”, The Electricity Journal 33 (2020) 106817, contents list available at ScienceDirect: www.elsevier.com/locate/tej

BIO-DATA

AFTAB ALAM
Damodar Valley Corporation

Date of Birth:	07-06-1988
Qualification:	B.Tech. in Mechanical Engg. from BIT Sindri Dhanbad, Jharkhand (Session: 2009-13) MBA in Power Management from CCE, UPES, Dehradun (Jan,2022 batch)
Designation:	Manager (Mechanical)
Present Organization:	Damodar Valley Corporation
Field of Expertise:	Erection, Commissioning & Operation of 500MW Thermal Power Plant Commercial domains including Billing vertical in respect of HT Consumers, Tariff related works i.r.o. FGD and Solar.
Mobile:	+91 99554 92890, 70333 18085
Email:	aftabalam1500@gmail.com aftab.alam@dvc.gov.in

BRIEF PROFILE

I am a power professional with extensive experience in India’s thermal power sector, specializing in both technical and commercial domains. With a focus on thermal energy, I have contributed to projects involving coal-based power plants. My expertise covers plant operations, performance optimization, and ensuring regulatory compliance for thermal power generation.

In the commercial department, I have overseen key aspects such as Billing, Tariff and financial planning to support the smooth functioning of power projects.

My work has been pivotal in driving efficiency improvements and contributing to our corporation’s trajectory towards sound commercial growth in the power sector.

USER-CENTRIC LOAD SCHEDULING FOR PLANNING AND EXECUTION OF DEMAND SIDE MANAGEMENT

Nisha Agarwal | Basant Kumar Pandey
Bidgely Technologies Pvt Ltd

ABSTRACT

Demand Side Management (DSM) is the process of modifying consumer-side demand for energy to ensure that energy demand never crosses the desired limit. The present methods include electricity rate alteration, rebate programs, and spreading awareness. The ultimate goal is to mitigate the energy needs of an individual, in peak hours without compromising on overall lifestyle. Traditional DSM methods are naive and usually contain a small set of non personalized actions that do not guarantee the required reshaping of the demand curve because of lower likelihood of consumers taking these actions. Hence, there is a need for a concrete strategy to decrease uncertainties in the DSM initiative and increase the likelihood of consumers taking an action towards fulfilling utility goals.

In this paper, we present an intelligent demand-side energy management framework that will assist utilities to alter their peak load demand as per their requirements. The method takes advantage of energy disaggregation algorithms and optimizes the utility objectives by ranking and generating personalized actionable insights for each consumer. It takes into account the utility objectives, demographic information, appliance consumption, and different constraints along with user lifestyle to solve an optimization problem for user ranking and personalized recommendations. The framework allows targeting of major appliances like pool pumps, water heaters, HVAC, and electric vehicles. Additionally, it also has the capability to recommend the most suitable rate plan for each consumer.

To validate the framework, we have used Advanced Metering Infrastructure (AMI) data and disaggregated appliance consumption of ~10,000 homes from varied geographies. This data is used to create simulations with varied sets of users clustered based on different criteria such as region, property type, and owned appliances. The outcome of experiments reaffirms the reduction and redistribution of peak load conforming to given utility constraints.

KEYWORDS

demand-side management, energy efficiency, electric vehicle, load shifting, constrained optimization, energy pricing, smart grid

1. INTRODUCTION

With a rise in economic and technological development, energy demand is growing, and it has become a challenging task for electric utilities to ensure reliable power supply. For instance, in the coming years, the rise in the number of electric vehicles (EVs) as mentioned in [3] will lead to an increase in load on the grid. To accommodate this, utilities will have to adopt either expansion of generation plants or the concept of Demand-side management (DSM) to ensure demand does not exceed the operational constraints limit. DSM programs do not guarantee a decrease in total consumption but can help in lessening the need for investment in power plants to meet the increasing demand and, at the same time, ensure grid reliability.

These programs include energy efficiency programs, and demand response programs designed to reduce peak load or shift the demand from peak hours to off-peak hours. The major shortcoming of these non-user-centric initiatives is that the suggested actions do not incorporate the prior knowledge of their respective user-level propensities. Hence, there is a need for a user-centric load scheduling mechanism to execute the demand response programs that should target appliances contributing significantly to the increased demand on the grid. It should also take into consideration the constraints involved while scheduling these appliances.

One agent-based approach mentioned by Ramchurn et al. is not feasible to be deployed in all regions [12]. Method described by Zhu et al. is based on consumption scheduling using linear programming, which does not take into account appliance level complexities involved in the load reschedule [16]. Similarly, the optimization framework described in [7, 9, 10] might not suit all appliances in practice. The direct load control (DLC) mechanism described in multiple papers, might not fit utility objectives since it requires agreement between the utility and customer to control the appliances to modify the demand curve remotely [2, 5, 11, 14, 15]. Few techniques for smart energy pricing mentioned in work done by Herter et al. [6] and Centolella et al. [1] may drive customers to shift their load away from peak hours. On the contrary, it might also be difficult for customers to schedule usage as per the prices that are changing every hour and might also lead to a shift of a large portion of demand from peak hours to off-peak hours leading to undesirable change in demand curve. An approach mentioned by Logenthiran et al. performs the DSM planning in a smart grid using a Heuristic Optimization based algorithm, which considers utility objective function and user-level constraints [8]. The major drawback is the non-scalability of the approach since it is tested in a small region, and the appliance data is gathered using hardware sensors.

If the demand response methods mentioned by Gellings et al. [4] and Suraj et al. [13] were more user and appliance centric, the likelihood of achieving the objective demand curve will increase. Hence, the focus of this paper is to calculate the suitable appliance usage hours, amount of appliance potential that contributes to achieving utility objective, personalized recommendations, and accordingly rank users to lessen the peak demand load while meeting specific requirements of all individual appliances.

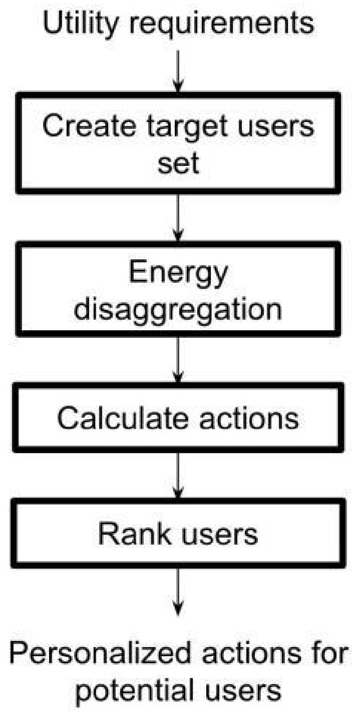


Figure 1: Complete flow of proposed Demand Side Management load scheduling strategy.

2. IMPLEMENTATION

2.1 Experimental Setup

The dataset comprises homes from varied geographies, including Nevada (USA), Florida (USA), and Indiana (USA), and Slovakia.

The vital data requirement of the process is the hourly level consumption of shiftable appliances i.e appliances whose time of usage can be shifted. This information is gathered using disaggregation algorithms that provide appliance consumption at the timestamp level. The user of the framework provides all other information like zip code, total consumption, property type, and the number of occupants used to perform simulations. The total energy consumption is collected using Advanced Metering Infrastructure (AMI) with a sampling rate of 15 min, 30 min, or 60 min as per the configurations of the user's smart meter. If the sampling rate is higher than 60 min, the disaggregated appliance consumption is down-sampled to 60 min, and actions are calculated at an hourly level. The overall flow of the process is shown in Figure 1.

2.1 Utility Preferences

The first step of the process is to identify the set of homes the utility aims to choose. These target homes can be either provided by the utility or filtered by the framework according to their preferences. The framework provides the capability to target users based on zip code, property type, or owned appliances. It also provides the functionality to target single or multiple appliances. For instance, if a utility wants the customers in the Las Vegas area, having owned houses, to shift their EV and pool pump usage to lessen the peak load, the framework will prepare the target set accordingly. After specifying the users and appliance requirements, the utility can either choose to:

1 Reduce consumption in specific hours of the day

2 Reduce consumption in certain days of the month

3 Reduce a given amount of energy usage

4 Ensure the total consumption does not exceed a specific limit

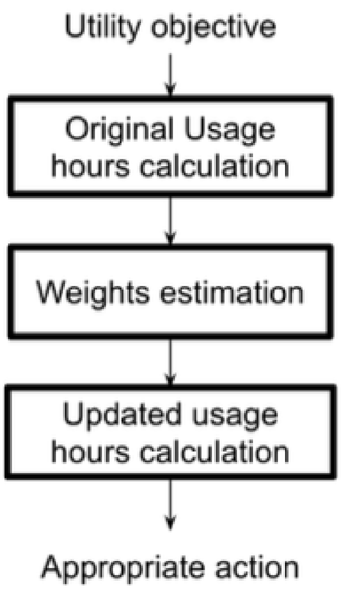


Figure 2: Flow of computation of action for each user-appliance combination.

2.3 Problem Formulation

The objective function is formulated based on utility requirements. The function mentioned below is defined to maintain the hourly load within the limit *l* units i.e. maximum required hourly demand provided by the utility.

Objective function :

$$\sum_{i \in T}(\sum_{j \in Y} P_{ij} - l) \quad (1)$$

Constraint :

$$max\{\sum_{j \in Y} P_{ij} : i \in H\} <= l \quad (2)$$

$$T = \{i : i \; where \sum_{j \in Y} P_{ij} > l\} \quad (3)$$

where P_{ij} is the total energy consumption of a user j at hour i, *T* is the set of hours where total demand exceeds the limit *L*, *Y* is the set of all target users, and *H* is the set of hours in the day ranging from 0 to 23. The objective function aims to minimize the consumption in the hours where the total energy is greater than the limit and at the same time ensuring the consumption does not overshoot the limit during remaining hours.

Proposed Algorithm

The block diagram of the steps in the algorithm is shown in Figure 2. It depicts calculation of hours of usage of an appliance and recommends an alternate start time if objective function value decreases by taking the action. The set of hour of usage U_{kg} of an appliance *k* in a timeframe is calculated using the hourly level consumption data A_k. This timeframe can be a month, season or a year.

$$P_{ij} = \sum_{k \in Z} A_{kij} \quad (4)$$

$$U_{kj} = \{i : i \; where \; \delta_{kj} A_{kij} > 0\} \quad (5)$$

where A_{kij} is the consumption of appliance *k* of the user *j* at hour *j*. *i* is the set of all domestic appliances. If an appliance is absent for a customer, the corresponding A_{kij} vector will be zero. U_{kj} is the set of usage hours of appliance *k* of user *j* that can be modified further if needed. 8_{kj} is a binary digit representing whether the appliance k of user j is shiftable. If the value given is zero, the usage hours will be empty and will not be targeted for the given utility objective.

When usage hours overlap with the utility's peak hours, a new start time of the appliance is calculated. This start time is identified for all users to minimize the objective function and consider the utility-level constraints and multiple appliance level factors. These factors include - shifting the appliance to off-peak hours, keeping the difference between new and previous start times minimum, and constraints related to the user's lifestyle. For instance, a water heater should be used before a user leaves the house at 7 am or another user can charge their electric vehicle only after 9 pm. These appliances are suggested to be shifted only in an available band of hours, thus increasing the likelihood of a user considering the recommended action. The pseudocode for the algorithm is described as follows:

Algorithm 1: Calculate suitable appliance usage hours

Calculate T ;
for $j \in Y$ **do**
  for $k \in Z$ **do**
    Calculate U_{kj};
    if $n(T \cap U_{kj}) > 0$ **then**
      $C_{kj} = \sum_{m \in X} Y_{mkj} f_1(U_{kj}, D_j, C_m)$
      $B_{kj} = f_2(\sum_{j \in Y} P_j)$
      $W_{kj} = w_b B_{kj} + w_r R_{kj} + w_c C_{kj}$
      $n_{kj} = \{i : i \text{ where } W_{kij} == max(W_{kj})\}$
      $\Delta_{kj} = n_{kj} - \{i : i \text{ where } U_{kij} == min(U_{kj})\}$
      $M_{kj} = \{g + \Delta_{kj} : g \in U_{kj}\}$
    end
  end
end

C_m is the vector form of m^{th} lifestyle constraint.

Y_{mkj} is a boolean number which communicates whether the constraint C_m is valid for the given combination.

D_j is a set of lifestyle attributes of user j.

Function f_1 converts a given constraint into binary vector form.

W_{kij} is the weight vector, stating the fitness of user j to start an appliance k at hour i.

Function f_2 calculates available energy bandwidth using total load demand curve.

n_{kj} is the new start hour of the appliance.

Δ_{kz} is the change in original start index of the appliance.

M_{kj} is the set of modified usage hours.

The set of all possible appliance and user lifestyle related constraints is defined as X. It comprises information like - to be used in sleeping hours, to be used during house vacancy hours, to be used before vacancy, etc. W_{kj} is a combination of three factors: B_{kj} Bandwidth weights, R_{kj} - Proximity weights and C_{kj} - Appliance constraints weights. W_b, W_r, and W_c are the weightage assigned to respective factors.

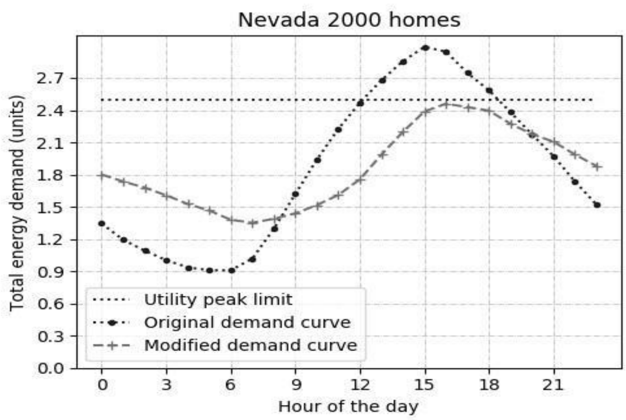


Figure 3: Change in demand curve of 2000 Nevada homes.

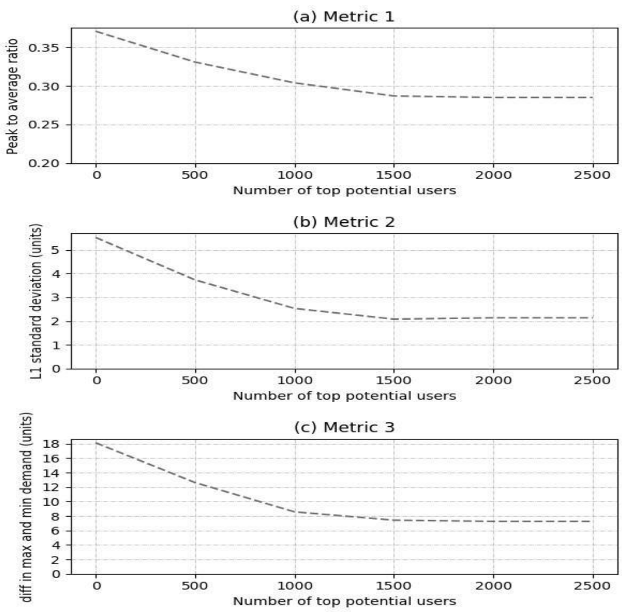


Figure 4: Metrics depicting change in demand curve parameters as number of users taking action increases.

Similarly, actions are calculated for all relevant combinations of appliance and user. The potential value is calculated as the amount of energy the user contributes to minimizing the objective function. The users are further ranked based on the potential reduction, dollar savings, and propensity to take actions. A final ranked list of users with their actionable insights for all available appliances is provided as the output of the framework along with a possible amount of reduction in load at peak hours.

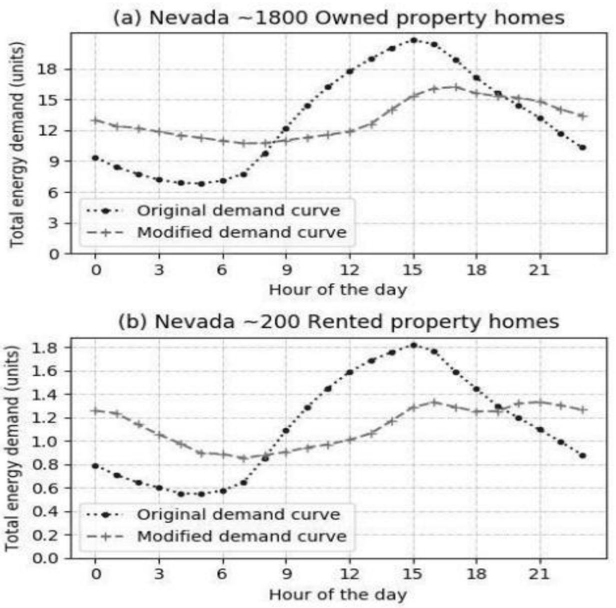


Figure 5: Change in demand curve for both property types.

Rate Plan Recommendation

Objective function :

$$\sum_{i \in H} \alpha_{qi} P_{ij} \tag{6}$$

Constraint :

X - Set of user and appliance level constraints

where α_{qi} is the electricity price at hour i as per rate plan q. First, all the available rate plans given by a utility are clustered based on A. Type of rate plan(e.g., TOU based or tier-based plan) B. Hourly pattern C. Seasonality. In this case, the purpose is to minimize the user's total consumption in rate plan peak hours to minimize the energy charges. The objective function and constraints are redefined for individual users, and corresponding actions are calculated for appliances. The action computation is repeated for each rate plan cluster, and the rate plan with the minimum bill amount is chosen.

RESULTS AND DISCUSSION

The performance of the framework is evaluated using three metrics

Difference between maximum and minimum hourly energy demand

L1 norm standard deviation of demand curve

(3) Peak to average ratio (PAR)

The objective chosen to perform simulation on ~2000 Nevada homes is to minimize the energy demand crossing the limit 2.5 units. The hours where the limit initially exceeds are 12 pm to 6 pm and the value of objective function is 1.79 units. Figure 3 shows the change in demand curve of targeted user sets considering their specific recommended actions. For all the peak hours, the objective is met with some buffer. This buffer allows for the possibility of some users not taking the recommended actions.

The metrics of the simulation depicted in Figure 4 saturates beyond a point since the users are ranked in decreasing order of their potential reduction in peak hours. The plots in Figure 5 show user's segregation based on their property type and their original and modified energy demand curves. Figure 6 presents the results of experiments in varied geographies, including Slovakia, Indiana, and Florida.

The framework shows the feasibility of attaining a particular DSM objective by indicating the maximum possible amount of energy reduction in peak hours, achievable for a given user set. It also maps the homes at a zip code level to assist the utility to plan its execution of the DSM program. All these output quantities and visualizations are readily available once the utility requirements are processed through the framework.

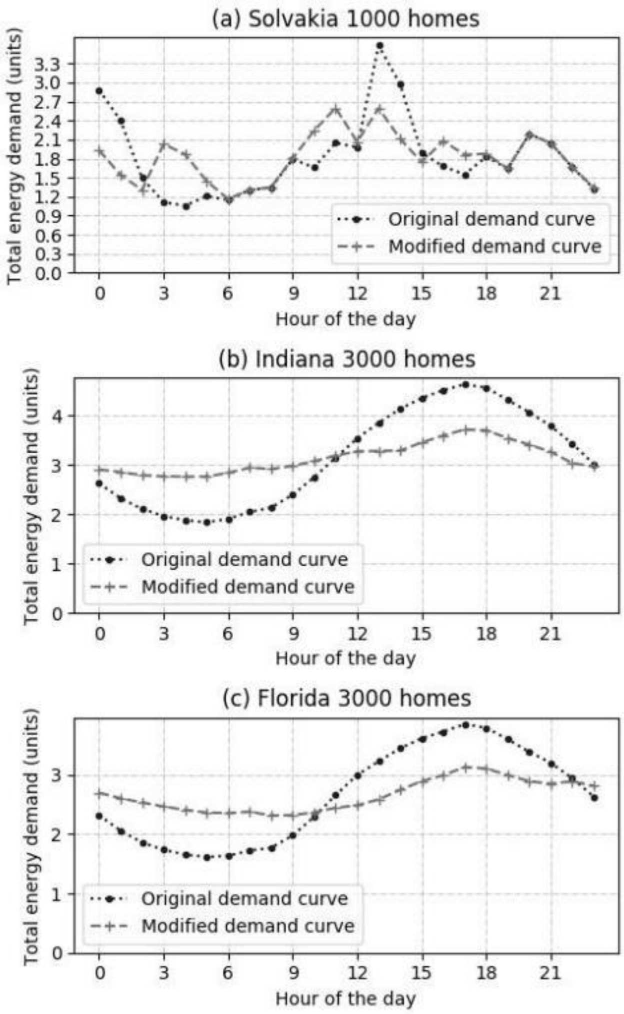


Figure 6: Change in demand curve in various regions.

CONCLUSION

This paper presents a DSM load scheduling strategy that can be easily used for smart grid management to increase the reliability of power supply and, at the same time, minimize the operation cost for the utility. The proposed mechanism aims to assist utilities to prepare a concrete plan to decrease uncertainties in a DSM initiative and increase customer likelihood to take action towards their goals. The framework calculates consumer-specific actions and ranks them based on their propensity of contributing towards utility objectives. The simulation outcomes convey that the proposed method can handle diverse sets in case of both users and appliances. The metrics justify the change in the demand curve based on the given utility objectives in the simulation environment. The ideas stated in this paper can be extended to several directions involved in modifying the demand curve as per utility needs.

