Indo – German Energy Program

Energy Transition with Discoms

Roadmap for Smart Meter Interoperability in India

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Contents

List of figures

List of tables

List of abbreviations

Refer to Annexure 7.

Executive Summary

India is taking great strides to install 250 million smart meters by 2025-26 across all states with an overarching objective of achieving grid modernisation and consumer centricity. To ensure a successful rollout that will reap benefits in the future, extensive planning is critical to make sure that on-ground issues don't arise post implementation. Ensuring seamless experience, requires interoperability across all components of the Advanced Metering Infrastructure (AMI).

Enabling interoperability at the hardware, network and application level after setting up smart meter systems will need infrastructure upgradation which is cost intensive and will lead to operational disruption. Therefore, it is critical to ensure interoperability in the initial stages of planning to help the Discoms upgrade their systems as and when required and circumvent undue dependence on any single vendor, as the technologies evolve, and the number of service providers increase. Since India is at the advent of its journey, it is a critical time for Indian power distribution sector to understand the extent to which interoperability is required and accordingly plan towards it.

With this background, this report aims to understand the following:

1. Existing smart meter landscape in India
2. Importance of interoperability
3. Current efforts taken to ensure interoperability across different layers (hardware, application and network layers)
4. Areas of development for India with respect to the global best practices
5. Way forward to facilitate AMI interoperability

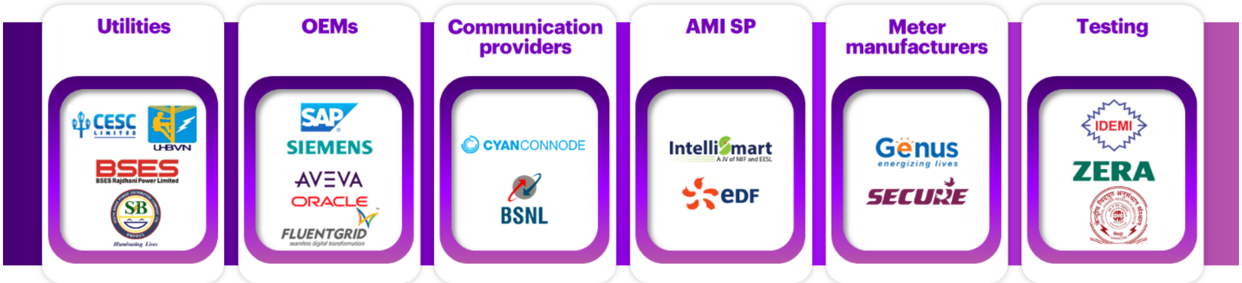
To achieve this objective, some key aspects of the industry were analysed, such as:

- Different layers of interoperability and their current status in India
- Technical standards and specifications that facilitate interoperability in India and globally
- Smart meter testing ecosystem in India, including standards and laboratories
- Current smart meter deployment journey and practices by Indian Discoms and International DSOs to facilitate interoperability

The following approach was followed to gain insights into the above-mentioned areas:

- Primary interactions with the relevant stakeholders:
  - Accenture experts with on-ground experience with Indian and global utilities
  - Smart meter ecosystem players such as utilities, OEMs, communication providers, AMI Service Providers, meter manufacturers, testing agencies, testing equipment manufacturers, etc.

Figure 1: Stakeholder interactions



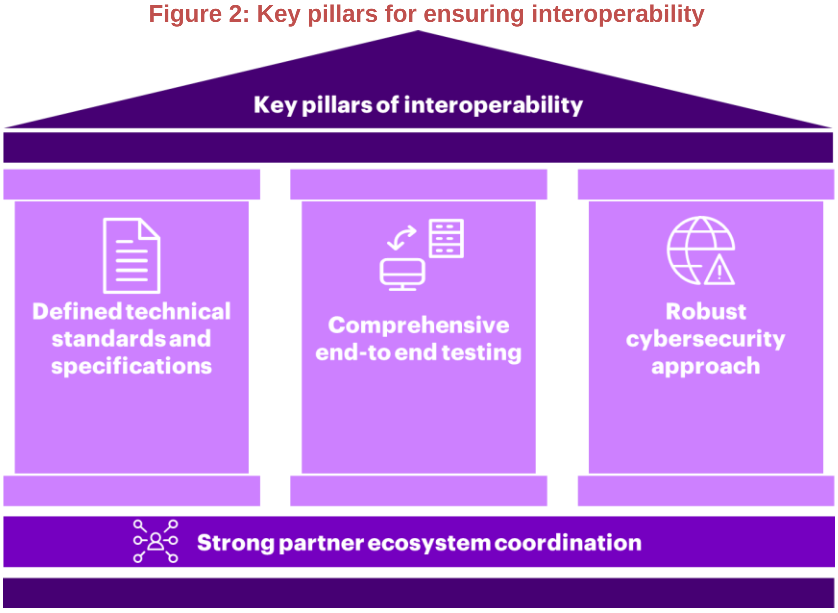
- Secondary research through publicly available documents and websites:
  - Standard documents released by renowned Indian and global standard bodies such as BIS, IEEE, IEC, etc.
  - Official websites of Indian Discoms/ International DSOs and testing laboratories
  - Tender documents for AMI deployment

A critical set of insights were generated through the different sources of study. A key component was the discussion and analysis with Indian and global utilities. The three Indian Discoms that were studied were South Bihar Power Distribution Company Ltd. (SBPDCL) and North Bihar Power Distribution Company Ltd. (NBPDCL), Uttar Haryana Bijli Vitran Nigam Limited (UHBVNL) and CESC Ltd. Additionally, four global DSOs' smart meter programmes were studied: UK Smart Meter Implementation Program (SMIP), EDF-Enedis' Linky smart meter programme, AMI implementation of a large North-American utility and Kansas City Power & Light (KCP&L) Smart Grid Demonstration Project (SGDP).