REFERENCES

[1] Paul Centolella. 2009. The integration of Price Responsive Demand into Regional Transmission Organization (RTO) wholesale power markets and system operations. Elsevier Energy (September 2009). https://doi.org/10.1016/j.energy.2009.06.046

[2] Chi-Min Chu, Tai-Lang Jong, and Yue-Wei Huang. [n.d.]. A Direct Load Control of Air-conditioning Loads with Thermal Comfort Control. ([n.d.]).

[3] P. Finn, C. Fitzpatrick, and D. Connolly. 2012. Demand side management of electric car charging: Benefits for consumer and grid. ELSEVIER Energy (April 2012). https://doi.org/10.1016/j.energy.2012.03.042

[4] Clark W. Gellings. 1985. The Concept of Demand-Side Management for Electric Utilities. 73, 10 (October 1985).

[5] A. Gomes, C. H. Antunes, and A. G. Martins. 2007. A Multiple Objective Approach to Direct Load Control Using an Interactive Evolutionary Algorithm. IEEE TRANSACTIONS ON POWER SYSTEMS 22, 3 (3 2007). https://doi.org/10. 1109/TPWRS.2007.901468

[6] Karen Herter. 2006. Residential implementation of critical-peak pricing of electricity. Elsevier Energy policy (September 2006). https://doi.org/10.1016/j.enpol.2006.06.019

[7] Arthur I.Cohen and C. Wang. 1988. AN OPTIMIZATION METHOD FOR LOAD MANAGEMENT SCHEDULING. IEEE transactions on Power Systems 3, 2 (May 1988).

[8] Thillainathan Logenthiran and Dipti Srinivasan. 2012. Demand Side Management in Smart Grid Using Heuristic Optimization. IEEE transactions on smart grid 3, 3 (September 2012). https://doi.org/10.1109/TSG.2012.2195686

[9] Petra Mesaric and Slavko Krajcar. 2015. Home demand side management integrated with electric vehicles and renewable energy sources. ELSEVIER Energy and Buildings (September 2015). http://dx.doi.org/10.1016/j.enbuild.2015.09.001

[10] Michael Angelo A. Pedrasa, Ted D. Spooner, and Iain F. MacGill. 2009. Scheduling of Demand Side Resources Using Binary Particle Swarm Optimization. IEEE transactions on Power Systems 24, 3 (August 2009). https://doi.org/10.1109/ TPWRS.2009.2021219

[11] Badri Ramanathan and Vijay Vittal. 2008. A Framework for Evaluation of Advanced Direct Load Control With Minimum Disruption. IEEE TRANSACTIONS ON POWER SYSTEMS 23, 4 (November 2008). https://doi.org/10.1109/TPWRS. 2008.2004732

[12] Sarvapali D. Ramchurn, Perukrishnen Vytelingum, Alex Rogers, and Nick Jennings. 2011. Agent-Based Control for Decentralised Demand Side Management in the Smart Grid. Int. Conf. on Autonomous Agents and Multiagent Systems – Innovative Applications Track (May 2011).

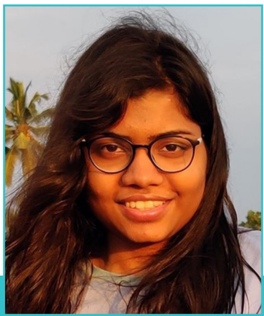
[13] Suraj S and Senthil K. 2019. DEMAND SIDE MANAGEMENT: DEMAND RESPONSE, INTELLIGENT ENERGY SYSTEMS AND SMART LOADS. International Journal of Electrical Engineering & Technology (IJEET) 10, 1 (February 2019).

[14] D.D. Weers, NCM. A. Shamsedin, Inc. Charlotte Process Systems, and SC South Carolina Electric & Gas, Columbia. 1987. TESTING A NEW DIRECT LOAD CONTROL POWER LINE COMMUNICATION SYSTEM. IEEE Transactions on Power Delivery PWRD-2, 3 (July 1987).

[15] Leehter Yao, Wen-Chi Chang, and Rong-Liang Yen. 2005. An Iterative Deepening Genetic Algorithm for Scheduling of Direct Load Control. IEEE TRANSACTIONS ON POWER SYSTEMS 20, 3 (August 2005). https://doi.org/10.1109/TPWRS.2005.852151

[16] Ziming Zhu, Jie Tang, Sangarapillai Lambotharan, Woon Hau Chin, and Zhong Fan. 2011. An Integer Linear Programming Based Optimization for Home Demand-side Management in Smart Grid. IEEE (2011).

BIO-DATA



NISHA AGARWAL
Bidgely

Date of Birth:	07-Oct-1997
Qualification:	B.Tech IIT Roorkee
Designation:	Senior Data Scientist
Present Organization:	Bidgely
Field of Expertise:	Data Science
Mobile:	+91 75001 82645
Email:	nisha@bidgely.com

BRIEF PROFILE

Nisha is a data science professional with over 5 years of industry experience. She graduated with a degree in Electrical Engineering from the Indian Institute of Technology, Roorkee in 2019. Currently, Nisha holds the position of Senior Data Scientist at Bidgely Technologies Pvt Ltd, where she specializes in energy-driven projects such as Demand-side Management and Customer Behavioral Analysis. Her expertise extends to developing innovative solutions for smart scheduling of EV charging and home energy usage disaggregation.

BASANT KUMAR PANDEY
Bidgely

Date of Birth:	20-Aug-1986
Qualification:	B.Tech-M.Tech Dual Degree IIT Roorkee
Designation:	Director Data Science
Present Organization:	Bidgely
Field of Expertise:	Data Science
Mobile:	+91 81056 96669
Email:	basant@bidgely.com

BRIEF PROFILE

An an IIT Roorkee Graduate, Basant is a data Science professional with over 14 years of industry experience in this field. As a data science director at Bidgely Inc., he leads his team for innovations and state-of-the-art AI solutions to solve energy problems and driving clean energy future. Prior to Bidgely, while working with Samsung Advance Research (SAIT) and Tata i-labs, he was involved in the development of ML/DL solutions in computer vision and virtual reality. Basant with dual B.Tech - M.Tech degree in Electronics and Communication Engineering, specializes in wireless communication. He has a keen interest and passion towards drawing a parallel between modern physics and ancient Vedic science.

DASHBOARD FOR MONITORING THE DISTRIBUTION TRANSFORMER'S OPERATIONAL PARAMETERS AND UTILIZATION BASED ON AMR DATA

Veeramuruganandan Paramasivan | Ruman Maknojia
Tata Power Co Ltd, Mumbai

ABSTRACT

Tata Power Co Ltd has license to distribute power in the Mumbai location. Tata Power Mumbai is supplying power to 7.63 lakh consumers spread across 485 sq km area. Tata Power has installed different types of revenue meters including conventional and smart at consumer premises and Distribution Substations.

This paper presents a pioneering approach to enhancing the operational efficiency and maintenance strategies of distribution transformers through advanced analytics of energy meter Automatic Meter Reading (AMR) data. The project, implemented by Tata Power Mumbai Distribution, focuses on leveraging AMR data to monitor and analyze the key operational parameters of distribution transformers. By developing a Transformer Operational Monitoring Dashboard, powered by Microsoft Power BI and supported by in-house Robotic Process Automation (RPA) solutions.

The project aims to provide actionable insights into transformer performance, loading patterns, voltage trends, and power factor dynamics. This integrated approach enables proactive maintenance scheduling, optimized asset utilization, and predictive maintenance strategies. The paper details the methodology of data collection, processing, and analysis, emphasizing the transformative outcomes in operational efficiency and reliability achieved through this innovative initiative. The results demonstrate significant improvements in operational decision-making, cost optimization, and overall sustainability of the distribution network.

1 INTRODUCTION

In the realm of electrical distribution systems, the efficient operation and maintenance of distribution transformers play a crucial role in ensuring reliability, sustainability, and cost-effectiveness. Traditional approaches to monitoring transformer performance often rely on periodic inspections and manual data collection, which can be labour-intensive and limited in providing real-time insights. However, with advancements in technology and the widespread adoption of Automatic Meter Reading (AMR) systems, there exists a significant opportunity to revolutionize how we monitor and manage distribution transformer assets.

This paper introduces a novel approach developed by Tata Power Mumbai Distribution that harnesses the power of AMR data to analyse and optimize the operational parameters of distribution transformers. At its core is the development of a Transformer Operational Monitoring Dashboard, powered by Microsoft Power BI and supported by an in-house Robotic Process Automation (RPA) solution. This dashboard integrates data from energy meter AMR systems, enabling real-time monitoring and analysis of critical transformer metrics such as loading patterns, voltage trends, power factor variations, and operational anomalies.

The primary objective of this initiative is to move beyond traditional maintenance practices towards a data-driven, proactive maintenance strategy. By leveraging AMR data, the project aims to enhance the accuracy of transformer performance monitoring, optimize asset utilization, and facilitate predictive maintenance strategies. These efforts are geared towards improving operational efficiency, reducing downtime, and ultimately, ensuring the reliability and sustainability of the distribution network.

This introduction sets the stage for detailing the methodology, implementation, results, and impact of our innovative approach. By providing a comprehensive overview of our methodology and the transformative outcomes achieved, this paper aims to contribute to the broader discourse on leveraging data analytics for enhancing operational efficiency and maintenance practices in electrical distribution systems.

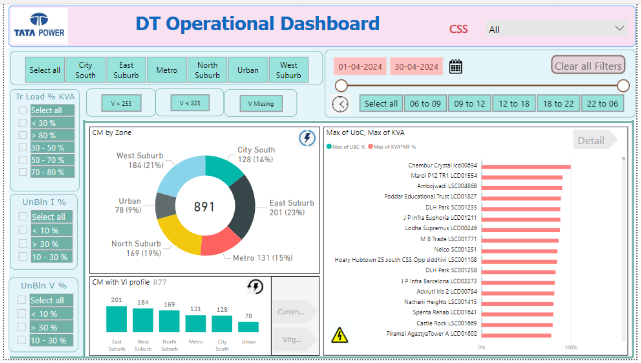


Fig-1: Summary page of Microsoft Power Bi Distribution Transformer Operational Dashboard.

2 FUNCTIONALITIES AND FEATURES OF THE ANALYTICAL DASHBOARD

The Analytical Monitoring dashboard designed to provide real-time and historical data visualizations. Graphs, charts, and maps were incorporated to simplify the interpretation of intricate data sets, empowering stakeholders with actionable insights. In addition, empowering the operational team with actionable insights. By leveraging energy meter data, we can understand the operational trends of transformers and uncover critical information. Some of the key insights from the dashboard are as follows:

- **Loading patterns:** Analyzing the energy meter data allows for a detailed examination of loading patterns on transformers, providing insights into usage trends and potential areas for optimization.
- **Unbalance current:** Detection of unbalanced loads through energy meter data analysis helps in addressing issues that could impact the efficiency and performance of transformers.
- **Loading hours:** Understanding loading hours provides a deeper understanding of how transformers are utilized over specific time periods, aiding in load management strategies.
- **Min Max Voltage trend:** Monitoring the minimum and maximum voltage trends aids in identifying potential voltage-related issues and maintaining optimal voltage levels across the distribution system.
- **Low Power factor:** Identifying instances of low power factor enables corrective measures to improve the efficiency of the distribution network.
- **Feeder Power Failure Duration:** Analyzing energy meter data for feeder power failure duration helps in understanding and addressing disruptions, ensuring a reliable distribution network.
- **Under & Overrated Transformer:** Identifying transformers operating under or over their rated capacity allows for proactive measures to optimize resource allocation and prevent potential issues.
- **Predictive maintenance strategies**: The maintenance team benefits greatly from the transition to predictive maintenance enabled by the dashboard. By leveraging real-time data and analytical insights, the team can move away from reactive maintenance practices and instead schedule maintenance activities based on actual usage patterns and load stability.

Its robust design enables comprehensive oversight, ensuring that each transformer's operational performance and health are systematically tracked and analyzed. This scalable solution demonstrates its efficacy in handling the complexities of a large-scale distribution network, providing valuable insights for efficient management and strategic decision-making across the extensive transformer and network infrastructure.

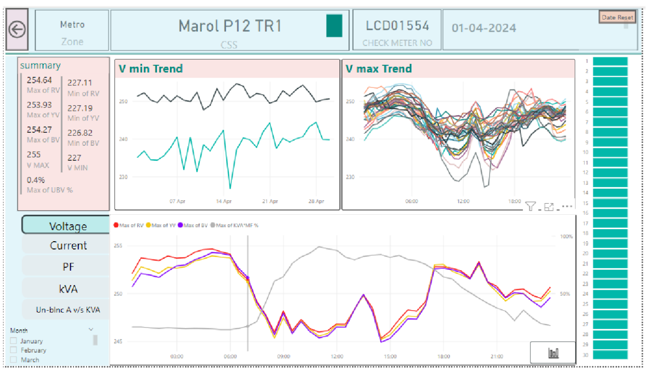


Fig-2: Voltage, Current, KVA, PF, Detailed graph w.r.t date and time instant.

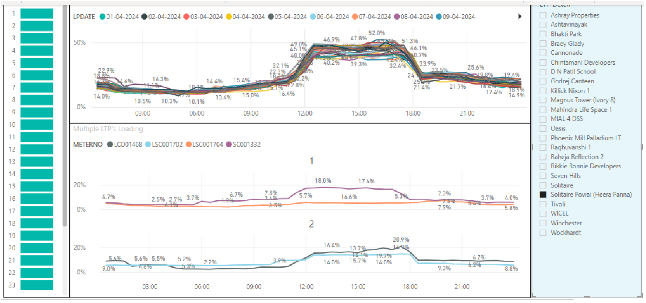


Fig-3: Multiple LTP and Transformer loading details of individual substation.

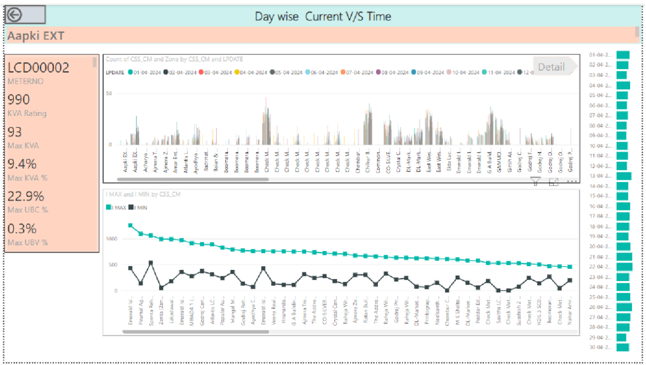


Fig-4: Day wise Current/ Voltage distortion w.r.t Time.

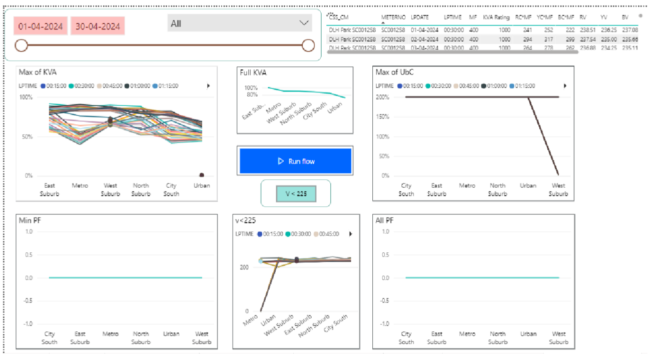


Fig-5: Individual Transformer operational raw data extraction page.

3 IMPACT OF THE PROJECT

This analytical dashboard for distribution transformers has a significant impact on energy management, infrastructure maintenance and Asset utilization. Few of them are mentioned below.

- **Performance Monitoring:** This dashboard can track real-time performance metrics of distribution transformers, such as Voltage, current, load, power factor. This helps in identifying deviations from normal operation, predicting potential failures, and optimizing their performance. Loading patterns, Unbalance load, Loading hours, Min Max Voltage trend, low Power factor, Feeder Power Failure duration, Under & overrated Transformers

- **Predictive Maintenance:** By analyzing historical data and patterns, these dashboards can predict when a distribution transformer might fail or require maintenance. Scheduling the transformer regular maintenance based on the Loading hours. This proactive approach minimizes downtime, reduces repair costs, and improves overall reliability.

- **Energy Efficiency:** Monitoring energy consumption and losses through the dashboard enables identification of inefficiencies in the distribution system. This data can be used to optimize energy distribution, reduce losses, and improve overall efficiency.

- **Decision Making:** The insights derived from the analytical dashboard aid in making informed decisions related to transformer upgrades, replacements, load management strategies, and infrastructure design planning for future extension.

- **Safety and Reliability:** By constantly monitoring parameters like Voltage and load, potential hazards or overloads can be detected early, ensuring the safety of the transformer and preventing possible outages.

- **Operational Cost saving:** Identifying Transformers operating under or over their rated capacity allows for proactive measures to optimize resource allocation within available assets in distribution network and minimize the capital or operational cost of purchasing new transformer.

Overall, an analytical dashboard for distribution transformers enhances operational efficiency, prolongs equipment life, and helps operational team manage their resources more effectively.

4 ENERGY METER DATA FLOW ARCHITECTURE

Integration of the Energy meter data with the analytical monitoring dashboard Involves several stages like Data Collection and Integration, Data Preprocessing, Analytical Model Development, Dashboard Design and Implementation, Validation and Testing, Deployment and Training, and Daily Report Generation and Auto Emailers. Each phase is critical to ensuring the success of the project.

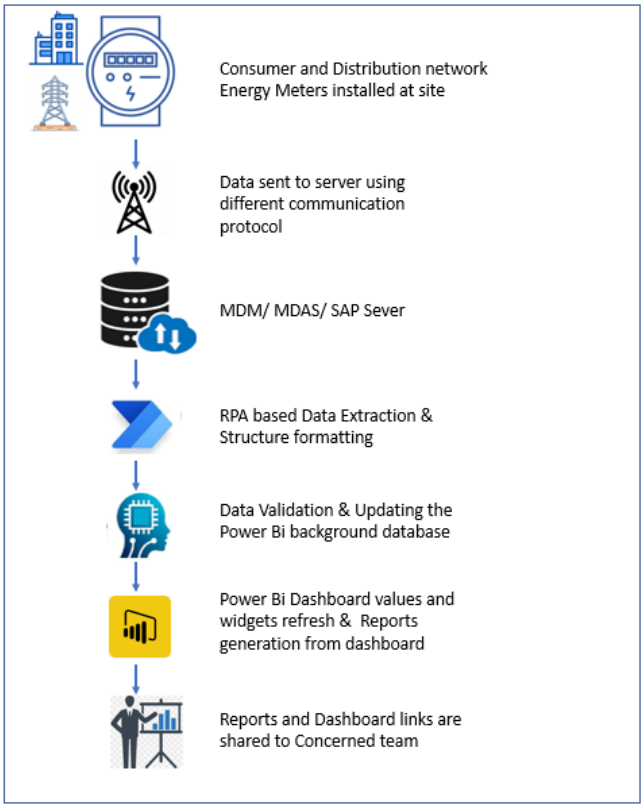


Fig-6: Energy Meter data flow architecture used in Monitoring dashboard development.

5 THE INSIGHT DERIVED FROM THE ANALYTICAL MONITORING DASHBOARD

The analytical monitoring dashboard, designed with robust and scalable architecture, provides comprehensive oversight of each transformer's operational performance and health.

The analytical monitoring dashboard provides detailed insights and observations that significantly enhance the stability of the distribution network and optimize the utilization of available assets, leading to cost-effective operational maintenance. Our recent Insight and observation from the dashboard for the month of May 2024 are mentioned below.

- **45** DT are loaded more than 70 % of its rated KVA capacity.
- **61** DT experienced more than 10 % unbalance current when loading exceeds 60 % of its rated KVA capacity.
- **09** DT showing voltage trend less than 225 V when loading exceeds 50% of its rated KVA capacity.
- **06** DT having Power factor less than 0.86 Lag when loaded more than 30 % of its rated KVA capacity.
- **71** DT meters recorded intermediate voltage failure.
- **54** DT transformers never loaded more than 10 % of its rated KVA capacity for whole month.
- **301** DT transformers never loaded more than 30 % of its rated KVA capacity for whole month.

These insights collectively enhance the efficiency of managing a large-scale distribution network, supporting strategic decision-making, and optimizing operational performance.

6 KEY CHALLENGES FACED

The project is based on optimizing the utilization of energy meter data beyond traditional meter reading and consumption processing this lead to several key challenges which are being addressed. The project distinguishes itself by overcoming the limitations of manufacturer-specific proprietary platforms tailored for individual energy meter models. These challenges include:

Diverse Energy Meter Models: Managing and analyzing data from various models of distribution transformer (DT) energy meters installed across the entire distribution network was a significant challenge. Each manufacturer's proprietary platform is typically tailored to specific energy meter models, making it difficult to integrate and standardize data across different systems.