Post the preliminary analysis and the in-depth discussion with the utilities and other stakeholders, it was inferred that while steps are being taken to ensure interoperability at the hardware and application layer, the network layer interoperability still needs to be addressed. Since, network interoperability will be key to exchanging and using data across different communication technologies and multiple service providers, it will be critical to ensure network interoperability as India scales up smart meter deployment. Considering India has diverse geographical areas, no single communication technology will be able to completely fulfil all criteria with respect to reliability and ease of implementation across different areas. Hence, smart meters equipped with dual communication system (primary & secondary/ back-up communication technology) can be a potential solution. However, this would increase the overall costs and the Discoms will need to evaluate the envisaged benefits with respect to the specific rollout.

The insights based on the study helped in identifying the following key pillars, that will be critical in enabling end-to-end interoperability in India:

Figure 2: Key pillars for ensuring interoperability



i. **Defined technical standards and specifications:** Common technical standards and specifications are essential to ensure the long-term viability of smart meter operations. To make communication between different AMI components seamless, it's important that different vendors involved in the AMI ecosystem are adhering to common guidelines. In India and globally, central bodies have been formed to ensure standardised and harmonised functioning of activities. However, in the Indian context, while metering requirements are specified, no standards enabling end-to-end AMI interoperability have been defined yet. Different independent committees are working towards the same.

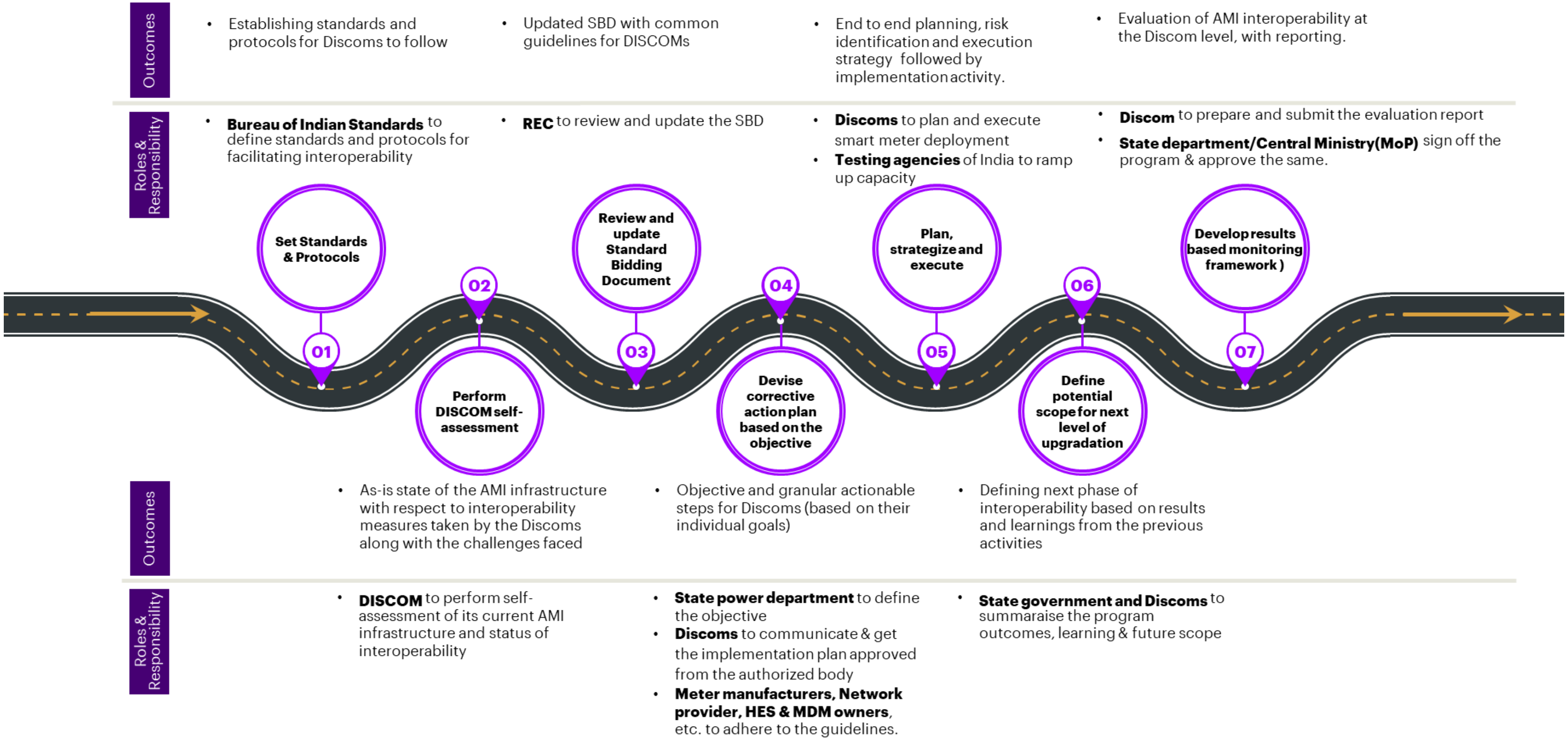
ii. **Comprehensive end-to end testing:** End-to-end testing is crucial for ensuring quality and reliability of smart meters, to ascertain their performance as per relevant standards. For this, availability of testing laboratories that test smart meters for metrology, data exchange and communication become vital. Currently, there exists limited number of smart meter testing laboratories in India, which must be ramped up as India moves towards increased installations.