Proprietary Platform Limitations: Manufacturer specific platforms often have limited interoperability, creating silos of data that are difficult to integrate. Our project overcame this by developing a unique capability to map and analyze diverse energy meter models, providing a comprehensive and unified analytical solution using Microsoft Power Bi Platform.

Data Integration and Management: Integrating the energy meter Master Data Management (MDM) database with the Microsoft Power BI platform required meticulous planning and execution. Ensuring seamless data flow using Microsoft Power Automate RPA was critical to maintaining data accuracy and consistency.

7 CONCLUSIONS

The successful implementation of our innovative project, leveraging energy meter AMR data for the analytics of distribution transformer operational parameters, marks a significant advancement in the field of electrical distribution network management. By developing a comprehensive Transformer Operational Monitoring Dashboard, Tata Power Mumbai Distribution has achieved transformative outcomes in operational efficiency, predictive maintenance, and asset utilization.

The detailed insights derived from the dashboard, such as loading patterns, unbalanced loads, voltage trends, power factor monitoring, and predictive maintenance alerts, have significantly enhanced the stability and reliability of the distribution network. This data-driven strategy has led to optimized maintenance schedules, reduced operational costs, and improved overall network performance.

The project's success highlights the potential of leveraging data analytics to drive strategic decision-making and operational excellence in the electrical distribution industry. Future work will focus on expanding the dashboard's capabilities, integrating additional data sources, and continuously improving the system's performance to meet evolving operational challenges.

8 REFERENCES

[1] Tata Power Company Limited. (2023). Tata Power Distribution System. [Corporate Report]. Mumbai, India: Tata Power Company Limited.

[2] Kumar, A., Singh, S., & Gupta, N. (2017) Automated Meter Reading System for Efficient Energy Management [Journal Article].

[3] Yeo, H., Lee, S., & Kim, H. (2018) Real-Time Monitoring of Distribution Transformers Using Smart Meters [Conference Presentation].

[4] Zhang, J., Li, H., & Wang, Y. (2019) Machine Learning-Based Predictive Maintenance for Distribution Transformers Data Management in Smart Spaces. [Research Paper].

[5] Smith, J., Brown, T., & Garcia, L. (2020) Implementation of Analytical Dashboards for Reducing Transformer Failures [Conference Presentation].

[6] Sandeep Kumar (2024), Complete Microsoft SQL Server Masterclass Beginner to Expert [Udemy Online portal].

[7] Pavan Lalwani (2024) Power BI Tutorial for Beginners -Introduction to Power BI. [Web Content].

ABBREVIATIONS AND ACRONYMS

AMR	Automatic Meter Reading
GPRS	General packet radio service
RF	Radio frequency
RS485	Recommended standard 485.
HT	High Tension
LT	Low Tension
MDMS	Meter Data Management System
DT	Distribution Transformer
SAP	System, Application & Product
ERP	Enterprise Resource Planning
KVA	Kilo Voltage Ampere
PF	Power Factor
W.R.T	With Respect to
SQL	Structured Query Language
LTP	Low Tension Panel
SLD	Single Line Diagram

Bio data of Authors along with Photographs
Bio data of Authors are Uploaded with registration form.

BIO-DATA

VEERAMURUGANANDAN PARAMASIVAN
Tata Power Co. Ltd.

Date of Birth:	19.01.1993
Qualification:	MSC. (Renewable Energy & Environment)
Designation:	Lead Engineer, Meter Management Group
Present Organization:	Tata Power Co. Ltd.
Field of Expertise:	Energy Metering, Monitoring and Analytics
Mobile:	+91 80976 45370
Email:	veera.sivan@tatapower.com

BRIEF PROFILE

Energy Data Monitoring, and Analysis Specialist based in Mumbai, possess strong expertise in managing the communication and data handling of AMR energy meters of consumers and distribution networks. Proficient in developing Energy monitoring dashboards and reports based on energy meter data. Experienced in performing Energy analysis for production units, rooftop solar systems, smart meter communications, distribution network operational analysis, and performance monitoring of utility equipment in manufacturing plants. With a focused approach on optimizing energy usage and improving data accuracy, always contribute significantly in Energy Monitoring, improving System Efficiency and sustainability initiatives on a large scale.

RUMAN MAKNOJIA
Tata Power Co. Ltd.

Date of Birth:	28-07-1978
Qualification:	Diploma in Electronics
Designation:	Group Head - AMR & Complaint Analysis
Present Organization:	Tata Power Co. Ltd.
Field of Expertise:	Energy Metering and AMR/AMI technologies
Mobile:	+91 92235 89446
Email:	ruman.maknojia@tatapower.com

BRIEF PROFILE

More than 20 years of combined experience in the field of meter manufacturing industry and distribution utility. Headed many projects like meter installation, implementation of smart metering systems, implementation of workflow system for metering.

MONITORING THE ELECTRIC VEHICLE CHARGING AND THEIR INTERACTIONS WITH SOLAR ENERGY IN DISTRIBUTION NETWORK

Sujata Guruji | Veeramuruganandan Paramasivan
Tata Power Co. Ltd.

ABSTRACT

Tata Power Co Ltd has license to distribute power in the Mumbai location. Tata Power Mumbai is supplying power to 7.63 lakh consumers spread across 485 sq km area. Tata Power has installed different types of meters for revenue monitoring that including conventional and smart meters at consumer premises, EV charging Station and Distribution Substations.

With an ambitious target becoming net zero by 2045, India has a bigger plan of adding more renewable in the system. The monitoring and managing of these distributed energy sources will soon be greater challenge for any distribution utility.

The integration of rooftop solar installations and Electric Vehicle (EV) charging stations into distribution networks presents a significant opportunity for advancing sustainable energy practices and promoting clean transportation. This research focuses on monitoring and analyzing these technologies within a distribution network, aiming to enhance overall system reliability and green power penetration. By systematically gathering and analyzing data from solar generation meters, net metering systems, and EV charging infrastructures meters, we have developed an innovative analytical dashboard.

This dashboard tracks Solar energy production, system efficiency, and potential issues affecting solar performance, while also monitoring EV charging behaviors and their impact on grid demand. Our analysis reveals critical insights into the efficiency of rooftop solar installations, Solar Export energy and utilization patterns of EV charging and their interactions with Solar Energy to become self-sustain within the broader energy ecosystem. This study represents a paradigm shift in energy management, providing actionable strategies to optimize the performance and integration of Distributed Energy resources in modern distribution networks.

1 INTRODUCTION

The integration of rooftop solar installations and Electric Vehicle (EV) charging stations into distribution networks presents a significant opportunity for advancing sustainable energy practices, promoting clean transportation and offering significant potential to reduce carbon footprints and enhance energy efficiency.

As renewable energy sources and clean transportation become more prevalent, there is a pressing need to understand and manage the complexities they introduce to traditional energy systems.

This research focuses on monitoring and analyzing these technologies within a distribution network, aiming to enhance overall system reliability and green power penetration. By systematically gathering and analyzing data from solar generation meters, net metering systems, and EV charging infrastructure meters, we have developed an innovative analytical dashboard. This dashboard tracks solar energy production, system efficiency, and potential issues affecting solar performance, while also monitoring EV charging behaviors and their impact on grid demand. Our analysis reveals critical insights into the efficiency of rooftop solar installations, solar export energy, and utilization patterns of EV charging, as well as their interactions to become self-sustaining within the broader energy ecosystem. We specifically monitor the percentage of EV charging energy sourced from consumers' solar export energy. The findings underscore the importance of data-driven decision-making in managing distributed energy resources (DERs), contributing to a more resilient, sustainable, and self-sufficient energy future. This study represents a paradigm shift in energy management, providing actionable strategies to optimize the performance and integration of DERs in modern distribution networks.

2 FUNCTIONALITIES AND FEATURES OF THE ANALYTICAL DASHBOARD

The Analytical Monitoring dashboard is integrated with MDM (Meter Database Management), EV infrastructure, Net metering system designed to provide real-time and historical data visualizations. Graphs, charts, and maps were incorporated to simplify the interpretation of intricate data sets, empowering stakeholders with actionable insights. In addition, the dashboard evaluates and communicates the positive environmental impact of the project, showcasing reductions in carbon emissions associated with rooftop solar and electric vehicle adoption. Overall, this dashboard represents a comprehensive tool that not only monitors and analyses distributed energy resources but also contributes to informed decision-making, peak demand periods, load fluctuations, sustainability, and a smarter energy future.

Real-time Insights: Our analytical dashboard provides real-time visibility into critical metrics, including the Average Solar Specific Yield of installed RTS systems. This data stands as an evidence to the efficiency and performance of these systems, showcasing their capability to generate a substantial portion of the total solar energy production.

Environmental Impact: By precisely quantifying the CO2e offset through Total Solar Generation, we've tangibly demonstrated the environmental benefits of the distributed solar infrastructure. Our findings showcase the positive ecological footprint, aligning with sustainable energy objectives.

Grid Contribution: We've accurately tracked and documented the Total Solar Generation exported to the grid. This metric underlines the role of distributed solar resources in contributing to the overall energy supply, reducing dependence on traditional energy sources.

Self-sufficiency: Through our analysis, we've determined the extent to which EV consumption can be met by Solar Export, showcasing the potential for a self-sufficient energy ecosystem. Moreover, our insights reveal that the overall demand of RTS consumers has been largely fulfilled by their own Solar Generation, marking a significant stride towards energy autonomy.

Anomaly Detection and Resolution: The dashboard has proven invaluable in identifying anomalies in export patterns, enabling swift corrective action. By pinpointing cases of abnormal export, we've promptly intervened, ensuring network stability and optimal resource utilization.

It empowers each participant in this network to actively contribute to a more sustainable and efficient energy ecosystem.

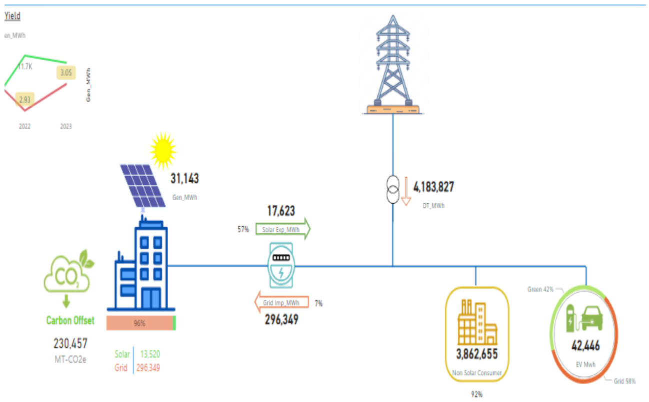


Fig-1: Analytical dashboard developed to monitor the Solar Energy Generation & Export, Percentage of EV-Charging and its Green offset.

3 IMPACT OF THE PROJECT

Consumer Empowerment: The dashboard has empowered consumers by providing real-time information about their solar generation. By promptly notifying them about instances of zero solar generation, consumers can take proactive measures to ensure their solar setup functions optimally. This proactive approach safeguards their energy generation and minimizes disruptions, fostering greater confidence in their renewable energy investment.

Revenue Protection and Efficiency for the Utility: The ability to track abnormalities in generation concerning export data has been instrumental in averting revenue losses. By identifying abnormal exports resulting from manual meter reading issues, the utility can swiftly rectify discrepancies. This proactive measure ensures accurate billing and prevents revenue leakage, ultimately bolstering financial efficiency.

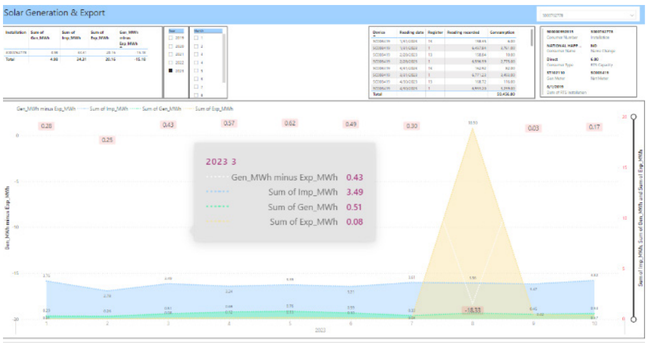


Fig-2: Abnormal Solar Energy Exports due to manual meter reading issues are identified using the dashboard.

Network Planning and Optimization: Through the identification of specific zones and regions within the network with higher solar penetration, the dashboard aids the network planning team to take strategic decisions regarding network infrastructure and load distribution. Helps to monitor and optimize infrastructure of distribution channels, ensuring efficient allocation of green power to meet the expanding EV demand. This proactive approach aligns network expansion and upgrades with the growing shift towards sustainable energy consumption, fostering a more resilient and environmentally conscious network.

Quantifying EV Load compensated from Solar: By utilizing this analytical insight, our network planning team can accurately measure the proportion of EV load powered by solar energy. This granular understanding allows for precise calculations, indicating the degree to which EVs are utilizing clean, renewable energy sources. Such data is invaluable, offering crucial insights into the interplay between EV adoption and green energy utilization within the network.

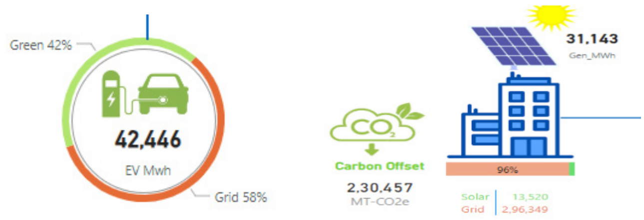


Fig-3: Bifurcation of EV Energy from Grid and Solar Export compensation. Consumer Solar generation and subsequent Carbon Offset.

Environmental Impact Assessment: The dashboard's capability to track the Mus (Million Units) saved through solar generation annually is pivotal for environmental evaluation. This data quantifies the positive environmental impact of utilizing solar energy, providing tangible evidence of reduced carbon emissions. It serves as a crucial metric for evaluating progress towards sustainability goals and informs future environmentally conscious decisions.

4 ENERGY METER DATA FLOW ARCHITECTURE

Integration of the Energy meter data with the analytical monitoring dashboard Involves several stages like Data Collection and Integration, Data Preprocessing, Analytical Model Development, Dashboard Design and Implementation, Validation and Testing, Deployment and Training, and Daily Report Generation and Auto Emailers. Each phase is critical to ensuring the success of the project.

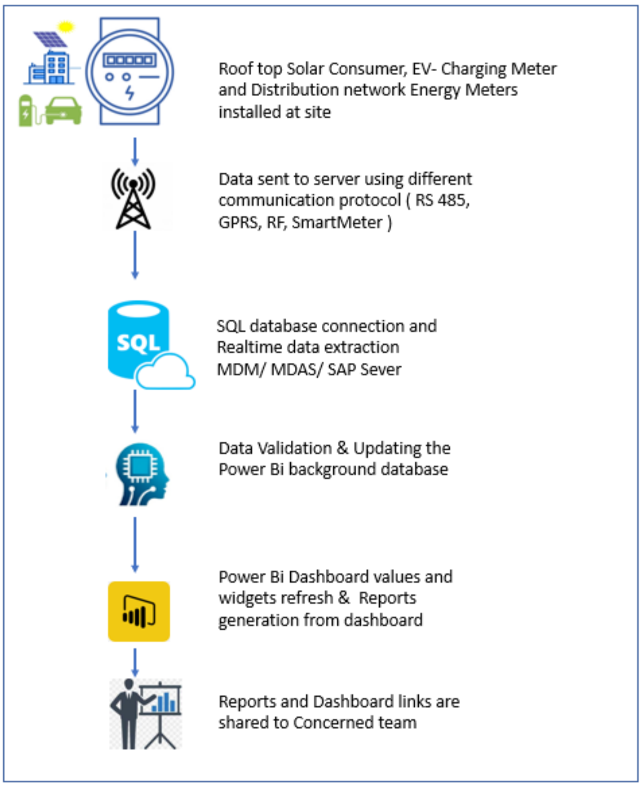


Fig-4: Energy Meter data flow architecture used in Monitoring dashboard development.

5 KEY CHALLENGES FACED

The project distinguishes itself by addressing the limitations of manufacturer-specific proprietary platforms tailored for individual solar inverters. Unlike these specialized systems, our project boasts a unique capability to map and analyze diverse models of consumers' solar meters. This distinctive feature positions the project as an indispensable tool for comprehensively managing distributed energy resources. By providing a unified interface for monitoring and analyzing various consumer solar installations, the project offers a holistic and integrated solution, overcoming the constraints of individual manufacturer-centric platforms.

6 CONCLUSIONS AND FUTURE IMPLICATION

The insights derived from this Analytical dashboard have far-reaching implications for Energy management. By analyzing the efficiency of rooftop solar installations and the utilization patterns of EV charging stations, we can better understand their role in the energy ecosystem. This understanding is crucial for developing strategies that support a resilient, sustainable, and self-sufficient energy future.

Few insights and observations have been derived from the Analytical monitoring dashboard.

1. Average Solar Specific yield of RTS installed is **3.09** KWh/KWp
2. **31 Mus** of Total Solar generation, offsetting 230 Kilotons of CO2e till date.
3. **56 %** of Total Solar Generation has been Exported to Grid till date.
4. **42 %** of EV consumption can be sufficed by Solar Export.
5. **4 %** of overall demand of the RTS Consumers has been meet by their own Solar Generation.
6. **1** Case with abnormal Export has been spotted out and corrective action has been taken.
7. **2** Cases found with abnormality in Generation w.r.t Export data, further detailed analysis need to be done.
8. **9** Consumers' KWh/KWp is Abnormally high, need further detailed analysis on Generation figure.
9. Monitoring the Roof top Solar Specific Yield at overall and individual Consumer level.

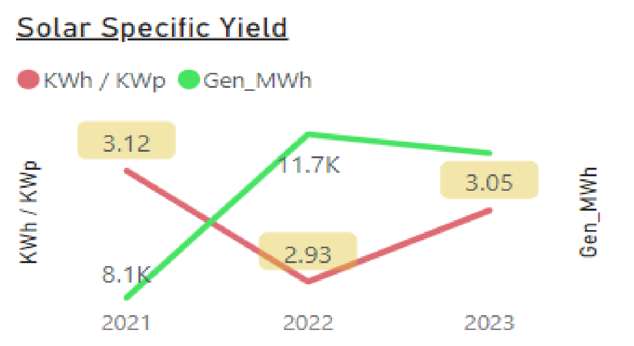


Fig-5: Monitoring the Roof top Solar Specific Yield at overall and individual Consumer level.

Future Implications: The insights gained from this research have far-reaching implications for energy management and policymaking. this study provides a foundation for developing strategies that support a more sustainable and efficient energy system. Future Scope and integration in the dashboard are:

- Integral part of power portfolio management
- Online solar calculator and network feasibility
- Integration of DERMS (Distributed Energy Resource Management) system
- Including Solar PPA green Power purchase
- Tata Power's ambitious targets for Increasing Renewable Energy & EV adoption demand a robust and scalable monitoring system.

In conclusion, this study represents a paradigm shift in energy management. By focusing on the monitoring and analysis of rooftop solar installations and EV charging stations, we have provided actionable strategies to optimize the performance and integration of DERs in modern distribution networks. Our findings contribute to the ongoing transformation towards a more sustainable, resilient, and efficient energy system, paving the way for a greener and cleaner future.

7 REFERENCES

[1] Tata Power Company Limited. (2023). Tata Power Distribution System. [Corporate Report]. Mumbai, India: Tata Power Company Limited.

[2] Kumar, A., Singh, S., & Gupta, N. (2017) Automated Meter Reading System for Efficient Energy Management [Journal Article].

[3] Yeo, H., Lee, S., & Kim, H. (2018) Real-Time Monitoring of Distribution Transformers Using Smart Meters [Conference Presentation].

[4] Almeida, P., & Santos, R. (2021) Big Data Analytics in Power Systems [Energy Report]

[5] Jones, M., & Lee, K. (2022) Smart Grid Technologies and Their Applications in Distribution Networks [Conference Presentation].

[6] Miller, D., & Taylor, S. (2023).Real-Time Data Analytics for Energy Efficiency. [Journal of Renewable Energy].

[7] Sandeep Kumar (2024), Complete Microsoft SQL Server Masterclass Beginner to Expert [Udemy Online portal].

[8] Pavan Lalwani (2024) Power BI Tutorial for Beginners -Introduction to Power BI. [Web Content].

ABBREVIATIONS AND ACRONYMS

DER	Distributed Energy Resources
AMR	Automatic Meter Reading
GPRS	General packet radio service
RF	Radio frequency
RS485	Recommended standard 485.
HT	High Tension
LT	Low Tension
MDMS	Meter Data Management System
EV	Electrical Vehicle
DT	Distribution Transformer
SAP	System, Application & Product
ERP	Enterprise Resource Planning
KVA	Kilo Voltage Ampere
PF	Power Factor
Coin MD	Coincident Maximum Demand
ABT	Availability Based Tariff
W.R.T	With Respect to
SQL	Structured Query Language
ETL	Extract Transform and Load

BIO-DATA

SUJATA GURUJI
Tata Power Co. Ltd.