iii. **Robust cybersecurity approach:** The vulnerability of cyberattacks on smart meters poses a threat not only to vendors, but also to the consumers. To combat this and instill consumer confidence, a robust cybersecurity approach should be part of any AMI implementation.

iv. **Strong partner ecosystem coordination:** AMI ecosystem comprises of multiple diverse stakeholders with their own set of solutions and limitations. For high operational efficiency of the AMI, it is important that the devices and systems (smart meters, communication modules, HES, MDMS) of different OEMs, are compatible with each other, in terms of communication capabilities and data reception and management. This will not only allow an end-to-end interoperability but will also ensure that the system does not fail to operate in case the components/ vendors are required to be changed in the future.

With the help of these enablers, a phased implementation plan must be followed with defined roles for each stakeholder involved in the AMI ecosystem. Since AMI interoperability is still an evolving subject in India as well as globally, a prescriptive approach involving distinct interventions will not be feasible. Therefore, we propose a collaborative, guided, and stepwise approach which will be instrumental in facilitating interoperability, as India scales up smart meter deployment. The following figure illustrates the implementation roadmap to achieve this objective.

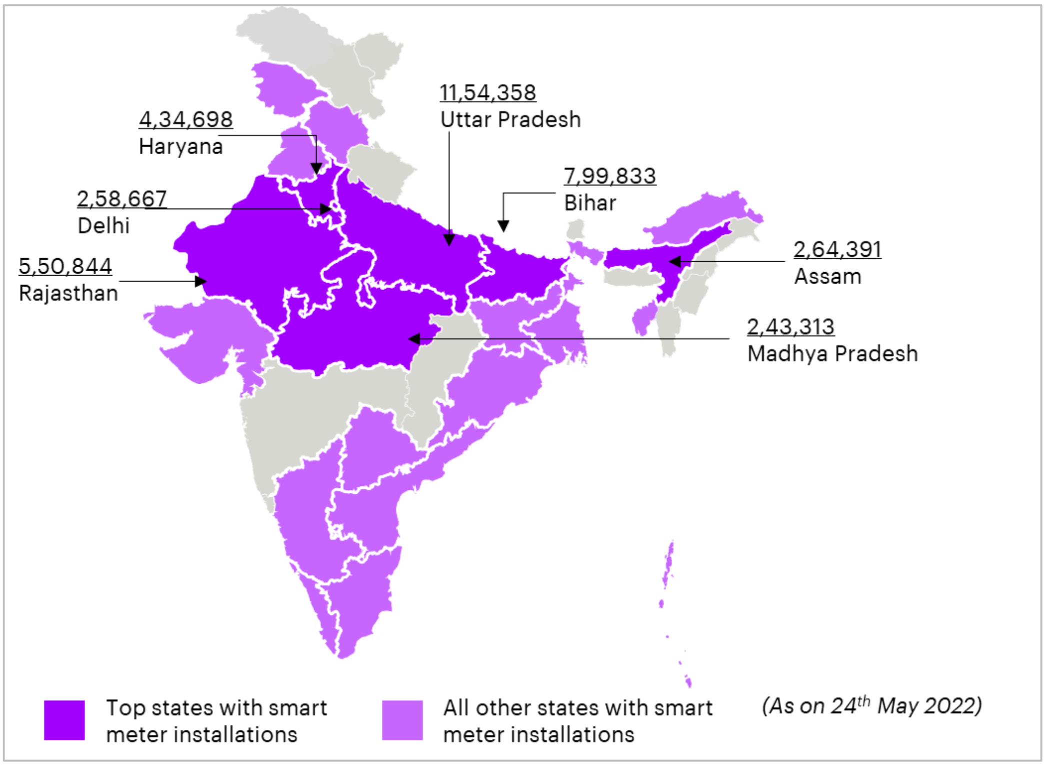
Figure 3: Proposed roadmap to facilitate AMI interoperability



1. Introduction

As India moves towards grid modernisation, the rate of installation of smart meters continues to increase at a rapid pace. With a target of installing 250 million smart meters by 2025, India has currently undertaken installation of ~4.4 million smart meters[1] under different initiatives in multiple states across in India.

Figure 4: Smart meter deployment status in India



As India aims to scale up its smart metering programme along the length and breadth of the country, it becomes crucial to have a unified mechanism to allow seamless integration of all the meters for a successful and sustainable scale up, requiring minimum capital re-investment into new assets for integration.

India, being at the onset of the smart meter journey, is presented with the ideal opportunity to ensure implementation in a manner that will reap benefits in the future. A key consideration to a successful rollout is ensuring interoperability at the initial stages across the components of the AMI. This shall help during systems upgradation later and circumvent any undue dependence on any single vendor, as the technologies evolve, and number of service providers increase.

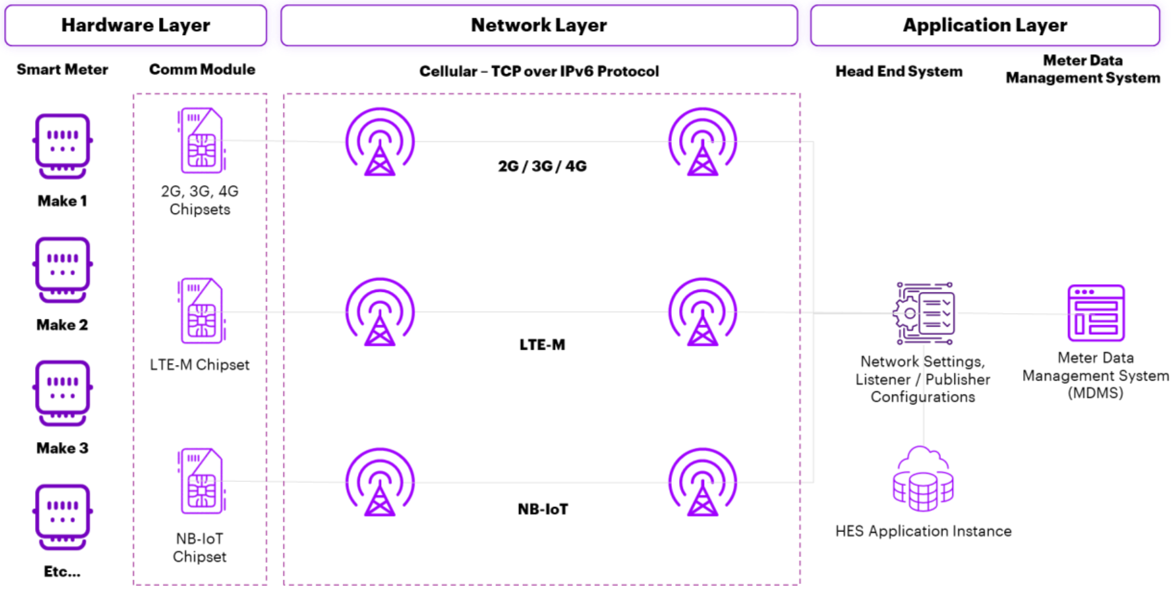
[1] Source: NSGM; accessed on 24th May 2022

2. Understanding Advanced Metering Infrastructure (AMI)

Advanced Metering Infrastructure (AMI) is an integrated system of equipment, communications, and information management systems for utilities to remotely collect customer usage data in real time. AMI collects and analyses data from smart meters using two-way communications between user domain and utility domain and gives intelligent management of various power-related applications and services based on that data. The implementation of AMI is widely seen as the first step in the digitalisation of the electric grid control systems.

The basic components of AMI are depicted below:

Figure 5: Components of AMI infrastructure



AMI's main functionalities encompass power measurement facilities, assisting adaptive power pricing and demand side management, providing self-healing ability, and interfaces for other systems. AMI helps in achieving financial benefits, improved services, and opportunities for consideration of environmental concerns.

The AMI includes smart meters at customer premises, access points, communication modules and backbone networks between customers and service providers and the head-end-system and the meter data management system to measure, collect, manage, and analyse the data for further processes. The key components and their functionalities are defined below:

i. **Smart meter:**

In AMI systems, smart meters are regarded as the key interfaces for physical, information, and social domains of the smart grid. Smart meters are electronic electricity meters which are equipped with communication capabilities. According to CEA, smart meters are required to be equipped with features such as bi-directional communication, integrated load limiting switch, remote firmware upgrade, net metering, prepaid, post-paid, and time of day tariff features, over and above facilities for measurement of electrical energy parameters.

A smart meter can assess the power consumption in much more detail than a conventional meter can and periodically send the collected information back to the utility for data analysis, load monitoring and billing purposes. Full integration of smart meters on the distribution system and at consumers' end would enable better tracking of AT&C losses along with enhanced revenue collection and demand-side management. Loss reduction, improved billing, and collection efficiency along with quicker detection of outages and elimination of billing errors are some of the benefits expected from smart meters.

ii. **Communication network:**
Communication Network is critical to transmit data from smart meters to back-end applications in an accurate, reliable and timely manner. Three networks are commonly referred to in the context of the AMI: WAN, NAN and HAN.

- Home Area Network (HAN): HAN provides connections between the smart meters of the home appliances, other integrated systems such as rooftop photovoltaic (PV) system, distributed sensors, plug-in electric vehicle/ plug-in hybrid electric vehicle, in-home display (IHD), smart thermostat, etc.
- Neighborhood Area Network (NAN): NAN provides communication links between a number of individual smart meters and a data concentrator using communication technologies.
- Wide Area Network (WAN): WAN performs the task of connecting an AMI end in the local utility network and a data concentrator. Data concentrator collects data from a group of smart meters over a smart meter network and sends this bulk data to the HES.