Date of Birth:	05-10-1984
Qualification:	Post Graduate Program in Data Science and Business Analytics - Great Lakes Execute Learning BE - Electrical (VJTI) Veermata Jijabai Technological Institute, Mumbai
Designation:	Head Demand Side Management
Present Organization:	Tata Power Co. Ltd.
Field of Expertise:	Demand Side Management, Solar Net Metering, Scada, BESS.
Mobile:	+91 99713 95315
Email:	sujata.guruji@tatapower.com

BRIEF PROFILE

Power System Manager with over 18 years of valuable experience in Demand Side Management, Realtime Power Management and Scada at Tata Power Company Limited, overseeing major verticals like Value Added Services, Solar Net Metering, and Demand Side Management.

Well experienced in Real-Time Power Management & BESS (Battery Energy Storage System) Management. Outage Management and SCADA Administrator.

Track record of successful implementation of best practices in power distribution, leading to improved efficiency, optimized power purchase costs, and enhanced overall performance.

BIO-DATA

VEERAMURUGANANDAN PARAMASIVAN
Tata Power Co. Ltd.

Date of Birth:	19.01.1993
Qualification:	MSC. (Renewable Energy & Environment)
Designation:	Lead Engineer, Meter Management Group
Present Organization:	Tata Power Co. Ltd.
Field of Expertise:	Energy Metering, Monitoring and Analytics
Mobile:	+91 80976 45370
Email:	veera.sivan@tatapower.com

BRIEF PROFILE

Energy Data Monitoring, and Analysis Specialist based in Mumbai, possess strong expertise in managing the communication and data handling of AMR energy meters of consumers and distribution networks. Proficient in developing Energy monitoring dashboards and reports based on energy meter data. Experienced in performing Energy analysis for production units, rooftop solar systems, smart meter communications, distribution network operational analysis, and performance monitoring of utility equipment in manufacturing plants. With a focused approach on optimizing energy usage and improving data accuracy, always contribute significantly in Energy Monitoring, improving System Efficiency and sustainability initiatives on a large scale.

ENHANCING UTILITY OPERATIONS AND CONSUMER EXPERIENCE WITH SMART METER

Priyanshu Praliya | Mukesh Patel | Ankit Kumar | Ankur Sangwan | Sovik Sharma
Tata Power Delhi Distribution Limited

ABSTRACT

This paper explores the transformative impact of leveraging smart meter data to address India's energy challenges amid rapid urbanization and rising energy demands. It highlights how digital technologies, advanced analytics, can optimize energy efficiency and improve resource utilization. By fully utilizing smart meter data, utilities can enhance consumption forecasting, generate revenue insights, and deliver significant value to consumers. The study underscores the need for a collaborative approach, empowering consumers with quality power supply. Engaging a network of trusted stakeholders is essential to unlock the full potential of smart metering for both utilities and consumers.

1 INTRODUCTION

In today's rapidly growing population, India faces significant challenges in meeting the increasing energy demands while ensuring sustainable and efficient urbanization. However, the convergence of digital technologies and electrification is paving the way for transformative changes. Advanced analytics and machine learning further optimize energy generation, maximizing resource efficiency. This discussion explores how smart meters and related concepts enhance utility and consumer's experience, especially during the era of high energy demand and supply.

Globally, the power sector is undergoing a digital transition by undertaking digital initiatives and leveraging digital disruptions to upscale overall performance. Now is the time to unlock the true potential of smart meters and leverage their benefits beyond addressing as current grid problems of stability and loss reduction. custodians of the vast amount of data generated by smart meters, distribution companies need to fully utilize smart meter data analytics to improve consumption forecasting, thereby creating revenue insights for energy utilities and value for consumers. A collaborative approach involving consumers, their empowerment, and active participation must be prioritized.

Smart metering holds the potential to enhance energy availability by improving energy efficiency and reducing household energy bills. However, smart meters alone do not automatically lead to energy savings for residential consumers. The absence of an effective display of consumption patterns, such as an in-home display to provide consumer feedback on energy use, can impair performance. Only end-users who actively choose to use and are motivated by these tools can achieve energy savings. Empowering consumers by engaging and activating a network of trusted stakeholders is essential for any successful smart meter rollout.

2 HVDS VIRTUAL METERING

Traditionally, the peak loading of High Voltage Distribution System (HVDS) transformers has been estimated using the Maximum Demand Indicator(MDI)or sanctioned load of downstream consumers, supplemented by clamp-on meter readings. This conventional approach often leads to a decrease in the utilization factor of transformers and necessitates frequent additions to transformer capacity, resulting in increased capital expenditure (CAPEX).

To address this challenge, we propose the development of a Virtual Metering Dashboard utilizing consumer smart meter data. This innovative solution integrates data from Meter Data Management Systems (MDMs), Geographic Information Systems (GIS), and SAP, leveraging big data technologies to provide comprehensive loading reports for non-metered DTs. To address this challenge, we propose the development of a Virtual Metering Dashboard utilizing consumer smart meter data. This innovative solution integrates data from Meter Data Management Systems (MDMs), Geographic Information Systems (GIS), and SAP, leveraging big data technologies to provide comprehensive loading reports for non-metered DTs.

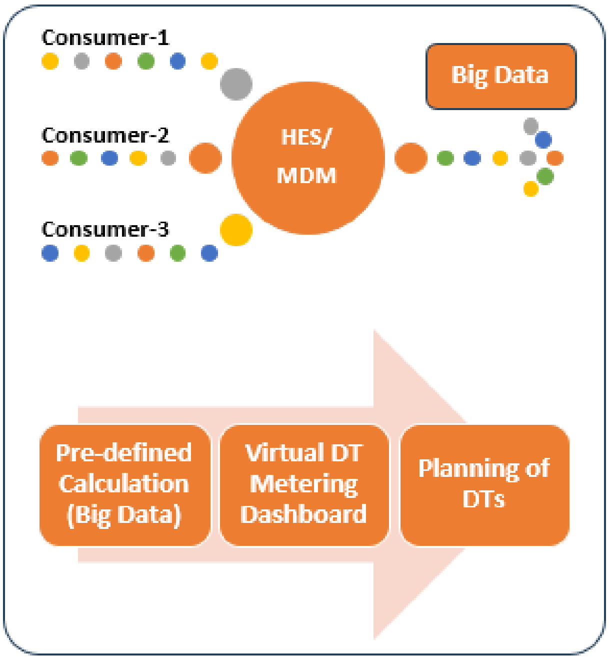


Fig 1: Methodology

The Virtual Metering Dashboard offers features such as load curve analysis and comparative analysis of DT loading patterns, enabling accurate comparisons between different DTs. By implementing this virtual metering concept, unmetered DTs connected to downstream smart consumers can be monitored for load curves, providing valuable insights into the loading patterns and utilization of different transformer ratings. This approach eliminates the need for manual clamp metering, enhancing safety and efficiency in DT planning.

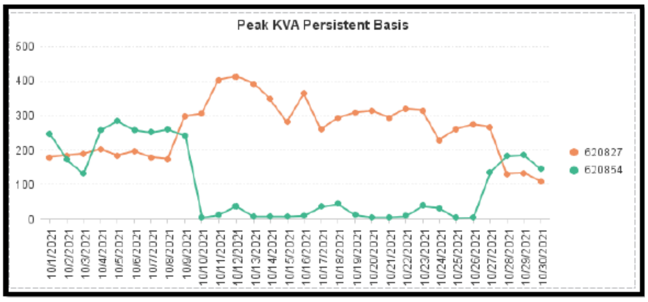


Fig 3: Sample Comparative Analysis

The development methodology involves several key steps. First, consumer smart meter is fetched from the MDM. Slot-wise meter data of consumers is then moved to a big data platform. HVDS data is fetched from the GIS, while SAP provides additional data such as multipliers (MF) and consumer information. This data is aggregated to generate load curves based on predefined logic. Peak loading is identified and the relevant data is moved to the dashboard for planning and analysis. This comprehensive approach allows for accurate identification of lightly loaded, overloaded, and optimally loaded DTs, facilitating efficient asset management and strategic planning. Ultimately, this virtual metering solution enhances the overall efficiency and reliability of the power distribution network, addressing the critical challenge of peak load monitoring in a cost-effective and sustainable manner.

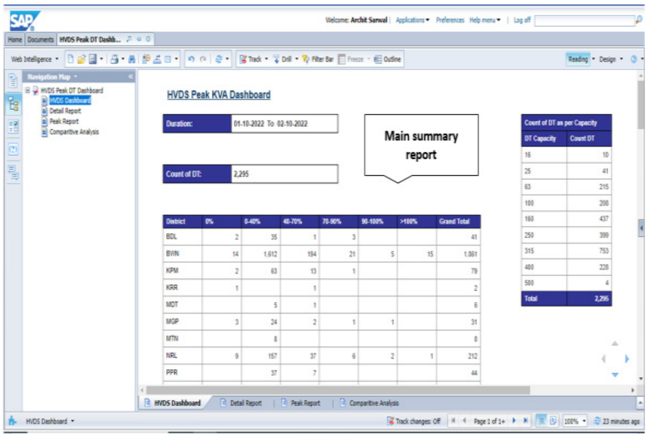


Fig 2: HVDS Virtual Metering dashboard

This project has eliminated the need for installing meters directly at High Voltage distribution transformers. Using Smart Meter's data, load curves for approximately 3400 High voltage distribution transformers have been derived. Furthermore, the dashboard has effectively identified lightly loaded and overloaded transformers, leading to 75 instances of transformer swapping. This initiative has significantly improved asset utilization and reduced the need for capital expenditure in the system. Moreover, over planning is avoided, possible theft can be identified, GIS indexing can be improved.

3 VOLTAGE VIOLATION ANALYSIS USING SMART METER

This section presents a case study on how a data-driven approach using smart meter data analysis significantly improved customer complaint resolution for voltage sag and swell issues. Traditionally, investigating these complaints relied on limited data and time-consuming manual processes. This project demonstrates how leveraging smart meter data and Python scripting transformed the complaint resolution process.

1. **Data Acquisition: Collection of smart meter data from three sources:**

   a. Smart Consumer meters: Provided detailed voltage readings at the customer premises.

   b. Distribution transformers (DT) Smart meters: Offered insights into voltage levels at distribution points.

   c. Grid meters: Captured voltage data at the overall grid level.

2. **Data Analysis: We have developed inhouse Python scripts to analyze the collected smart meter data. The scripts performed the following tasks:**

   a. **Data Filtering:** Extracted voltage data relevant to specific customer complaints.

   b. **Voltage Calculations:** Calculated key voltage metrics like average voltage, maximum voltage experienced, and number of high/low voltage slots.

   c. **Power Factor Analysis:** Analyzed power factor data (where available) to identify potential contributing factors to voltage violations.

   d. **Trend Analysis:** Analyzed historical complaint data to identify seasonal variations or recurring issues.

3. **Complaint Resolution: Based on the analyzed data, we identified root causes of voltage violations for each complaint. Examples include:**

   a. **High voltage and leading power factor at the consumer end:** This indicated potential equipment malfunction or improper load balancing at the customer's facility. The utility could recommend corrective actions to the customer.

   b. **Low voltage throughout the year:** Analysis of historical data and long LT feeder information suggested voltage drop due to distance. The utility could plan infrastructure upgrades like installing voltage regulators or extending feeder lines.

Results and Discussion

The implementation of smart meter data analysis resulted in significant improvements:

a. **Faster and More Accurate Root Cause Identification:** By analyzing detailed voltage data, we pinpointed the root cause of voltage violations more efficiently compared to traditional methods.

b. **Targeted Solutions:** Based on the identified cause, we could recommend specific solutions to the customer or address issues within the grid infrastructure.

On the logics developed for the analysis, a portal is also developed to get the analysis done faster using technologies like bigdata

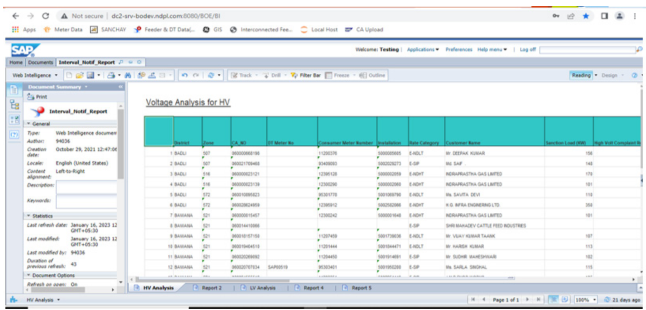


Fig 4: Voltage portal

4 CASE STUDY

1. **High Voltage and Leading Power Factor:** A customer complaint about high voltage revealed leading power factor at their facility through consumer meter data analysis. This suggested potential equipment malfunction or improper load balancing, causing voltage to rise. The customer was

advised to investigate their equipment or implement load balancing strategies.

2. **Low Voltage throughout the year:** Analysis of a low voltage complaint revealed consistent low voltage throughout the year in consumer meter data. Historical data and feeder information confirmed a long LT feeder as the culprit. This knowledge allowed the utility to plan infrastructure upgrades to address the voltage drop issue.

This visual representation would showcase the effectiveness of the approach in reducing voltage-related complaints.

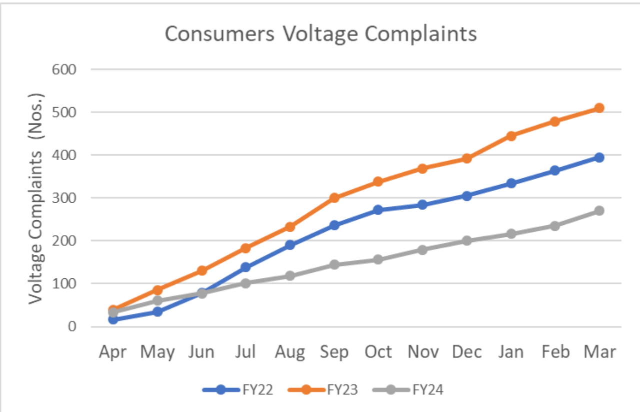


Fig 5: Comparative Analysis of Voltage complaints year wise

In above figure, it is showing that the trend of voltage complaints was increasing by year-on-year basis from 2021 and it was before the analysis.it is showing the trend of significant reduction in voltage complaints after the analysis. As it can be seen in the figure, complaints reduced by 31% in the year FY24.

5 CONCLUSIONS

This case study demonstrates the power of smart meter data analysis in enhancing customer complaint resolution for voltage violations. By leveraging Python scripts to analyze detailed voltage data, utilities can identify root causes more efficiently and recommend targeted solutions. This data-driven approach not only improves customer satisfaction but also contributes to a more reliable and efficient power grid.

Looking ahead, the potential applications of smart meter data are vast. Future uses may include more sophisticated predictive maintenance, advanced load forecasting, real-time energy consumption monitoring, and integration with renewable energy sources. This data-driven approach can continue to enhance operational efficiency, prevent outages, detect theft, and optimize grid management, paving the way for a smarter and more resilient power distribution network.

6 REFERENCES

[1]. https://en.wikipedia.org/wiki/Tata_Power_Delhi_Distribution_Limited

[2] *Defu Cai, Wenna Wang, Xianjun Ma, Min Xu, ZhentingHe, Zeyang Tang, Chu Zhou, Na Han, Ying Wang, Analysis of Heavy load and Overload Distribution Transformer in Regional Power Grid*

BIO-DATA

PRIYANSHU PRALIYA
Tata Power Co. Ltd.

Date of Birth:	22-12-1998
Qualification:	B.TECH
Designation:	Assistant Manager
Present Organization:	TataPower DDL
Field of Expertise:	Network Planning
Mobile:	+91 70600 42556
Email:	Priyanshu.Praliya@Tatapower-ddl.com

BRIEF PROFILE

Priyanshu Praliya, 25, is an electrical engineer with 3 years of experience at Tata Power Delhi Distribution Limited, currently working in the Network Engineering Department. Priyanshu specializes in optimizing power distribution networks and has authored numerous technical papers at platforms like CIGRE Paris, ISUW, and CBIP etc.

MUKESH PATEL
Tata Power Co. Ltd.

Date of Birth:	
Qualification:	B.TECH
Designation:	Assistant Manager
Present Organization:	TataPower DDL
Field of Expertise:	Network Planning
Mobile:	
Email:	Mukesh.patel@Tatapower-ddl.com

BRIEF PROFILE

Mukesh Patel, 25, is an electrical engineer with 3 years of experience at Tata Power Delhi Distribution Limited. Currently working as Senior Executive in the Network Engineering Department, Mukesh specializes in optimizing power distribution networks, enhancing system efficiency, and implementing innovative solutions for improved grid performance.

BIO-DATA

ANKIT KUMAR
Tata Power Co. Ltd.

Date of Birth:	
Qualification:	B.TECH
Designation:	Senior Manager
Present Organization:	TataPower DDL
Field of Expertise:	Network Planning
Mobile:	+91 93109 77599
Email:	ankit.kumar91@tatapower-ddl.com

BRIEF PROFILE

Mr. Ankit Kumar is currently working as Team Leader- Network Engineering Department 11 KV and Below Capex Planning at Tata Lower Delhi Distribution Limited. He is an alumnus of National Institute of Technology, Kurukshetra and has around 11 years of experience in Power Distribution Planning and EPC business of Oil and Gas Industry. His interest includes Power System Modelling, Data Analytics, Total Quality Management etc.

ANKUR SANGWAN
Tata Power Co. Ltd.

Date of Birth:	
Qualification:	B.TECH
Designation:	Assistant Manager
Present Organization:	TataPower DDL
Field of Expertise:	Network Planning
Mobile:	88000398355
Email:	mukesh.patel@Tatapower-ddl.com

BRIEF PROFILE

Head of Group, Network Engineering Group, Tata Power Delhi Distribution Limited,14 years learnings in Power Sector Engineering including Power Distribution Network Planning & Designing. Business Analysis including use cases of Smart Meters Data, Project Management, Digital Substation, Power Management, Network Operations (SCADA/ DMS/OMS).

BIO-DATA

SOVIK SHARMA
Tata Power Co. Ltd.

Date of Birth:	
Qualification:	B.TECH
Designation:	Senior Manager
Present Organization:	TataPower DDL
Field of Expertise:	Network Planning
Mobile:	
Email:	

BRIEF PROFILE

17 + years of rich experience in Power Distribution sector which includes different types of skill set like Power system analysis and Optimal planning, CAPEX DPR preparation for 11 KV and LT system, Operation and Maintenance, Energy Accounting from Grid to Consumer side, Meter data management and study, Detailed Project Report on Power Distribution system strengthening schemes like RAPDRP Part B, IPDS, DDUGJY &RRDS. Network Planning and Master Plan Preparation through Load Flow study, Load Forecasting and Contingency Method with the help of simulation tool CYME. Technical loss reduction plan reports for various distribution government and private discoms. Project Management Assistance to UPPCL under UDAY scheme whose main objective is to Reduce the AT&C loss below 15% and Reducing the ACS ARR gap to Zero. Giving assistance to discoms in analysis of major commercial parameters in order to improving the Billing and collection efficiency of the system

SUSTAINABLE AND CONSUMER-CENTRIC UTILITIES TOWARD NET ZERO: "AMI- EMPOWERING STAKEHOLDERS"

Ashish Mundra | Pratiksha Kulkarni
Adani Energy Solutions Ltd.

ABSTRACT:

The transition towards a net-zero future necessitates innovative approaches to energy management and consumption. Smart metering technology plays a pivotal role in this transition by empowering various stakeholders, including consumers, utilities, Original Equipment Manufacturers (OEMs) and meter installers. This paper explores how smart metering facilitates consumer-centric and sustainable utilities, aligning with net-zero goals, also explains the current challenges of AMI.

1. INTRODUCTION:

The drive towards sustainability and achieving net-zero emissions by mid-century has prompted significant advancements in energy technologies. Among these, smart meters have emerged as crucial tools in the energy ecosystem. Unlike traditional meters, smart meters offer real-time data on energy consumption, which benefits multiple stakeholders in the energy value chain. This paper examines how smart meters empower consumers, utilities, OEMs, meter installers and various vendors fostering a consumer-centric and sustainable utility landscape.

2. SMART METERING ARCHITECTURE:

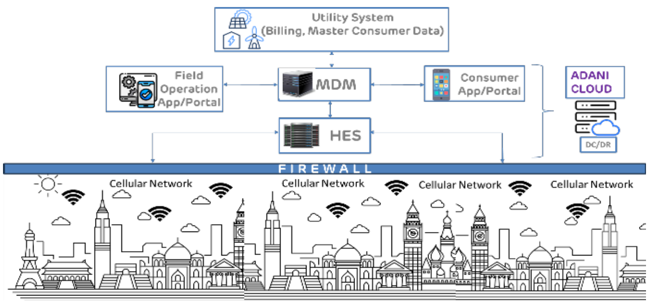


Figure 2.1 Smart Metering Architecture

Figure 2.1 depicts the architecture of smart metering. Smart meters installed across various locations (buildings) communicate through cellular networks. Data from these meters is sent through a security system to ensure security. The HES processes the incoming data and forwards it to the MDM. MDM integrates and manages this data, making it accessible to both the field operation app/portal and the consumer app/portal. The utility system at the top manages billing and consumer data based on the information processed by MDM and HES. All the data is securely stored and managed in the ADANI CLOUD, providing robust support for data center operations and disaster recovery. This architecture ensures efficient, secure and real-time management of energy consumption data, facilitating better decision-making for both utilities and consumers.

THE SIGNIFICANCE OF SMART METERING TECHNOLOGY:

Smart metering technology represents a paradigm shift from traditional metering systems by providing real-time monitoring, analysis and control of energy consumption. Smart meters empower users with valuable insights into their energy usage patterns by enabling two-way communication between consumers and utilities.

3. EMPOWERING CONSUMERS:

One of the primary advantages of smart metering technology lies in its ability to empower consumers. Through access to detailed information on their energy usage, consumers can identify opportunities for optimization, implement energy-saving measures and actively participate in demand response programs. This empowerment leads to cost savings for consumers and fosters a sense of ownership and environmental responsibility. By providing detailed consumption data, smart meters enhance consumer engagement. Consumers can monitor their energy usage through apps and online portals, set energy-saving goals and receive alerts about unusual consumption patterns. This proactive engagement fosters a more sustainable lifestyle.

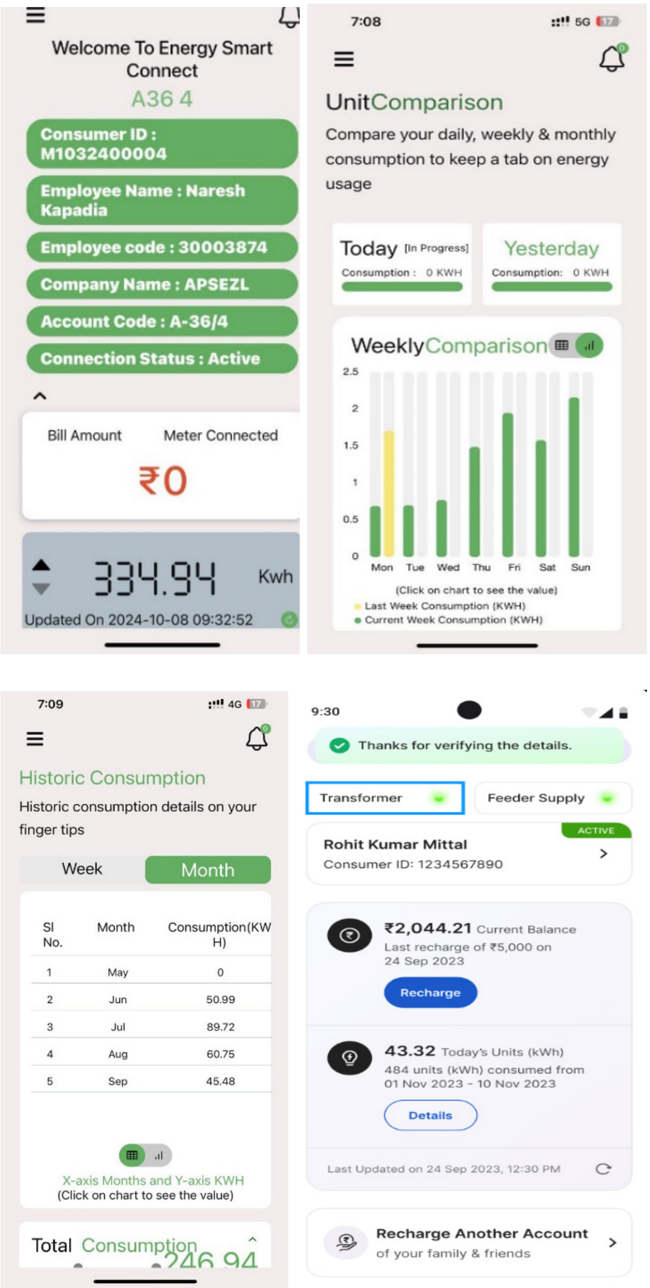


Figure 3.1 Consumer Application

CATALYSING GREATER SATISFACTION:

Smart metering technology enhances customer satisfaction by offering a range of benefits, including accurate and transparent billing, timely fault detection and personalized energy management services. By minimizing billing disputes and reducing downtime, smart meters contribute to improved service reliability and customer experience. Moreover, the availability of real-time data enables utilities to offer tailored solutions and proactive support, further enhancing satisfaction levels.

4. SUSTAINABILITY OF UTILITIES:

The integration of smart metering technology is instrumental in ensuring the sustainability of utilities by optimizing grid operations, reducing losses and facilitating the integration of renewable energy sources. Through advanced analytics and predictive modelling, utilities can gain valuable insights into consumption patterns, anticipate demand fluctuations, and optimize resource allocation.

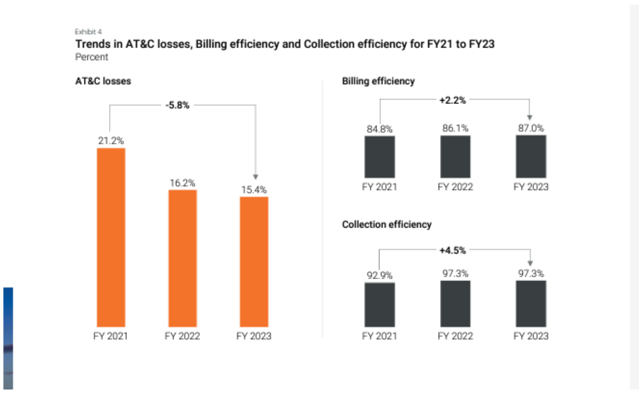


Figure 4.1 Improved efficiency of billing and collection and reduced AT&C losses

4.1 Load forecasting

(current scenario- past data dependent, AfteR SM installation- Real-time data-based)

The shift from traditional load forecasting based on historical data to advanced forecasting using real-time data from smart meters represents a significant technological advancement for utilities in India.

Dependency on Historical Data: Utilities in India predominantly rely on historical data to forecast electrical load. Historical data typically includes consumption patterns, seasonal variations, economic indicators, etc. Challenges are being faced due to dependency on past data such as inaccuracy due to changes in consumption behavior, delay in data collection, etc. Load Forecasting Scenario with Smart Meters: Smart meters provide real-time or near-real-time data on electricity consumption. This data is more detailed and can be broken down into smaller time intervals. Continuous data collection allows for more accurate load forecasting models, reducing errors and improving reliability leading to proactive management improving grid stability and efficiency.

4.2 DATA ANALYTICS AND MANAGEMENT TO INCREASE THE EFFICIENCY OF UTILITIES BY MAKING INFORMED DECISIONS:

Data analytics and management in smart metering are revolutionizing how utilities operate, making them more informed and capable of making decisions that drive sustainability and progress toward net-zero goals.

Below are the images of our Meter Data Management System developed to effectively collect, store, process and analyse the vast amount of data generated by smart meters.

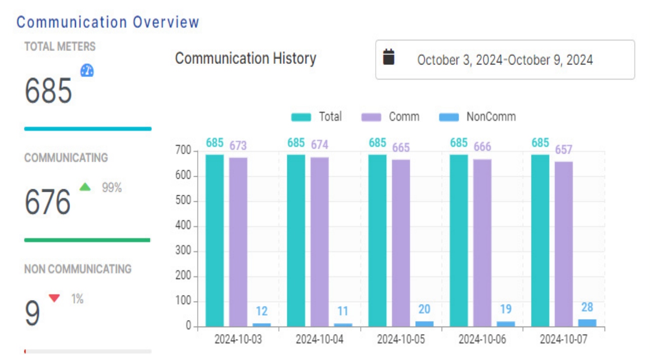


Figure 4.2.1 MDM showing communication report of installed smart meters

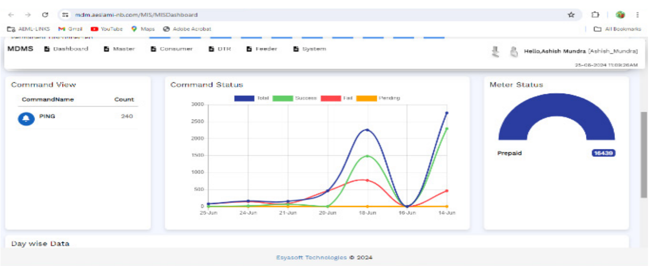


Figure 4.2.2 MDM showing prepaid data of installed smart meters

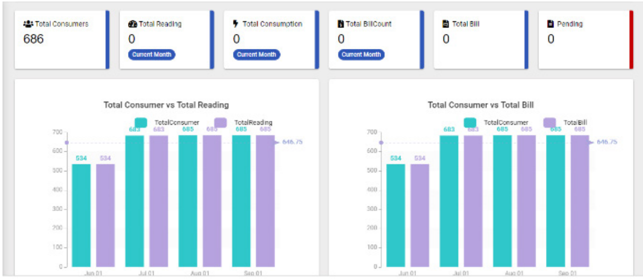


Figure 4.2.3 MDM dashboard showing total consumers Vs total reading

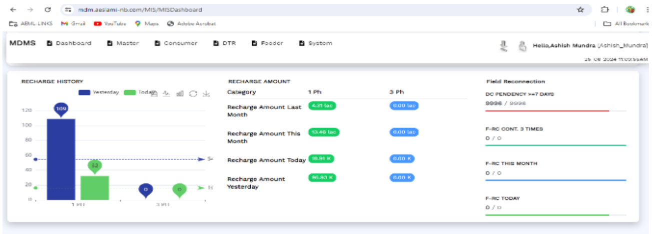


Figure 4.2.4 MDM dashboard showing revenue generation due to installed smart meters

5. INNOVATIVE APPROACHES THAT CONTRIBUTE TO THE EMPOWERMENT OF STAKEHOLDERS:

5.1 DEVELOPMENT OF VR MODELS FOR TRAINING INSTALLATION VENDORS: These models can simulate real-world scenarios, providing hands-on experience in a controlled environment. Trainees can practice without the risk of damaging equipment or causing safety incidents. Scenarios can be repeated as often as needed for the trainee to master the skills. Being cost-effective, it reduces the need for physical materials and travel, leading to cost savings. Incorporating VR models into training programs for smart meter installations can enhance the learning experience and improve the efficiency and safety of the installation process.

Figure 5.1.1 Use of VR Model for Training

Figure 5.1.2 Use of VR Model for Training

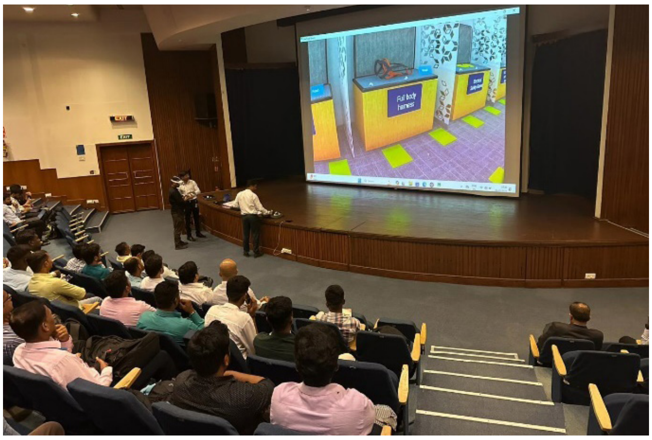


Figure 5.1.3 Use of VR Model for Training

Developed a Smart meter test lab to test and learn new technologies: Creating a smart meter test lab is a great initiative for testing and learning new technologies related to smart metering. This lab can serve as a controlled environment to evaluate smart meters' performance, integrate new technologies, and train personnel.

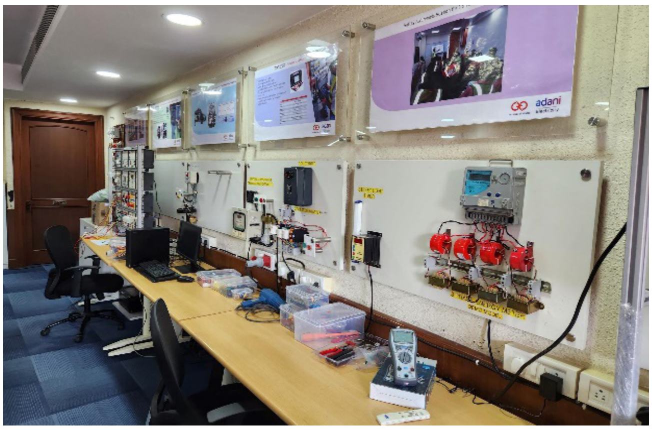


Figure 5.2.1 Smart Meter Lab

5.3 Development of an AI-based quality check tool: Developing an AI-based quality check tool for smart meter installation involves leveraging advanced technologies such as computer vision, machine learning, and IoT. This tool can help ensure that installations are performed correctly and adhere to all necessary standards and regulations—automated visual inspection to ensure correct positioning, wiring, and connections.

5.4 Development of a mobile application that performs auto allocation of field crew daily: Automated scheduling is done with the help of algorithms to automatically allocate daily tasks to field crews based on factors like availability, proximity, skill set, and workload balance. It provides detailed task information, including locations, required tools, and installation instructions.

Complementing India's Journey Towards Net Zero:

In India's ambitious goal to achieve net zero emissions, smart metering technology plays a pivotal role in enabling the efficient utilization of resources and the decarbonization of the energy sector. By promoting energy conservation, facilitating demand-side management and supporting the adoption of renewable energy, smart meters contribute to reducing carbon emissions and mitigating climate change impacts. Furthermore, the data-driven insights provided by smart meters can inform policy formulation and drive innovation in energy management practices, thereby accelerating India's transition towards a sustainable, low-carbon future.

6. CURRENT MAJOR CHALLENGES:

- **Technological hurdle**: Ensuring robust and secure communication networks, data management systems, and compatibility with legacy infrastructure.
- **Regulatory Considerations**: Navigating complex regulatory environments and aligning AMI deployments with evolving energy policies and standards.

- **Consumer Adoption**: Addressing consumer concerns about data privacy, security, and the perceived costs of smart meter installations.

- **Network Connectivity and Reliability**: AMI relies on robust communication networks for real-time data transmission. Ensuring consistent and reliable connectivity, particularly in remote or rural areas, can be challenging.

- **Interoperability Issues:** The integration of devices from different manufacturers and vendors can be challenging. Ensuring interoperability between different systems, protocols, and standards is necessary for seamless operation but is often difficult to achieve.

8. CONCLUSION:

In conclusion, the power of smart metering technology cannot be overstated in the context of India's journey towards net zero emissions. By empowering consumers and utilities, catalysing greater satisfaction and ensuring the sustainability of utilities, smart meters offer a multifaceted solution to the challenges facing the energy sector. As India continues to pursue its ambitious sustainability goals, the widespread deployment of smart metering technology will be essential in unlocking new opportunities for efficiency, resilience and innovation in the energy landscape.

9. REFERENCES:

- Smart Meters, Big Data and Customer Engagement: In Pursuit of the Perfect Portal- By Beth Hartman and William LeBlanc, E Source

- Sustainable Energy, Grids and Networks- By Rajesh K. Ahir, Basab Chakraborty

- Net Zero Energy Districts: Connected Intelligence for Carbon-Neutral Cities- By Nicos Komninos

- https://www.mdpi.com/2073-445X/11/2/210

- Perspectives of smart meters' roll-out in India: An empirical analysis of consumers' awareness and preferences- By Yash Chawla, Anna Kowalska-Pyzalska, Anna Skowrońska-Szmer

- Public Awareness and Consumer Acceptance of Smart Meters among Polish Social Media Users- By Yash Chawla, Anna Kowalska-Pyzalska https://www.mdpi.com/1996-1073/12/14/2759

- Data from the Ministry of Power, Government of India https://powermin.gov.in/

- Data from REC (Rural Electrification Corporation Limited) website. https://recindia.nic.in/revamped-distribution-sector-scheme

BIO-DATA

ASHISH MUNDRA
Adani Energy Solutions Limited

Date of Birth:	26/03/1986
Qualification:	B.Tech
Designation:	General Manager
Present Organization:	Adani Energy Solutions Limited
Field of Expertise:	Projects
Mobile:	+91 93213 30515
Email:	ashish.mundra@adani.com

BRIEF PROFILE

Professional with extensive experience in the energy sector, particularly in project management and operations of high-tension networks. Currently serving as the General Manager at Adani Electricity Mumbai Ltd, he leads a team responsible for monitoring multiple smart metering projects across India. His career spans over a decade, marked by roles of increasing responsibility and significant contributions to operational efficiency and project execution.

BIO-DATA

PRATIKSHA VIJAY KULKARNI
Adani Energy Solutions Limited

Date of Birth:	16/02/1997
Qualification:	MBA
Designation:	Assistant Manager
Present Organization:	Adani Energy Solutions Ltd.
Field of Expertise:	Project Monitoring
Mobile:	+91 96533 70621
Email:	pratiksha.kulkarni@adani.com

BRIEF PROFILE

I have been working with Adani Energy Solutions Ltd for a year in the Smart Metering Department. My core expertise is Project Monitoring of all the projects ongoing across India. I like to research and learn new technologies.

LEVERAGING METER DATA FOR CONSUMER & UTILITY

Ms. Sonali Umbre | Mr. Manish Thool
Tata Power Co. Ltd.

ABSTRACT

Accurate load forecasting is the most important activity to optimize power purchase cost (around 75% of any power distribution utility expenses). Tata Power-D Mumbai load consists of direct & welcome consumers i.e., Mumbai's unique load-mix situation. As welcome consumers aren't on its wires, no real-time/daily, base load data is available for load forecasting. Also, Due to severe climate change impact on electricity consumption, as well as new trends in smart grids accurate load forecasting has become a crucial need. Such forecasts are necessary to support the plans and decisions related to the capacity evaluation of generation capacity, power management, peak reduction, market evaluation, demand response strategies, and controlling the operation. Thus, with Accurate forecasting power purchase cost of Discom reduces, this ultimately reduces tariff of end consumers, and all the benefits are passed on to the consumers directly.

This paper gives an illustration on the experience during inhouse development of Load forecasting application at TATA Power based on the analysis of data acquisition from ABT meter installed & its comparison with real time SCADA system. The ABT meter has been installed for all TPCD feeders along with EHV Open Access consumers at Receiving station.

Keywords—ABT – Availability based Tariff Meter.

E-watch: Web Application for data acquisition & analysis of ABT data.

Behavioral based load forecasting, welcome consumers, power purchase cost optimization, machine learning technique.

1. INTRODUCTION

Load forecasting has an essential role in Energy Management as it facilitates Power Infrastructure planning, generation scheduling, Balancing supply & demand etc.

Demand forecasting is to be done every 15 minutes on day ahead basis, based on Historical data. Data is acquired from about a total of 35000 AMR and smart meters approximately & is necessary for scheduling optimum power. With the introduction of new settlement mechanism (DSM), being implemented in Maharashtra from 11th October 2021, penalties would be charged for inaccurate forecast and are not allowed to be adjusted in tariffs. Hence, schedules become datum from which deviation in drawl with reference to planning are measured & deviation penalties are linked to frequency. Each entity (Utility) prepares the requisition based on their own sources & forecasted demand for the day. The difference between forecasted demand & own availability becomes their requisition. Thus, forecasting demand accurately for each 15-minute block of the day has a major effect on the tariff.

TATA Power has basically deployed multivariable regression forecast/ Time Series model with historical data for extrapolation to predict the future load.

The block-wise historical data from ABT based data acquisition system (TPCD use M/s Secure Meter application E watch system) is being vastly used as in initial important data for processing.

The challenges of load forecasting experiences are as:

1) Difference in SCADA & E-watch (ABT) values on block level basis for TPCD & OA consumers

2) Realtime Market Trend & Bid placing according to Shortfall / Surplus

3) Change in regulations

4) Change in Weather Dependent Load

5) Forecasting Error margin > 8-10%

6) Schedule Vs Forecast Trend

7) REMC revision & their impact on the load forecasting was being done by using Proprietary software which was working on discrete inputs.

With these challenges, there was need to develop a tool based on actual meter data that will be used for real time monitoring in a comprehensive program for reducing forecasting errors of less than 2%.

Tata Power Mumbai needs to develop this comprehensive application to integrate the discrete time series data from E-watch system (ABT data), Real time market values (IEX), Block-wise Weather Inputs, Load monitoring of EHV open access consumers & linking external forecasting proprietary application etc.

This paper specifically explained the developments made by leveraging ABT data for improvement in load forecasting application at TATA Power.

2. METHODOLOGY

Power Management is structured into three key phases: Planning, Scheduling & Execution, and Validation. First the engine auto fetches three different types of demand from different sources and derives forecasted load for the next day with flexibility to address any further demand side changes. While forecasting the load, we need to take the following factors into consideration e.g. weather parameters, time of week, season, Holiday, and recent demand. utility must predict the time-wise demand of energy of the consumer base at 15-minute intervals- total 96 time slots per day.

To meet this forecasted demand, engine optimizes all different sources like Gas, base load Thermal, must absorb purchases, accommodates varying renewables, and adjust hydro generation in such a way to ensure either exchange power purchase at lower rate or sale at higher rate. Thereafter, bids are placed also, input is given to Billing Module wherein, DSM bills are received on Weekly Basis from State load Dispatch center, Drawl data for (7 days*96 blocks) is to be verified for 350+ meters.