Widely used communication technologies include cellular, RF mesh and Power Line Communication (PLC). Some wireless communications include ZigBee, 6LowPAN, SigFox, etc. Utilities examine their requirements in terms of bandwidth, latency, cost, coverage, cybersecurity considerations, etc. before choosing the most suitable communication technology.

iii. **Head End System (HES):**
Head End System is the host system whose main objective is to acquire meter data automatically, and to monitor parameters acquired from meters. The HES may provide a limited amount of data validation before either making the data available for other systems to request, or before pushing out the data to the MDMS.

iv. **Meter Data Management System (MDMS)**
The MDMS receives the data from the HES and manages the collected data and also maps the data to the relevant consumer. This data can be integrated with one or more key information and control systems of the utilities such as billing systems, customer information systems (CIS), geographic information systems (GIS), outage management systems (OMS), and distribution management systems (DMS).

3. Decoding AMI interoperability

3.1. Defining interoperability

Interoperability, as a term, refers broadly to the ability to exchange data or communicate between two disparate systems or devices. For two systems to be interoperable, they must be able to exchange data and subsequently present that data such that it can be understood by a user.

Interchangeability is the ability to exchange one device with another without reducing the original functionality. The focus of interchangeability is to replicate the device use experience in the same way.

Both interoperability and interchangeability are relevant terms in the context of the Indian distribution sector. While interoperability is required to enable devices to work together to produce insightful data which can be used by enterprise IT systems, interchangeability is required to seamlessly replace one device by another without altering the use experience.

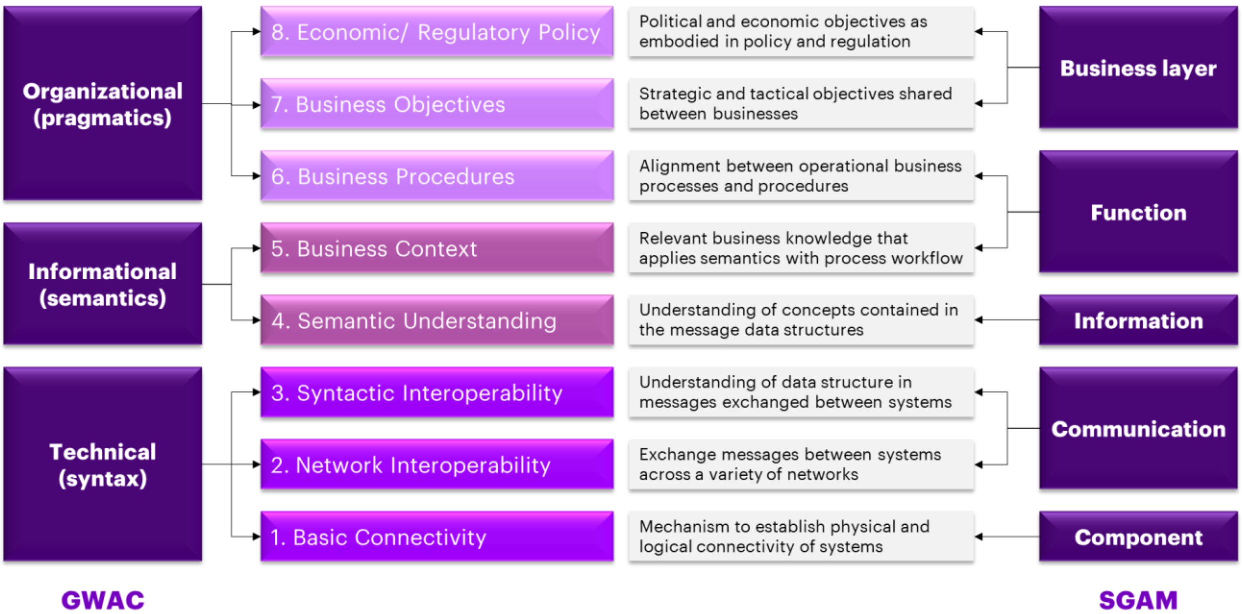
GridWise Architecture Council (GWAC), which was formed in 2004 by the U.S. Department of Energy, is designed to promote and enable interoperability among the many entities that interact with the electric power system. GWAC defines the concept of interoperability as one which incorporates the following characteristics:

- exchange of meaningful, actionable information between two or more systems across organisational boundaries
- a shared understanding of the exchanged information
- an agreed expectation for the response to the information exchange
- a requisite quality of service: reliability, fidelity, and security

A commonly understood objective for interoperability is the concept of “plug-and-play”, which allows the system integrator to configure an automation component into the system simply by “plugging” it in.

The GWAC proposes a context-setting framework that recognises that interoperability is only achieved when agreement is reached across many layers of concern. The framework identifies eight interoperability categories and layers them according to technical, informational, and organisational groups.

Figure 6: Interoperability layers and categories



i. **Technical:** Emphasises the pragmatic aspects of interoperation and represents the policy and business drivers for interactions.

ii. **Informational:** Emphasises the semantic aspects of interoperation and focuses on what information is being exchanged and its meaning.

iii. **Organizational:** Emphasises the syntax or format of the information and focuses on how information is represented within a message exchange and on the communications medium.

Subsequently in 2011, the **Smart Grid Architecture Model (SGAM)** was created in the M/490 mandate of the European Commission to the European standardisation bodies CEN, CENELEC, and ETSI with the focus on finding existing technical standards applicable to Smart Grids as well as identifying gaps in state-of-the-art and standardisation. The model derives the 8 interoperability categories from the GWAC framework and divides them into five layers:

i. **Business Layer:** Provides a business view on the information exchange related to Smart Grids. Regulatory and economic structures can be mapped on this layer.

ii. **Function Layer:** Describes services including their relationships from an architectural viewpoint.

iii. **Information Layer:** Describes information objects being exchanged and the underlying canonical data models.

iv. **Communication Layer:** Describes protocols and mechanisms for the exchange of information between components.

v. **Component Layer:** Physical distribution of all participating components including power system and ICT equipment.

Out of these five layers, the first two layers are related to functionality, whereas the lower three layers can be associated with the intended technical implementation.

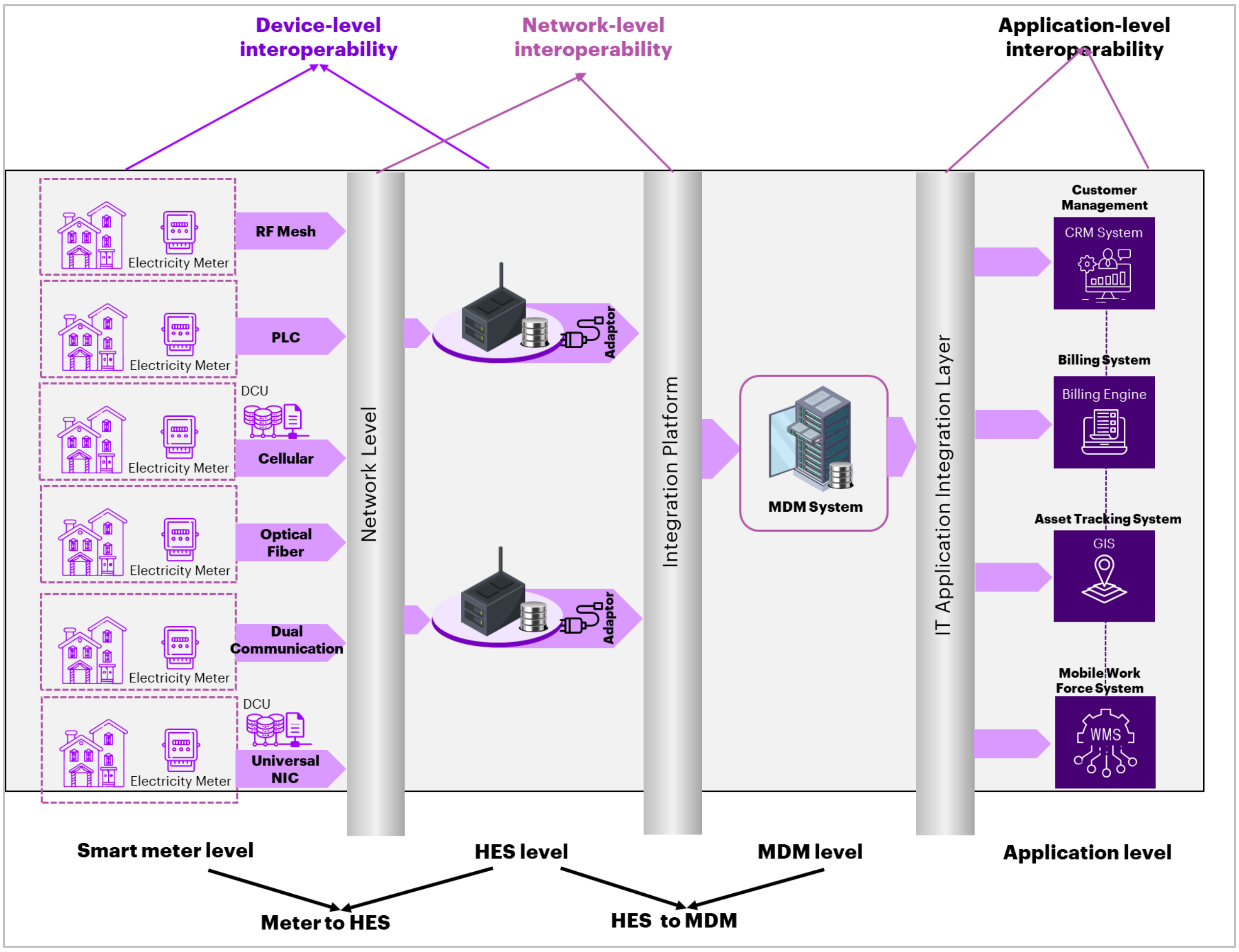
Interoperability between devices becomes essential to ensure ease of data integration, easy upgradation of the components, prevent vendor lock-in and achieve fast economies of scale.

If we consider the term in respect of AMI specifically, since multiple utilities plan to roll out smart metering initiatives across India simultaneously, there are likely to be multiple smart metering systems from different manufacturers utilised by the distribution companies. However, different manufacturers use different techniques to store, encode & transfer the data. Thus, in absence of a common standard to ensure integration and data collection from smart meters, it would be difficult & complex to integrate the data generated at a central level. Hence, interoperability becomes imperative to ensure that the data generated from smart meters can be used by the entire ecosystem.

3.2. Understanding layers of AMI interoperability

Interoperability could be achieved at different levels in the AMI system as explained below:

Figure 7: Interoperability layers for smart metering



i. **Hardware-level interoperability:**

Hardware-level interoperability would entail seamless communication between the smart meter and the HES of any make for which data exchange in communicable formats is key. This implies any smart meter will be supportive to any type of HES, and any make of HES will be operable irrespective of smart meter type, make or networking technologies.