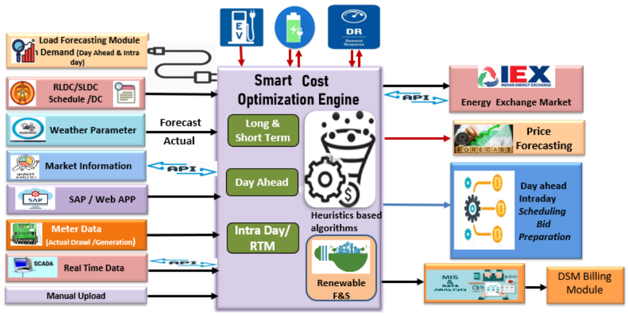


Fig 2.1 Block diagram of optimization engine

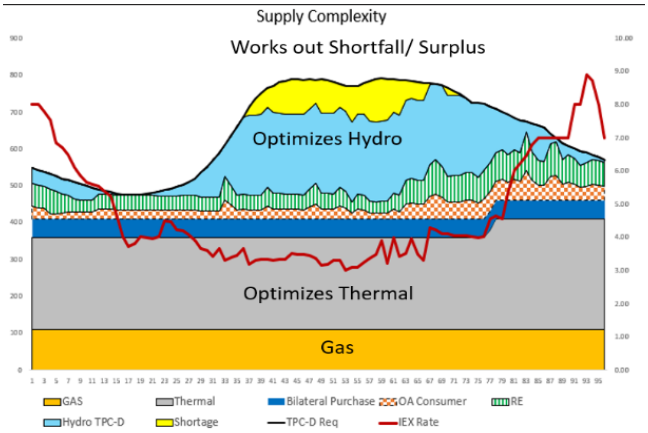


Fig 2.2 Typical Load Curve for TPC Mumbai fullfilled by various sources.

In this research, the task of forecasting is formulated as follows:

To build a model that would transform the input data (features) X into a forecast of daily loads for a Weeks/Months ahead Y: Y = f (X)

The mean absolute percentage error (MAPE) was chosen to be the indicator of the forecast accuracy:

$$M = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right|$$

M AP E =

Were,

n is the number of hours within the dataset.

At is the actual value,

Ft is the forecast value.

Σ is summation notation (the absolute value is summed for every forecasted point in time).

The mean absolute percentage error (MAPE) is the most common measure used to forecast error and works best if there are no extremes to the data (and no zeros).

Previously, our load forecasting for a total of load yielded high error rates. To mitigate this, we explored categorical load forecasting incorporating weather influences. However, given the diverse load profiles across different areas, this approach didn't yield the desired results. As a solution, we opted for a combined approach, integrating zone-specific load data with weather forecasting. This led us to install weather stations across all six zones, resulting in the desired accuracy in our forecasting methodology. TATA power Discom is divided into 6 different Zones, with different consumer base of total 7.6 lakhs.

Fig 2.3 Map Considering different zones of Mumbai City.

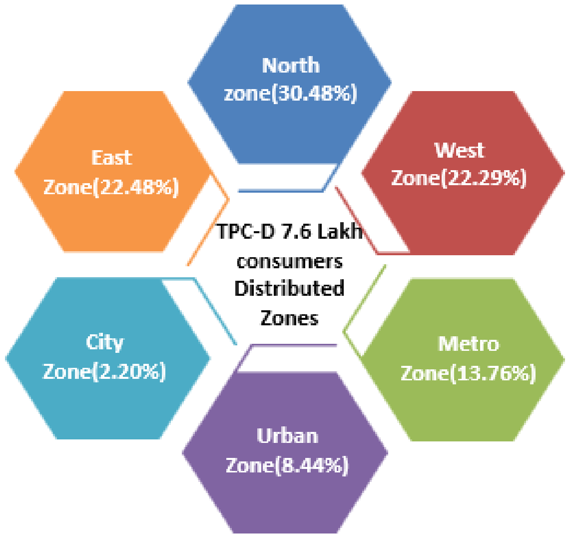


Fig 2.4 Consumer concentration in different zones of Mumbai City

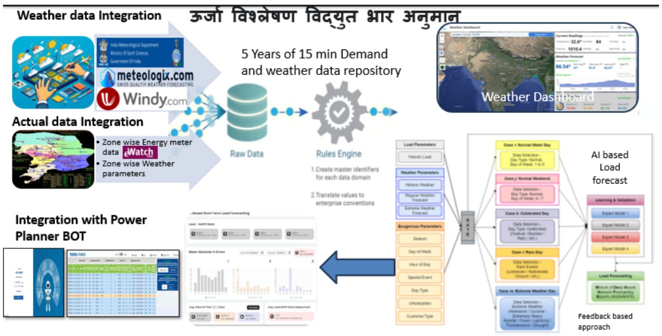


Fig 2.5 Block diagram of forecasting Module.

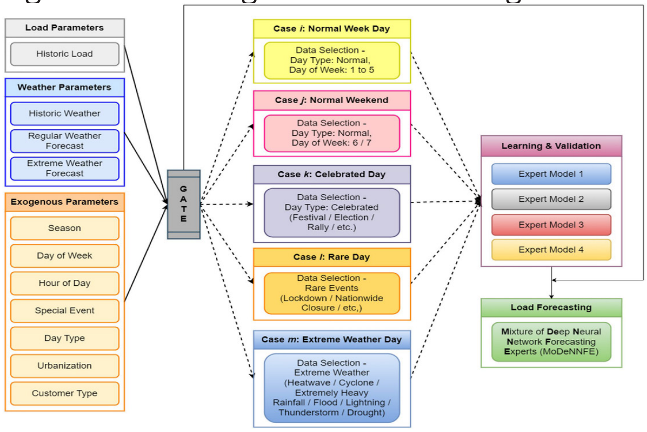


Fig 2.6 Weather dependent forecasting module

It begins with gathering inputs from various weather sites to forecast area-specific weather conditions, alongside data from weather stations for real-time parameters. These inputs are then fed into a weather dashboard. The forecasted weather for different zones is subsequently provided as input to our load forecasting module. Within this module, algorithms are developed to generate day-wise and area-specific load forecasts. These forecasts serve as inputs to our BOT-based power management system.

In power planner, the Forecasted load is continuously monitored for real time operation and load generational balance, Development of analytical display using logic & data quality has been done to take faster and accurate decisions.

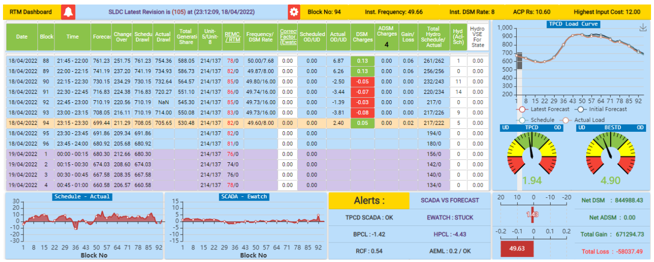
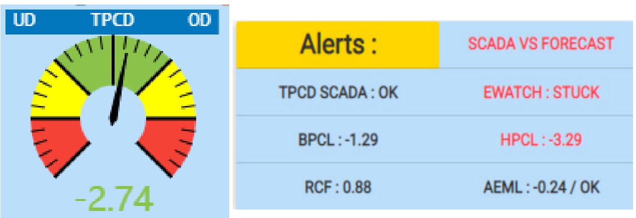
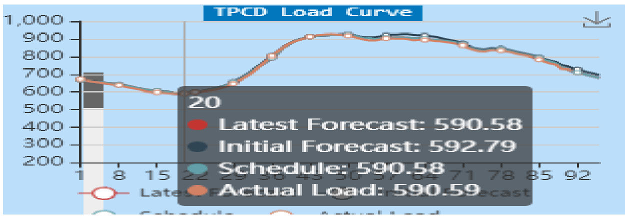
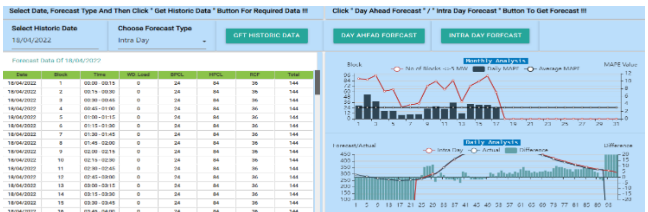


Fig 2.5: Integrated display using logics & data quality.

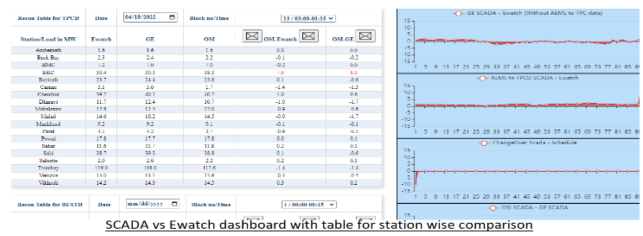




2.6 Comparison of Forecasted load with actual data



Forecast engine dashboard with click buttons to execute forecast



SCADA vs Ewatch dashboard with table for station wise comparison

2.7 Dashboards for further analysis as per DSM regulation.

3. ADVANTAGES

1) Helps Power Planning team for load prediction as weather load is being driven by EHV/ OA consumer or is being a Weather dependent load. This will help them with decision making at Day Ahead as well as real time level.

1.1) Comparison of Forecasted load with actual data

1.2) Weather parameter prediction (Temp & Humidity level) to understand impact of weather on forecasting

1.3) Indication of Bad data in case data is stuck/not available

1.4) Fetching historical data for analysis

2) Realtime Power Management:

2.1) Understanding consumption pattern & block wise load requirement of EHV & Open Access Consumers which direct impact on TPCD Load curve

2.2) Facility to fetch SCADA data without breaching Cyber Security protocol

2.3) Leveraging web API from external resources for monitoring (SLDC/AEML etc)

3) DSM & Billing Team

3.1) Understanding Market Trend on Realtime as well as Historical basis with all balance parameters

3.2) REMC revision & its impact on MOD

3.3) Daily review of Forecasting accuracy

4. BENEFITS:

This innovation helped TPC-D to improve load forecasting accuracy by around 2%. For the period FY25, we can forecast consumer demand more precisely. With implementation of DSM regulation, Any Deviation would have been directly deducted from the TPC-D profit margin and the same is non recoverable through consumer tariff. The second most important benefit is manual, person specific and time-consuming process is replaced by fast, accurate and system-based process. So, the manual errors are minimized, and output is available at a single click.

In the past three years the solution has covered various iterations pertaining to changes in regulations, addition of power & interfaces. As the practice covers various EPM processes right from planning & execution till billing, the SOP's & process flow were updated accordingly.

Additional benefits as Ease of data handling, Cycle time reduction, Digitalization through process innovation, Improved efficiency with analytics as well as Insights.

5. EASE OF USE

Complex, manual process is replaced by simplified, system based Accurate process.

Time saving of 1.5-2 Hrs./daily basis Now, result available on single click.

Abbreviations and Acronyms

TPC-D: Tata power Company - Distribution,

PSCC: Power System Control Centre, TATA Power Mumbai

API: Application Program Interface

SLDC: State Load Dispatch Centre

DSM: Deviation Settlement Mechanism

MOD: Merit Order Dispatch

AMR: Automated Meter Reading

CAPEX: Capital expenditure

MU's: Million Units

B. Units

Kwh: The kilowatt-hour (SI symbol: kW-h or kW h; commonly written as kWh) is a unit of energy equal to 3600 kilojoules (3.6 mega joules). The kilowatt-hour is commonly used as a billing unit for energy delivered to consumers by electric utilities.

MW: means the electrical power, being the product of root mean square (rms) voltage, root mean square (rms) current and cosine of the phase angle between the voltage and current vectors and measured in units of 'Watt' (W).

Accuracy in percentage: The ability of the instrument to measure the accurate value is known as accuracy.it is measured in percentage.

Future Scope and Planning

Currently, Load forecast is done for Day ahead & Intraday basis, Since the demand for electricity in Mumbai is increasing rapidly due to an increase in the customer base, changes in lifestyle and consumption patterns, which calls for continual accurate electric load forecasting, inclusion of Battery storage to meet consumer demand while optimizing the existing resources, providing with Peak shaving, backup power and grid stability.

EMERGING USE CASES IN SMART METERING - DISCOMS' PERSPECTIVE

Subhadip Raychaudhuri | Saurav Chandel | Balagurunathan G
Tata Power Co Ltd

ABSTRACT

The implementation of smart metering technology represents a significant advancement for power distribution utilities in India, addressing critical challenges and enhancing operational efficiency. Smart meters provide real-time, granular data on energy consumption, enabling both utilities and consumers to make informed decisions. This paper explores key data-based use cases of smart meters, focusing on their impact within the Indian power distribution context. By leveraging smart meter data, utilities can implement effective demand response strategies, balance supply and demand during peak periods, detect and address faults early, integrate renewable energy sources efficiently, and enhance customer engagement through personalized energy reports and alerts. This integration not only drives energy efficiency and reliability but also supports India's growing renewable energy sector and regulatory compliance, ultimately leading to a more sustainable and resilient electrical infrastructure.

1 INTRODUCTION

In an era where energy efficiency and reliability are paramount, smart metering technology offers transformative benefits for power distribution utilities such as Tata Power. As a leading utility operating across several locations (Delhi, Odisha, Mumbai) in India, having a combined consumer base of around 12.5 Lakhs (1.25 Million), we have implemented smart metering to modernize our infrastructure and meet the growing demands of our customers. In subsequent sections, we shall discuss the practical use cases of our smart meter deployment, illustrating its impact on various aspects of our operations. We will explore how smart meters have enabled precise energy consumption monitoring, facilitated effective demand response strategies, enhanced fault detection and predictive maintenance capabilities, and are a key enabler in integrating distributed renewable energy sources for both us and our customers. Our goal is to present a comprehensive analysis of these use cases, demonstrating how smart metering has not only improved our service reliability and efficiency but also empowered our customers with better control over their energy usage. Through this detailed exploration, we aim to provide valuable insights and a potential blueprint for other utilities looking to leverage smart metering technology.

2 ARCHITECTURE OF SMART METERING IN TATA POWER DISCOMS

There are broadly two communication categories in smart metering. The Neighbourhood Area Network (NAN), which refers to a local network that connects smart meters within a close geographic area. RF (Radio Frequency) Mesh is a communication technology used within NAN that creates a network where each smart meter acts as a node, relaying data to neighboring meters until the data reaches a central collection point. This communication technology has high reliability due to the mesh structure, which provides multiple paths for data to travel. It also has a self-healing capability, where the network can automatically reconfigure itself if a node fails or a path is disrupted. The other category of communication technology is the Wide Area Network (WAN) that connects smart meters over larger geographic areas, extending beyond the local neighborhood to cover an entire city or region. NB-IoT (Narrow Band – Internet of Things) and 4G are the communication technologies used presently within WAN to transmit data from smart meters to central systems over long distances. NB-IoT offers low power consumption and wide coverage, making it suitable for connecting devices that require reliable, long-range communication. 4G provides high-speed data transmission and extensive network coverage, ensuring timely and efficient communication. Tata Power DISCOMs have deployed smart meters based on communication technologies in both Neighborhood Area Network (NAN) – RF mesh and Wide Area Network (WAN) – NB-IoT and 4G in its licensed areas of operations. As depicted in Fig.1, there are two separate HES for WAN and NAN which are integrated into a unified Meter Data Management System (MDMS). It is a centralized system that stores, processes, and manages data collected from all smart meters across the utility's network. It integrates data from both the NAN and WAN HESs into a single platform, providing a unified view of all meter data. The MDMS supports data analytics, reporting and billing processes (through the billing engine of SAP), enabling the utility to make informed decisions and improve operational efficiency.

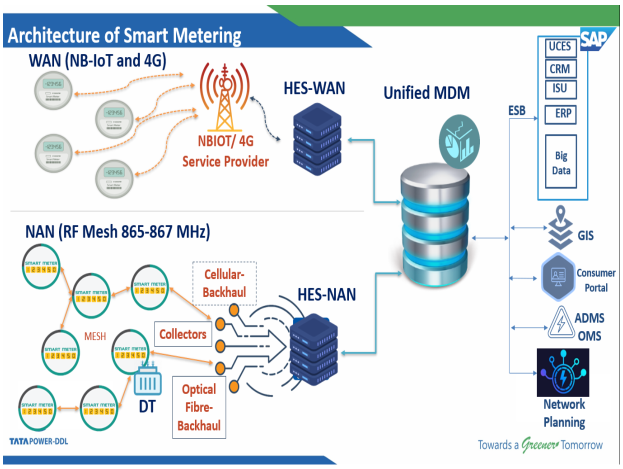


Fig. 1: Smart Metering Architecture at Tata Power DISCOMs

4 USE CASES

4.1 Network to consumer indexing in smart meter installation

DT (Distribution Transformer) wise indexing involves categorizing and mapping consumers according to the DTs they are connected to. Consumer indexing involves creating a detailed database of consumers connected to specific feeders and transformers. Thus it creates a correlated mesh of smart meters flowing from feeders, DTs and consumers.

4.1.1 Accurate Energy Auditing: Such indexing ensures accurate tracking of energy consumption and loss analysis at various network levels. This enables detailed energy auditing through accurate and granular consumption data from smart meters linked at various levels of the network. Also, this increases transparency and regulatory compliance.

4.1.2 Identification of Loss points: It also enables precise identification of energy loss points, as the entire path of energy flow can be traced and closely monitored. This inturn helps in targeted measures to reduce technical and commercial losses.

4.1.3 Meter Replacements: In the process of replacing existing meters with smart meters to enhance data accuracy and provide real-time monitoring capabilities, this consumer indexing with DT plays a pivotal role in phase-wise planning of meter replacement drive. Selecting areas for meter replacement based on potential benefits maximizes the impact of the smart metering initiative. At the same time, maximum number of meters within selected areas can be replaced to achieve widespread benefits and economies of scale. Prioritizing areas with high consumption, significant technical losses, or frequent billing disputes ensures that the most substantial improvements are realized. Further, comprehensive data coverage from indexed smart meters shall lead to better network insights and operational efficiencies.

DISCOMS are installing Smart meters in large quantity in distribution transformers and feeders. During such installations one common error committed by the installation crew is that phase interchange between meter and terminal. In Tata Power, such connection errors are avoided by directly fetching the Instantaneous values of the installed meter and there by verifying the Phase angle / PF and rectify the wiring mistake at the site. This validation avoids incorrect metering and multiple site visit there by increasing operational cost and effectiveness of the system.

4.1.4 Better management of customer care footfall: Improvement in customer handling by providing accurate billing and seamless online payments, thereby reducing the need for customers to necessarily visit customer care centers.

4.1.5 Improved reliability: Network to consumer indexing integrated with smart meter data not only enhances the Outage Management System (OMS) to proactively address the outages and thus reducing the overall downtime of the power supply, but it also verifies the discrete outage calls. It further aids the planning and execution of maintenance activities.

4.1.6 Effective Load Growth Planning in Concentrated Areas: The data from smart meters installed at DTs can be effectively utilized to plan for load growth in concentrated areas, ensuring the distribution network can accommodate future demand. This helps in optimized infrastructure investments and capacity planning. Further, there is a reduced risk of overloading and service interruptions in the future as well.

4.1.7 Value Added Services to Customers

Customers are the ultimate beneficiaries in the entire smart metering journey. Starting from effective self-load monitoring to providing insights to customers on their usage pattern based on energy disaggregation, benefits of smart metering are to be passed on to customers. TATA power distribution companies have empowered their consumers with monitoring their own energy / power consumption via interactive mobile app and customer portals. In addition, customers can set alerts for their electricity usage, demand breach and also can keep their power factor in check based on these alerts.

High revenue based customers are also made aware of the quality of Power that is being supplied by the DISCOM by providing them with the Total Harmonic Distortion

4.2 Technical feasibility check for a new connection

One of the key processes in a utility is to check the technical feasibility of a new connection demanded. With consumer and network indexed smart meter data, this check is being automated by checking the sustained peak loading and available capacity margin at the upstream connected DT through which that connection will be fed.

4.3 Reducing Meter Reader Intervention:

Currently Smart meters are getting deployed in large scale across discoms, where in utility has to adopt a hybrid way of meter reading in an area until the deployment of smart metering is completed. Many DISCOMS carry out spot billing for their customers so as to avoid multiple visit at customer premise for bill delivery, in which the energy consumption bill is generated on the spot by manually entering the consumed units by the meter reader. For such cases, the readings can be fetched from MDMS directly to Spot billing Machines. So that there are no chances of any manual errors by the meter reader.

4.4 Renewable energy integration - Peer to Peer (P2P trading):

A pilot project is underway for an innovative peer-to-peer (P2P) energy trading platform that can transform energy management and distribution. Smart meters provide the critical infrastructure required for real-time, precise measurement of energy generation and consumption at individual households and businesses. This capability allows consumers who generate renewable energy, such as solar power, to trade surplus energy directly with their neighbors or back to the grid. By facilitating P2P energy trading, utilities can enhance grid stability, optimize load management, and reduce peak demand pressures. This decentralized energy trading model also encourages the adoption of renewable energy sources, supporting the transition to a greener energy mix. A utility can leverage advanced data analytics and block chain technology to ensure secure, transparent, and efficient energy transactions.