If a Discom wishes to install new smart meters with different networking technologies, it would not be required to replace the HES. Similarly, if a Discom wants to replace an existing HES or install a new HES, it will not be required to change the MDM.

To understand interoperability at the hardware-level, the architecture can be divided into two parts:

a) **Meter to HES - device level interoperability** -The challenges and potential solutions to achieve the same are detailed below:

- Usually, HES is capable of communicating with its own set of meters (or the ones that it has collaborated with). Therefore, in the long run, if the Discom has to change any existing meter with a new meter of a different make, there is a chance that it would not be interoperable with the HES. This creates a vendor lock-in and a bottleneck for Discoms to upgrade the smart metering system.
- Currently in India, device level interoperability between meter to HES is achievable for meters using cellular technology, as most meters are DLMS compliant. The Discoms usually mandate multiple meters and HES OEMs to enable interoperability between each other, as evident from the recent MoP mandate. Additionally, Discoms also mandate the HES to follow specific integration protocols established by IS 15959 (DLMS-COSEM) to communicate with smart meters irrespective of the physical communication layer. Currently, multiple meters can communicate with multiple HES over cellular technology using the common DLMS. This has been demonstrated during the EESL smart meter rollouts.
- However, the RF mesh technology is proprietary as the meters must be customised according to the requirements of RF mesh vendor and therefore interoperability becomes a challenge. In an attempt to achieve hardware-level interoperability for RF mesh, some vendors (Silver Spring, now Itron, during rollout in Australia and Landis+Gyr for Tata Power's rollout in India) provided common RF modules to all meter manufacturers, who designed their meters accordingly.
- In the current scenario, it is difficult to gauge the extent to which device interoperability is required at all levels, given the operational constraints along with the cost. Enabling interoperability at the hardware level for existing smart meter systems will need infrastructure upgradation which is cost intensive and will lead to operational disruption.
- Currently, there are no standards that mandate interoperability in India. However, CEA/ CERC along with recent MOP guidelines mandate AMISPs to demonstrate communicability of a HES with at least 2 different makes of meters for future AMI rollouts[2].
- A Discom enabling dual communication technology (for example: RF mesh + PLC) to achieve maximum reliability of meter data communication should have meters and HES system (refer to Annexure 1) which will support both communication technologies. In order to achieve hardware-level interoperability (for smart meters & HES) the Discoms need to define & communicate the techno-functional features of the physical devices to the device manufacturers and vendors. The communication module inside the smart meter is a critical component in achieving interoperability across various communication technologies to enable seamless bi-directional data flow, which is the most unique feature of a smart meter. The pluggable communication module can be

[2] Link to standard bidding document by REC, at the behest of MoP, for participation in RDSS AMISP tenders: https://recindia.nic.in/uploads/files/AMISP-RFE21042022.pdf-

made to operate between different technologies, if made compatible with RF mesh and/ or legacy cellular technologies such as 2G/3G/4G as well as with evolving low power IOT based-technologies LTE-M and NB-IoT. Providing compatibility with multiple technology options is dependent on the communication module chipset's design with associated cost factors. Respective manufacturers of the physical devices need to work collectively to come up with a standard technical design of the respective devices which can support dual communication. Further, the Discoms and manufacturers need to define the testing criteria as well to support testing of the working devices.

- Additionally, a forum has been formed to evaluate enablement of a pluggable communication module which is compatible with different communication technologies (cellular as well as RF Mesh) through development of common standards. Some smart meter manufacturers have recently piloted the use of both cellular and RF mesh technology with the same meter design. However, discussions are ongoing within specific committees in India to assess the extent to which device interoperability should be sought based on the business benefits.

b) **HES to MDM - device level interoperability -** The challenges and potential solutions to achieve the same are detailed below:

- MDM systems are specific to the HES in majority of the cases, which is a bottleneck for the Discoms to upgrade the HES or MDM system leading to vendor lock-in on both sides.
- Upgradation of MDM system is also a challenge, as Discoms may need to change the entire existing IT infrastructure. This may lead to increased costs, operational bottleneck and technical risks.
- Another option is to install the HES system with the use of new adapters to communicate with the existing MDM system, which is also cost intensive.
- The standard bidding document released by REC[3] specifies the following requirements:
  - The HES solution should have been successfully integrated with at least 2 different MDMS/ other utility IT Solutions in the last 7 years which are in operation for at least 1 year.
  - The proposed MDM solution should have been successfully integrated with at least 2 different HES solutions in last 7 years which are in operation for at least 1 year.
- However, CEA had published a guideline in 2016 on the functional requirements of the AMI, which also highlights the working principle of HES[4]. These guidelines are henceforth referred to as “CEA Guidelines” in this document.

[3] Link to the SBD: https://recindia.nic.in/uploads/files/SBD-Version-3.pdf

[4] *Functional Requirements of Advanced Metering Infrastructure (AMI)*, Central Electricity Authority, 2016
Link to the CEA Guidelines: https://www.ipds.gov.in/Whats_New_Files/ami_func_req-Aug%202016.pdf

- A complete standardisation for data transmission should be done to remove any inter-dependency at upstream application layers including HES and MDM. Unified transmission layer protocols like TCP, IPv6 standards are currently well established among smart meter ecosystem partners.

ii. **Network-level interoperability**:

The communication technology used in AMI connects the systems and devices for network-side communication. AMI systems use a variety of communication technologies like RF mesh, PLC, cellular and optical fiber. With multiple communication networks to manage, utilities often look for solutions that support a combination of primary & back-up communication system and fully integrate into their future operational plans.