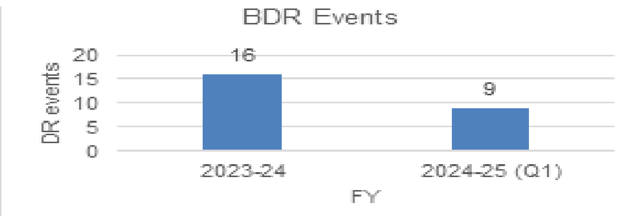
4.5 Demand Response: This is a system used by utilities to manage and reduce electricity usage during peak demand times. It involves encouraging or automatically adjusting how and when consumers use electricity to ensure a stable and efficient power supply. With the implementation of smart meters, utilities can effectively engage in two primary types of demand response - automatic and behavioral.

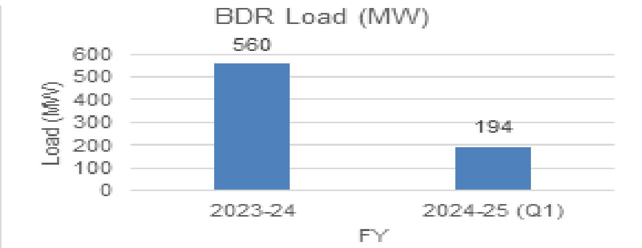
4.5.1 Automated Demand Response (ADR)

ADR involves automatically adjusting electrical loads in response to signals from the utility, without any manual intervention from the consumers signed-up for the associated contract. Smart meters provide the energy consumption data and facilitate communication between the utility and devices in homes or businesses. Due to this, utilities have accurate load patterns and can exercise control for required load at peak demand time intervals. This helps reduce peak demand, balance supply and demand, preventing grid overloads especially during high-demand periods or emergencies. ADR is particularly useful for integrating renewable energy sources by quickly responding to changes in energy generation.

4.5.2 Behavioral Demand Response (BDR)

BDR focuses on encouraging consumers to change their energy usage habits based on information, incentives, and feedback from the utility. Smart meters provide detailed insights into energy consumption, which are shared with consumers through mobile apps or/and websites. Utilities can use this data to design programs that motivate consumers to use electricity during off-peak times, thereby reducing their overall electricity consumption and hence the bills. BDR not only helps in managing peak demand but also promotes energy conservation and consumer engagement. Fig. 2 shows the implementation of BDR in the Tata Power utilities.





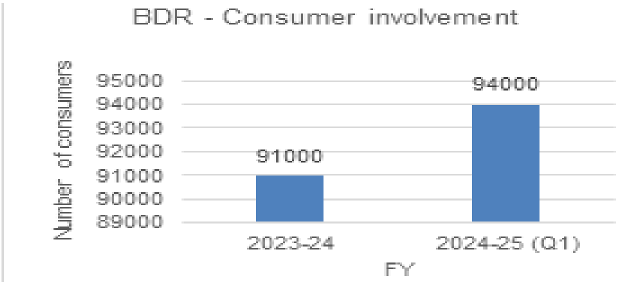


Fig. 2: BDR at Tata Power DISCOMs

4.6 Local Reconnection through push-button:

With smart meters implementation picking up full swing throughout the country, in both WAN and NAN communications, there is still a certain extent of apprehension about the communication failure issues. The most critical of them is successful disconnection of a smart meter through HES, but communication failure during the due re-connection. As an effective solution to this problem we have proposed a push-button actuated local re-connection function in the smart meters, for a fixed and configurable time duration, till the communication is restored reliably. This way the consumers are not deprived of the power supply on account of communication failures.

5 CONCLUSION

Smart metering technology offers a multifaceted solution to the challenges faced by power distribution utilities in India. By enabling precise monitoring, optimized load management, improved grid reliability, and enhanced customer service, smart meters pave the way for a more efficient, resilient, and sustainable power infrastructure. The strategic deployment and utilization of smart meters not only address immediate operational needs but also lay the foundation for future innovations and advancements in the energy sector. Through the insights and practices discussed in this paper, utilities can harness the full potential of smart metering technology to achieve transformative outcomes and drive the transition towards a smarter, greener energy future.

6 REFERENCES

Internal data reports of Tata Power DISCOMs.

BIO-DATA

SUBHADIP RAYCHAUDHURI
Tata Power Co. Ltd.

BRIEF PROFILE

He has graduated as Bachelor of Technology (Electrical) and subsequently MBA (Finance). He has an experience of 23 years in power distribution utilities in India. He is an active member of ETD13, Bureau of Indian Standards, and is working presently as Head – Engineering, Energy Audit, GIS & AMI Applications at Tata Power – DDL. His gamut of experience covers metering, protection, testing and specification design of distribution systems and substations.

SAURAV CHANDEL
Tata Power Co. Ltd.

BRIEF PROFILE

He has completed his graduation in Electrical and Electronics Engineering from Delhi Technological University in the year 2017. He has received the National Innovative Project Award from Indian National Academy of Engineering and had represented India at the semi-finals and finals of the prestigious IEEE International Future Energy Challenge 2017 in USA, for his research work on High-power Density High Efficiency Power Converters. He is an active member of ETD-13 Bureau of Indian Standards and presently working with engineering group at Tata Power – DDL. His areas of interest in research include smart metering, EV charging, battery chargers, power electronics converters, drives, electrical network planning etc.

BALAGURUNATHAN G
Tata Power Co. Ltd.

BRIEF PROFILE

He has done Master of Technology (Energy and Environmental Management) and B.E. (Electrical), having an experience of more than 15 years in power distribution industry. His area of expertise as a functional consultant are AMI, MDM, SAP-ISU. He is presently working as Head - Product - MDM (D&IT-T&D) at Tata Power.

USE OF SMART ENERGY METER IN MITIGATION OF ELECTRICAL ACCIDENTS AND FIRE – A FUTURISTIC APPROACH

Dr. Rajesh Arora
Delhi Transco Ltd

ABSTRACT

Nowadays, modern society is highly dependent on electrical power supply. To live & make our life comfortable, we use number of appliances/ gadgets at our residence/office. Every day we get up with the news of electrocution or electrical fires in residential or commercial buildings or public location or distribution transformer or substation. This forces us to ponder over the reasons/ causes of such accidents which lead to loss of lives as well as assets/properties. In today's evolving energy sector, smart metering is ready to become a game-changer in optimizing electricity management. Smart meters provide real-time data that allows utilities to do monitoring, manage & control the electricity usage patterns. Further this ensures accurate billing and reduces operational costs. Above all for consumers, it offers greater transparency and control over their energy consumption, leading to potential cost savings and more informed decision-making.

This paper provides insight about optimal use of smart energy meter in mitigation of electrical accidents and fire hazards for all locations.

Key Words: Electrocution, Electrical Fire, Insulation Failure, Short Circuit, Heating Effect, Arcing (Loose Connection), Grounding System & Smart Meter

Fig. 1 ELECTROCUTION ACCIDENTS

INTRODUCTION

Nowadays, modern society is highly dependent on electrical power supply. To live & make our life comfortable, we use number of appliances/ gadgets at our residence/office.

Electrocution, Electrical fire and Lightning kill 15,000 a year. Also 75000 (approx.) suffer because of these deaths, there is loss of property and assets, dreams of many people associated with deceased shatter.

The news of electric shock or electric fire killing people gives pain and forces everyone to find the solution but in a day or two we again forget and wait for another accident to happen. (Refer figure 1&2)

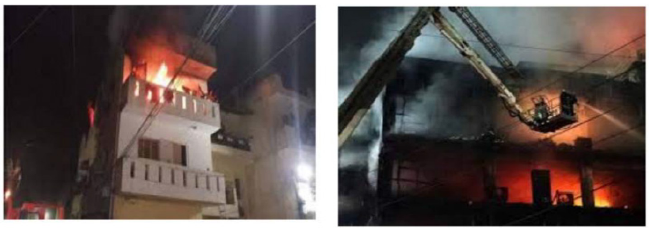


Fig. 2 Electrical Fire Accidents

There are too many tales that different parts of the country have to tell each day without fail (many cases are even not reported or recorded).

Keeping the figure for the injured aside, the numbers for the electrocution deaths in the country tell a story of their own. According to the National Crime Records Bureau, around one lakh people lost their lives because of electrocution in the last decade alone. The annual average of fatalities rose to 12,500 per year or 30 fatalities every day. Calling the 30 electrocution deaths per day in India "accidents" is something which is not justified as it tends to insulate all stake holder from accountabilities.

Around 1 lakh people died due to electrocution in the last decade, as per NCRB data. The detail of deaths due to electrocution & fire for last three years in given below in table 1.

Table 1 ncrb data of deaths due to lightning electrocution and SC fire 2020-222

NCRB DEATH DATA (LIGHTNING , ELECTROCUTION & FIRE DUE TO SHORT CIRCUIT)						
DESCRIPTION	2020	2021	2022	% OF TOTAL (2020,21,22)		
TOTAL DEATH	374397	397530	430504	100	100	100
LIGHTNING	2862	2880	2887	0.76	0.72	0.67
ELECTROCUTION	13446	12529	12918	3.59	3.15	3.00
FIRE DUE ELECT SC	1943	1808	1567	0.52	0.45	0.36

MAIN CAUSES OF ELECTROCUTION & ELECTRICAL FIRE HAZARD

Electrocution & Electrical Fires in Electrical Installation may be broadly caused by

- Over currents (overloads and short circuits)
- Harmonics
- Earth fault
- Electric arcs in cables and loose Connections
- Failure of protection device or Wrong selection of protection device
- Wrong selection of cables or wires
- Mismatch of illumination fittings rating and lamps used
- Use of extension cord for heaters or any other heavy loads
- Use of outlived (outdated) or damaged equipments
- Over voltages (Lightning) & arcing ground
- Consumer has become prosumer
- Inadequate design for earthing / grounding
- Improper or No verification and testing (commissioning or periodical)

2.1 BASIC OF OVER CURRENT IN THE ELECTRICAL SYSTEM

Electrical systems are designed to safely handle currents within specified limits. However, various conditions can lead to overcurrent situations, each with distinct causes, effects, and protective measures. This discussion will delve into overcurrent, overload, short-circuit, and earth fault currents, providing a comprehensive understanding of their characteristics and implications in electrical engineering.

Overcurrent: Overcurrent refers to any current in an electrical circuit that exceeds the rated or intended value.

Causes: A. Normal operational conditions: Momentary increases in current due to changes in load.

Abnormal conditions: Faults such as short circuits or ground faults.

Component failure: Malfunctioning equipment or aging components.

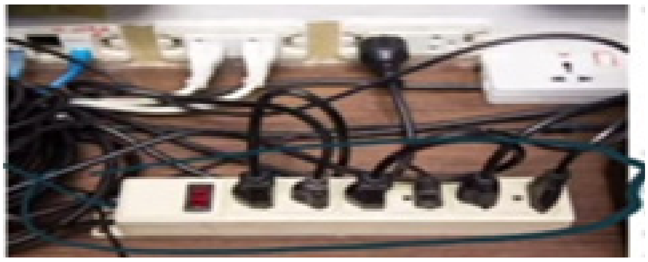


Fig. 3 Over Loading of Extention Board

2. Overload: Occurs when the current in a circuit exceeds the rated load current for an extended period.

Causes: Excessive connected load, sustained high-demand periods, or inadequate circuit capacity. (Refer figure 3)

Effects: Overheating of conductors, insulation degradation, and potential damage to equipment.

Protection: Circuit breakers, fuses, and thermal overload relays designed to trip at predetermined overload thresholds.

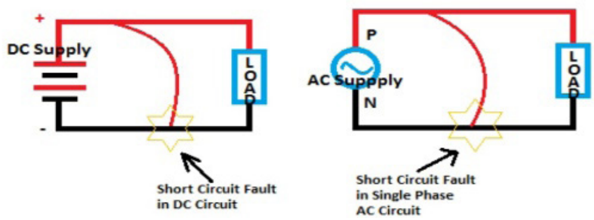


Fig. 4 SHORT CIRCUIT IN ELECTRICAL SYSTEM

3. Short-Circuit: A direct low-resistance path

between conductors of different phases or between a phase and ground.

Causes: Insulation failure, accidental contact between conductors, or equipment faults. (Refer figure 4)

Effects: Rapid rise in current, magnetic forces, and potential mechanical damage to conductors and equipment.

Protection: High-current rated fuses, circuit breakers with instantaneous trip settings, and protective relays designed to detect short circuits.

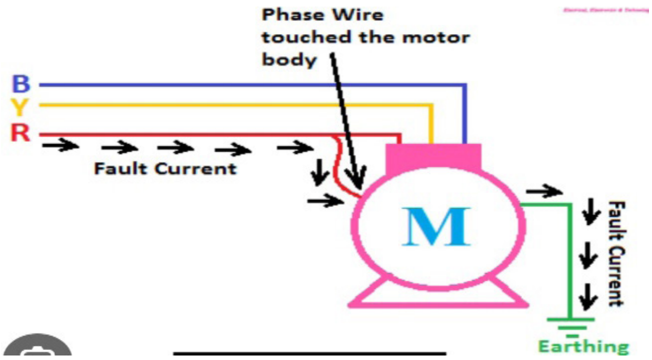


Fig. 5 EXAMPLE OF EARTH (GROUND) FAULT

4. Earth Fault: Occurs when a live conductor unintentionally contacts earth or a conductive part connected to earth.

Causes: Insulation breakdown, equipment faults, or accidental contact with grounded surfaces. (Refer figure 5)

Effects: Current flows from the phase conductor to ground, potentially causing equipment damage and safety hazards.

Protection: Differential relays, residual current devices (RCDs), and ground fault detectors designed to detect small leakage currents indicative of earth faults.

2.1.1 Characteristics and Implications:

Overload: Typically exceeds nominal operating current by 110% to 150%.

Short-Circuit: Can be several times higher than normal operating current, limited only by system impedance.

Earth Fault: Generally lower in magnitude compared to short-circuit currents, but significant enough to cause damage if not promptly detected and isolated.

2.2 Short Circuit In The Electrical System

Electrical fires very often take place in residential sector. This is because most of the people do not account for the rating of the appliances while placing or connecting them. Being an individual, most of us are not aware about the parameters we need to consider while purchasing the product. The only thing that people look for is the cost effectiveness which in turn leads to extreme situation resulting in electrical fires. Major reason for electrical fire in LV system is Short Circuiting i.e. flowing of current through unintended path.

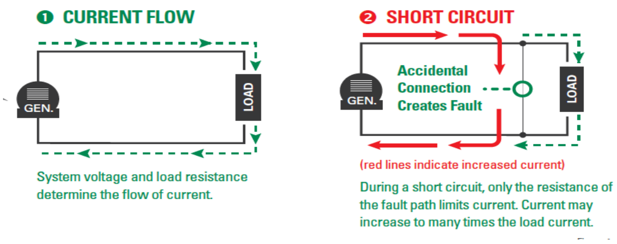


Fig.6 CONCEPT OF SHORT CIRCUIT

A short circuit is an abnormal connection between two nodes of an electric circuit intended to be at different voltages. This results in an electric current limited only by the equivalent resistance of the rest of the network which can cause circuit damage, overheating, fire or explosion (please refer figure 6).This high current generates high heat and presence of fuel or any other flammable materials may result in the fire hazard as governed by fire triangle in figure 7.

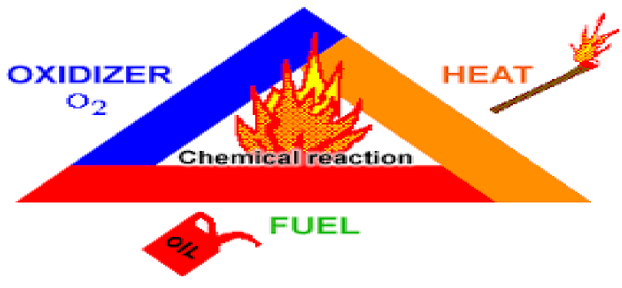


Fig.7 FIRE TRIANGLE

Short circuit happens mainly due to degradation of insulation. As the wire gets old, the insulation gets degraded, due to which there is a chance of short circuiting (figure 8) & this may lead to fire.

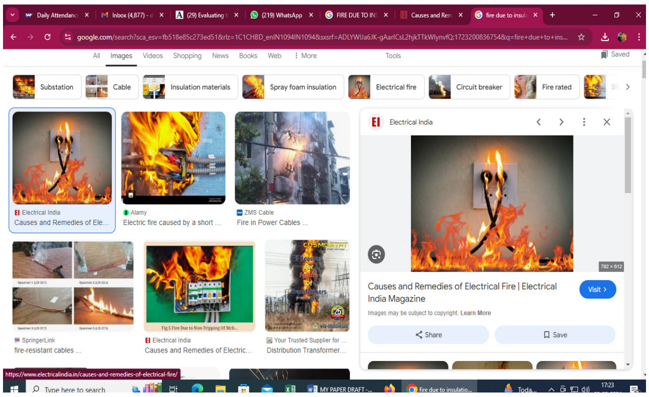


Fig.8 FIRE DUE TO INSULATON FAILURE

2.3 OVER VOLTAGE IN THE ELECTRICAL SYSTEM

Understanding the internal and external causes of overvoltage in power systems is essential for implementing effective protection and mitigation strategies. Internal factors like switching operations, capacitor switching, faults, and resonance require careful design and use of protective devices to minimize transient overvoltages.

External influences such as lightning strikes, electromagnetic interference, and grid switching necessitate robust grounding, surge protection, and system resilience measures. By addressing these causes comprehensively, power systems can maintain reliability, protect equipment, and ensure safe operation in diverse operational conditions. (Refer figure 9)

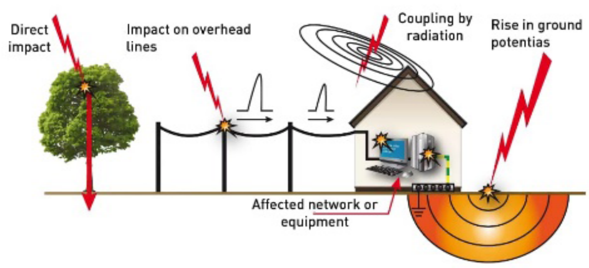


Fig. 9 LIGHTNING AND ITS IMPACT ON BUILDING

2.3.1 Theory of Arcing Ground-Ungrounded System

Ungrounded System is one where the neutral is not connected to earth. Thus, neutral of ungrounded system is isolated. Arcing Ground is an electrical phenomenon in which the voltage of faulty phase fluctuates due to capacitive charging current. This arcing ground phenomenon is prevalent in three phase ungrounded neutral system.

Let us now consider a fault condition. Suppose a single line to ground fault takes place in C phase as shown in figure 10 below.

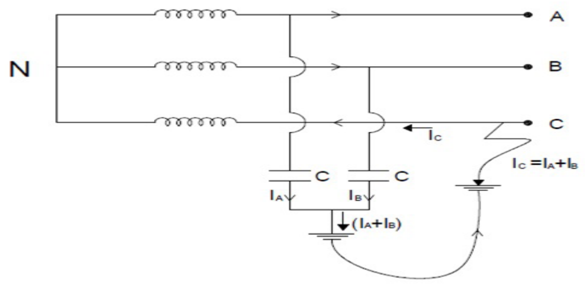


Fig. 10 IMPACT OF SLG FAULT ON UNGROUNDED SYSTEM

The fault current this case will complete its circuit as shown in figure above. Fault current I_C will be equal to the vector some of I_A and I_B. Therefore,

$$I_C = I_A + I_B$$

Please note that, I_C in C phase will flow toward the neutral. Therefore we can say that, phase voltage of C phase has reversed its direction. This in turn means that, the voltage of neutral point has shifted from ground potential to phase voltage.

Because of this shifting of neutral voltage, the voltage of healthy phase will become equal to the line voltage. Due to this raised voltage of healthy phases, charging currents will increase i.e. charging current in faulted phase is three times that of the normal charging current. Due to this heavy arcing will take place in the faulted phase. This phenomenon of arcing is known as Arcing Ground.

3.0 ROLE OF ADEQUATE EARTHING/ GROUNDING

Grounding/ Earthing means making a connection to the general mass of earth. The use of grounding is so widespread in an electric system that at practically every point in the system, from the generators to the consumers' equipment, earth connections are made.

There are two types grounding (Refer figure 11):

Neutral Grounding

General (Equipment) Grounding

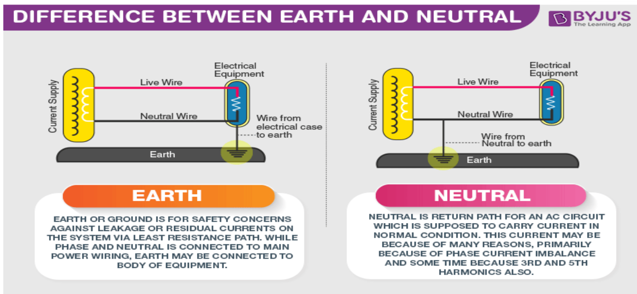


Fig.11 EQUIPMENT AND NEUTRAL EARTHING

The objectives of General Grounding system include:

To provide a low resistance return path for fault current which further protects both working staff and equipment installed in the premises (Refer figure 12).

To prevent dangerous GPR with respect to remote ground during fault condition.

To provide a low resistance path for power system transients such as lightning and over voltages in the system.

To provide uniform potential bonding /zone of conductive objects within substation to the grounding system to avoid development of any dangerous potential between objects (and earth).

To prevent building up of electrostatic charge and discharge within the substation, which may results in sparks.

To allow sufficient current to flow safely for satisfactory operation of protection system.

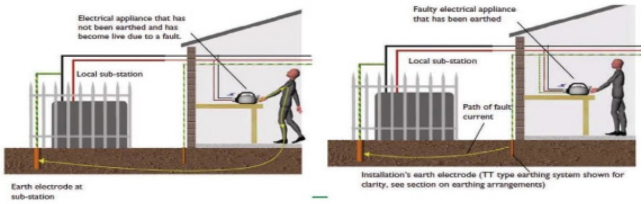


Fig.12 UNEARTH SYSTEM AND SHOCK HAZARD

The main objective of grounding electrical systems is to provide a suitably low resistance path for the discharge of fault current which ultimately provides safety to working personnel and costly installed equipment by providing sufficient current to safety devices.

Fig. 13 PROVISION OF EARTH TERMINAL AT METER BOX

In India, the use of earthing terminals in switchboards is often inconsistent, and this has serious safety implications. Earthing, or grounding, is a crucial electrical safety measure designed to prevent electric shocks and fires by directing stray currents safely into the ground. Despite its importance, many people in India neglect or fail to implement proper earthing in their electrical systems. Understanding the reasons behind this and the associated dangers can shed light on why this issue is so critical. (Refer figure 13)

1. Lack of Awareness and Understanding

2. Inadequate Implementation and Enforcement of Standards

3. Economic Constraints

4. Unqualified or Undertrained Electricians

Dangers Associated with Lack of Earthing : The dangers of neglecting earthing are severe and multifaceted. Without proper earthing, electrical faults such as short circuits or insulation failures can lead to electric shocks, which can cause injury or even death. Electrical appliances and wiring can become live with stray currents, posing a constant risk to anyone in contact with them. Additionally, the absence of earthing increases the risk of electrical fires, which can result in property damage, loss of life, and financial losses.

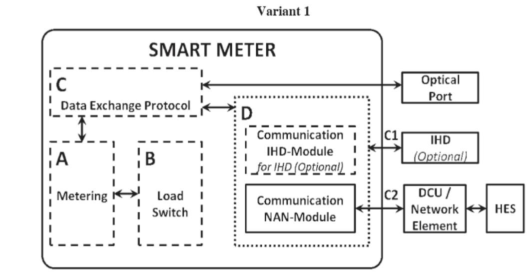
4.0 BASIC CONCEPT OF SMART METER

Smart meter is an ac static watt- hour meter with time of use registers, internal connect and disconnect switches with two way communication capability. It is designed to measure flow of forward (import) or both forward (import) and reverse (export), store and communicate the same along with other parameters defined in the standard. It shall be remotely accessed for collecting data/events, programming for select parameters.

The smart meter is a component of Advanced Metering Infrastructure. For the purpose of this standard the smart meter is conceived as single unit comprising of following functional zones:

- Metering,
- Load switch,
- Metering protocol, and
- Communication modules.

The Smart Meters may have wide usage and the buyer may like to choose desired features to meet the objectives of their overall system and site conditions. In order to facilitate such a flexible approach, the Smart Meter architecture are categorized into two variants. The two variants are diagrammatically represented in Fig. 14 and Fig. 15 respectively. These variants are applicable to both built intype and pluggable type of Smart Meters. Main components are described below:



LEGEND

A – Metrology
B – Load switch for control
C – Metering protocol
D – Communication

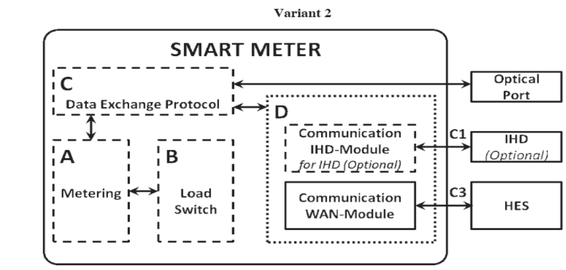
Optical port — As per IS 15959 (Part 2)
C1 – IHD Connectivity SM ↔ IHD (optional)
C2 – NAN Connectivity SM ↔ DCU

NOTES

1 The Smart Meter variant based on Fig. 1 shall provide connectivity C2 for two way communication with DCU using a NAN module.

2 If IHD is chosen this Smart Meter shall provide connectivity C1 for two way communication with IHD using the same NAN module or a suitable additional module as per buyer-seller agreement.

Fig. 14 VARIANT-1 OF SMART METER



LEGEND

A – Metrology
B – Load switch for control
C – Metering protocol
D – Communication

Optical port — As per IS 15959 (Part 2)
C1 – IHD Connectivity SM ↔ IHD (Optional)
C3 – WAN Connectivity SM ↔ HES

NOTES

1 The Smart Meter variant based on Fig. 2 shall provide connectivity C3 for two way communication with HES using a WAN module.

2 If IHD is chosen this Smart Meter shall provide connectivity C1 for two way communication with IHD using a suitable additional module as per buyer-seller agreement.

Fig. 15 VARIANT-2 OF SMART METER

NOTE *:- 1.Neighbourhood Area Network* ***[NAN]*** *2. Data Concentrator Unit* ***[DCU]*** *3. Head End System* ***[HES]*** *4. In Home Display* ***[IHD]***

5. Hand Held Unit ***[HHU]***

4.1 SMART METER FUNCTIONAL REQUIREMENTS

The Smart Meter developed as per the standard is required to support handling of following operational requirements:

4.1.1 Disconnection Mechanism

The Smart Meter shall support disconnection (all the switches shall operate) under the following conditions:

a. Over current (minimum 105% of I_{max} in anyphase for predefined persistence time),

b. Load control limit (programmable and set byutility),

c. Pre-programmed event conditions (factory set),

d. Disconnect signal from utility control centre, and

e. In case of pre-paid facility under defined/ agreed conditions.

It must be noted that as per relevant Indian Standard

1 Persistence time value to be provided by utility.

2 List of events for disconnection to be pre-programmed shall be provided by utility.

4.1.2 Reconnection Mechanism

The local reconnection due to disconnection under over current and load control limit shall be as follows:

The switch re-connection is decided by meter locally. It will try to re-connect the load up to predefined time, with predefined interval (time and interval is programmable by utility). If the consumption is within limits meter shall remain in normal connect mode,

If the consumption is still more than the programmed limits, ***it will lock out and wait for 30 min (lock out period). After this period the meter shall reconnect the load and if the consumption is still above the limit, the procedure as defined*** above in (a) shall be repeated with status update to HES, and

In all conditions other than 'Over current and load control limit' reconnection shall normally be done from HES. In case of failure of communication with HES, reconnection shall be possible through optical port locally with specified security.

Reconnection Mechanism for Prepayment Meter

As per agreed prepayment structure with utility.

4.1.3 Status of Load Switch: Indication of status of load switch (that is connected/ disconnected) shall be available on display as well as at HES.

5.0 LOAD SWITCHES FOR PROTECTION AGAINST FIRE AND ELECTROCUTION

Smart meters are sophisticated devices that play a crucial role in modern energy management, offering enhanced capabilities beyond traditional meters. One of their most critical functions is improving safety, particularly in preventing fire and electrocution risks. A key component in achieving this is the load switch, an integral feature in many smart meters. This section explores how load switches in smart meters contribute to safety by preventing fire and electrocution, and provide guidelines for their effective use.

Understanding Load Switches in Smart Meters

A load switch in a smart meter is essentially a relay or circuit breaker that can control the flow of electricity through the meter. It can be remotely operated and is designed to disconnect the electrical load if certain conditions are met. This capability is crucial for enhancing safety by enabling immediate response to dangerous situations.

Protection Against Fire

Overcurrent Protection: One of the primary functions of a load switch is to provide overcurrent protection. Excessive current can cause overheating in electrical wiring, potentially leading to fires. Smart meters equipped with load switches can detect when the current exceeds a safe threshold. When this happens, the load switch can automatically disconnect the circuit, preventing overheating and reducing the risk of fire.

Overvoltage Protection: In addition to overcurrent, overvoltage conditions can also pose a fire risk. Smart meters with load switches can protect against this by disconnecting the circuit when voltage levels exceed safe limits. Overvoltage conditions may result from issues such as lightning strikes or power surges. By disconnecting the load, the smart meter helps to prevent potential damage and fire hazards associated with these conditions.

Protection Against Electrocution

Ground Fault Detection: Ground faults occur when electrical current unintentionally flows to the ground, often through a person or conductive material. This can result in electric shock or electrocution. Smart meters with load switches can incorporate ground fault detection features that monitor for abnormal current paths. If a ground fault is detected, the load switch can quickly disconnect the circuit, significantly reducing the risk of electrocution.

Detection Mechanisms: The load switch in a smart meter can be equipped with ground fault sensors that measure the difference in current between the live and neutral wires. Any imbalance, indicating a potential ground fault, triggers the switch to disconnect the load, protecting individuals from electric shock.

Residual Current Protection: Residual Current Devices (RCDs) are crucial for protecting against electrocution. Some smart meters integrate RCD functionality into their load switches. These devices detect residual currents that may indicate leakage or faults in the system. When an unsafe residual current is detected, the load switch disconnects the circuit, thus preventing potential electric shock.

Sensitivity Settings: Load switches with RCD capabilities can be adjusted for sensitivity, ensuring they react appropriately to varying levels of residual current. Proper calibration is essential to balance sensitivity and minimize false tripping while still providing effective protection.

HEALTHINESS OF EARTHING (GROUNDING)CONNECTION

How It Works:

Monitoring Voltage Levels: Smart meters can measure the voltage between different points in the electrical system, including between live and earth. If there is an open earth connection, the voltage between the live wire and the earth might be significantly different from normal values.

Detection of Abnormalities: Significant deviations in voltage readings can indicate a problem with the earthing system.

Practical Guidelines for Effective Use

To maximize the benefits of load switches in smart meters for fire and electrocution protection, users and installers should adhere to several practical guidelines:

Proper Installation: Proper installation is critical for the effective operation of safety features. Incorrect installation can lead to malfunctions and reduce the effectiveness of protection mechanisms.

Regular Maintenance: Conduct regular maintenance checks on the smart meter and its load switch. This includes verifying that the load switch operates correctly, inspecting for signs of wear or damage, and ensuring that safety features are functional.

Configuration and Calibration: Properly configure and calibrate the load switch settings according to the specific requirements of the electrical system. This includes setting appropriate thresholds for overcurrent and overvoltage protection and calibrating RCD sensitivity.

User Education: Educate users about the importance of load switches and safety features in smart meters. Providing information on how to recognize signs of electrical problems and what actions to take in case of a safety alert can further enhance overall safety.

Emergency Procedures: Establish clear emergency procedures in the event of a fault or safety alert. Users should be aware of how to safely disconnect the power supply and seek professional assistance if needed.

6.0 CONCLUSION

Overcurrent refers to any current in an electrical circuit that exceeds the rated or intended value. Main causes of over current are momentary increases in current due to changes in load, faults such as short circuits or ground faults & malfunctioning equipment or aging components. Typically exceeds nominal operating current by 110% to 150%.Short-Circuit can be several times higher than normal operating current, limited only by system impedance. Earth Fault generally lower in magnitude compared to short-circuit currents, but significant enough to cause damage if not promptly detected and isolated.

Understanding the internal and external causes of overvoltage in power systems is essential for implementing effective protection and mitigation strategies. Internal factors like switching operations, capacitor switching, faults, and resonance require careful design and use of protective devices to minimize transient overvoltage.

In India, the use of earthing terminals in switchboards is often inconsistent, and this has serious safety implications. Earthing, or grounding, is a crucial electrical safety measure designed to prevent electric shocks and fires by directing stray currents safely into the ground. Despite its importance, many people in India neglect or fail to implement proper earthing in their electrical systems.

Load switches in smart meters play a pivotal role in enhancing electrical safety by providing critical protection against fire and electrocution. Through features such as overcurrent protection, overvoltage protection, ground fault detection, and residual current protection, these devices help prevent dangerous situations that could lead to significant harm. Effective use of load switches involves proper installation, regular maintenance, accurate configuration, and user education. By adhering to these practices, the benefits of smart meters in safeguarding against electrical hazards can be fully realized, contributing to a safer and more reliable electrical environment.

REFERENCES

[1] IS 3043-2018,Code of practice for earthing

[2] CEA 'Measures relating to Safety and Electric Supply' Regulations 2023.

[3] CEA 'Installation and Operation of Meters' (Amendment) Regulations, 2019.

[4] IS 16444 A.C. Static Direct Connected Watt-hour Smart Meter Class 1 and 2— Specification

BIO-DATA

DR RAJESH ARORA
Delhi Transco Limited

Date of Birth:	09-10-1974
Qualification:	PhD In Earthing System Design
Designation:	Senior Manager (Technical)
Present Organization:	Delhi Transco Limited
Field of Expertise:	Substation Design and Earthing
Mobile:	+91 98186 51574
Email:	drrpdarora@gmail.com

BRIEF PROFILE

Dr. RAJESH KUMAR ARORA obtained the B. Tech. & Master of Engineering (ME) degrees in Electrical Engineering from Delhi College of Engineering, University of Delhi, India in 1999 and 2003 respectively. He completed his PhD in grounding system design from UPES, Dehradun. He is also certified Energy Manager and Auditor and has worked in 400kV and 220kV Substation for more than 14 years in Delhi Transco Limited (DTL). He has also worked as Deputy Director (Transmission and Distribution) in Delhi Electricity Regulatory Commission (DERC) for 03 years and 06 months. He has also given his contribution in the OS department of DTL for more than 2 years and rendered his services in the SLDC of Delhi Transco Limited (DTL) also. Presently he is working in D&E (Design and Engineering) department of DTL.

Empowering Indian electricity utilities for 3+ decades
with accurate measurements, efficient billing, and
enhanced reliability and trust.

Product range of Smart & Digital meters:

- Residential & Consumer metering
- System metering
- Industrial metering
- Grid & Audit metering

Schneider Electric India Private Limited

Metering & Protection Systems

Manufacturing location : Plot no. 324-330, KIADB Industrial Area, Hebbal-Hootagalli, Mysuru, Karnataka – 570018.

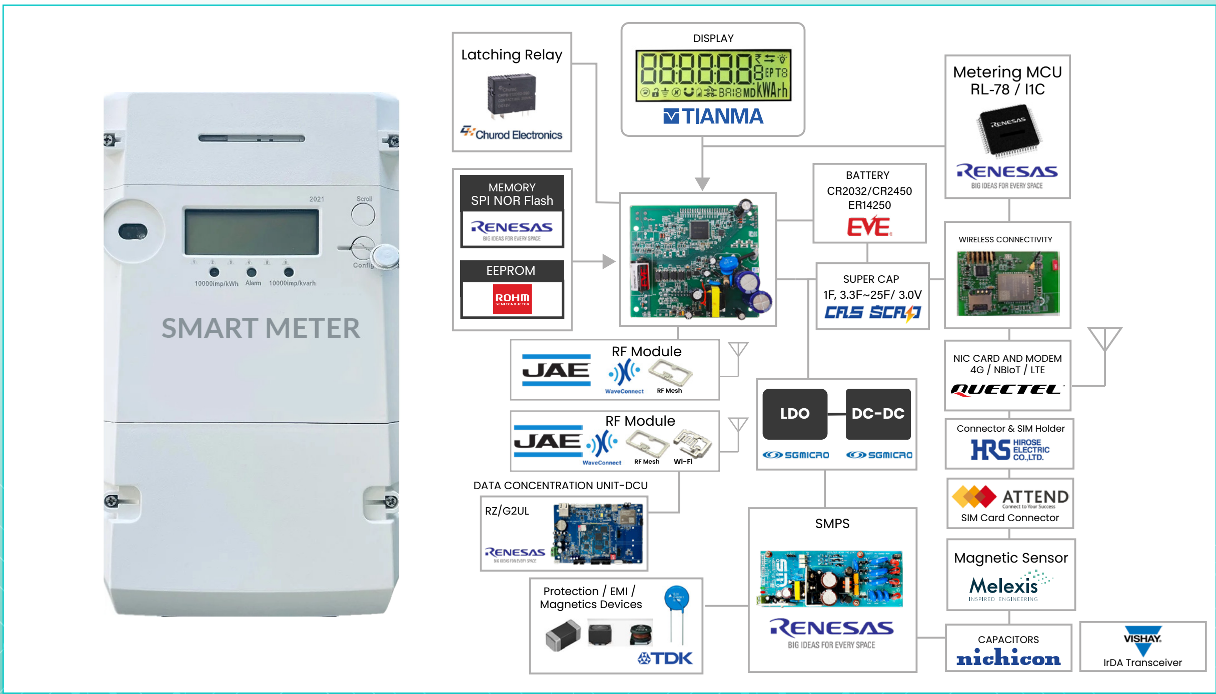
Corporate office: 9th floor, DLF Building No. 10, Tower C, DLF Cyber City, Phase II, Gurgaon - 122002, Haryana.

ieema
your link to electricity

Innovative Edge

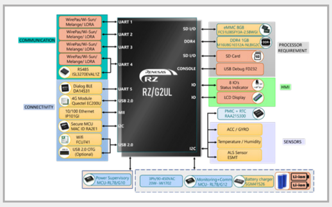
SM Electronic Technologies Pvt. Ltd

READY SOLUTIONS FOR **SMART METERING**



Data Concentration Unit-DCU

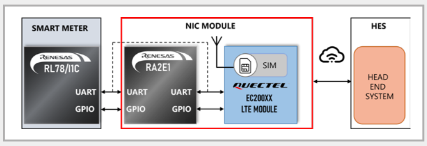
- Processor: RISC-V CPU - RZ/G2UL Single Core Cortex®-A55 (1.0 GHz) CPU
- Memory: RAM-1GB DDR4, eMMC-8GB, uSDCard
- Connectivity:
  - USB2.0 CDC
  - LTE Module: EC200U LTE Modem, SIM Interface MUX with eSIM and micro-SIM Holder
  - Wifi FCU741 for Diagnostics and Communication
  - Ethernet: Wired TCP/IP
  - Bluetooth: Dialog DA14531
- Communication: Node Connection
  - Wired: RS485
  - Wireless: Sub GHz / GHz Modules (Wirepas, Wi-sun, Melange, LORA....)
- Protocols:
  - DCU to MDAS: TCP/IP Based Socket /FTP
  - Others: TCP/IP, UDP, HTTP, FTP, PPP, CURL, DHCP



Network Interface Card-4G /NB-IoT/LTE

NB-IoT / LTE NIC Card Features:

- Operating voltage : 4V
- Common PCB for n-BIOT and n-BIOT with 2G fallback modules.
- UART Interface
- Firmware upgrade connector is provided.
- SMD Antenna



SMET Value Addition

- Ready Solution for 1P & 3P Smart Meter, Compliance to IS16444 PART -2 / IS15959.
- Kitting Support for complete BOM
- Turnkey Solutions for DCU, NIC (Communication Module) & SMPS.
- FAE Team with expertise in Smart Metering
- Support for RF /Antenna/ PCB Layout to Qualify Compliances Viz : EMI/EMC/EFT/35KV Surge-Jammer
- Bootloader/Firmware FOTA Support
- DLMS Green book for Architecture & Protocol (IS15959)
- HDLC Protocol Support (ISO13239)

BENGALURU | SINGAPORE | NEW DELHI | PUNE | HYDERABAD | CHENNAI | MUMBAI | AHMEDABAD

080 6673 4567 sales@mysmindia.com www.smetgroup.com

Kimbal Mega Plant

High Precision Smart Meters Designed For Reliability

Moving Towards
Zero Defect Goal

At Kimbal, Our commitment to high quality and maximum productivity is matched by our unwavering focus on safety and sustainability.

Kimbāl®

PRINCIPAL SPONSORS

ASSOCIATE SPONSORS

KIT SPONSORS

ORGANISER

"Metering India" seminar organized by IEEMA, the representative national organization of manufacturers of electrical, professional electronics and allied equipment in India. IEEMA undertakes various activities for the benefit of the electrical industry and its users, major ones being dissemination of information such as production statistics, government policy changes; representing the industry's views to the government; evolving price variation clauses covering a wide range of products and evolving of industry standards; training, etc. IEEMA also works with the Ministry of Power, Government of India on Power Development and Reforms Programmes. IEEMA publishes a popular monthly journal, IEEMA Journal, which is devoted to techno-commercial aspects of the industry and utilities. IEEMA provides a forum for discussion on technical and commercial matters.

IEEMA also organizes ELECRAMA Exhibition, the largest exhibition of electrical, industrial electronics and allied products in the world.

For further details please contact:

UTTAM KUMAR
(Organising Secretary)
M: +91 97175 18502 | E: uttam.kumar@ieema.org

VISHAKHA CHAUDHARY
M: +91 82873 22144
E: vishakha.chaudhary@ieema.org

RAJNISH KAUSHIK
M: +91 99911 10246
E: rajnish.kaushik@ieema.org

ieema
your link to electricity

Indian Electrical and Electronics Manufacturers' Association
Established in 1948

Rishyamook Building, First Floor, 85 A, Panchkuian Road, New Delhi – 110 001 (India)

FOLLOW US ON

facebook.com/followIEEMA
twitter.com/tweetieema
linkedin.com/company/ieema
YouTube youtube.com/@IEEMAelectrifyingindia

Visit: meteringindia.ieema.org