Network interoperability implies the ability of smart meters to operate on multiple communication technologies and service providers without making any additional changes to the system and can be broadly classified into two parts: inter-technology interoperability and intra-technology interoperability.

a) Inter-technology interoperability refers to supporting of different communication technologies like, cellular, RF mesh or PLC etc. for enabling network level interoperability at the meter to HES layer, and a common data integration platform which can support network level interoperability at both HES and MDM layers.

The AMI architecture (refer to Figure 7) highlights inter-technology network interoperability at two broad levels:

1. Meter to HES: Network-level interoperability
2. HES to MDM: Communication-level interoperability

Current interoperability challenges related to network communication irrespective of urban, semi-urban, rural areas are discussed below:

Network interoperability challenges for meter to HES layer:

- In the Indian context, most HES are specific to a networking technology. Hence, if a Discom wants to install new smart meters with a different communication technology, it will need to install a new HES which can support the new communication technology
- Upgradation of existing HES system is challenging and a cost intensive programme for a Discom.
- Most of the deployed HES do not support interchangeable networking technology within a single meter. In the near future, to implement interchangeability of networking technologies at the meter level (with dual communication or any other mechanisms as explained in Annexure 2), the current HES will pose operational challenges
- Currently, interoperability standards are not available in India

Network interoperability challenges for HES to MDM layer:

- Communication between HES to MDM through inter-supportive integration mechanism between a few set of HES & MDM vendors creates vendor lock-in for the Discoms

- If the Discom needs to install a new HES system which is not capable of communicating with legacy MDM system, upgradation of MDM is a cost intensive affair posing data loss and security risks
- An alternate way to integrate HES and MDM through configuring a common integration platform is also cost-intensive and requires a change in infrastructure
- CEA/CERC guidelines are available for integration architecture (SOA). But there are no specific standards or configuration recommendations available for integration platform.

b) **Intra-technology interoperability** refers to supporting of different communication network providers within the same technology or supporting of different version/ generation of the same networking technology[5]. This is applicable for network level interoperability at the meter to HES layer only.

Table 1: Challenges for intra-technology network interoperability

#	Interoperability technologies	Challenges
1	**Cellular** Intra-technology interoperability includes interoperability between network providers as well as between various cellular technology generations 2G, 3G, 4G, LTE.	• Although cellular is widely used in Indian smart meter systems, there still exist network connectivity issues in urban & rural areas. • There is lack of available standards and specific communication testing standards. Universal SIM card is one of the solutions that can help in facilitating intra-network interoperability. The universal SIM can enable switching between network service providers, to the one which one has better signal strength in a certain area.
2	**RF Mesh** This is one of the most popular and internationally proven communication technologies. Rural and semi-urban areas have been using RF Mesh technology proprietary to some vendors.	• RF communication is specific to a certain frequency level. Different meter manufacturers have different proprietary frequency bands to create the communication mesh for its meters. This poses the challenge of vendor lock-ins and lack of meter-level interoperability with RF mesh technology. • Another cause of lack of interoperability is that there is no mandate to use a specific frequency level for the meter manufacturer using RF mesh and different vendors use different frequency levels.
3	**PLC**	Intra-technology interoperability is not applicable for PLC systems, as the communication takes place through a power line by superimposing the modulated data on the power supply voltage.

[5] Inter-technology or intra-technology interoperability can also be defined as interchangeability as this can only be achieved by dual communication system, universal SIM card or standardized common communication system

#	Interoperability technologies	Challenges
4	**Optical fiber**	Intra-technology interoperability is not applicable for optical fiber systems, as the communication takes place through optical wave propagation within fiber line which is based on total internal reflection principle.

Currently, achieving network interoperability is perceived to be difficult for both inter and intra technology level. Most meters communicating using cellular technologies are unable to switch between 2G/3G/4G technologies or between communication service providers, if the connection is lost. Additionally, for PLC/RF mesh technology, the meters are vendor agnostic because of implementation of vendor self-centric algorithm adaptation for authentication with higher level devices. This implementation cannot be brought to be interoperable as vendors will have to share their proprietary logics and algorithms with each other which is a high uncertain point and will take a huge time and effort to be driven.

Thus, network interoperability is currently a key concern area. Experiences from around the globe show that no single solution individually offer 100% reliable connectivity all the time. The best range of reliability offered is between 95-98%; and in many cases it is well below 90%. Some popular communication architectures deployed for AMI worldwide are depicted in Annexure 3.

Potential solutions to facilitate network interoperability:

To achieve interoperability on the network-level, smart meters equipped with a dual communication system, which supports both cellular and non-cellular (PLC/ RF Mesh), can be a potential solution. However, this increases the overall cost, as NIC cards will be required to support multiple technologies and again will not provide a complete solution.

Currently, in India, a dual communication system for AMI has not been implemented on a large-scale. Based on the current scenario of the Indian distribution sector, a dual communication system which is a combination of RF Mesh communication, PLC, cellular network & fiber optics (in some areas) could be a potential way forward to achieve network-level interoperability. However, since this system will be a very costly solution, there needs to be a solution that will strike a balance by opening the device selection at the consumer level for any of the technologies. To achieve the interoperability at the aggregator node, a common technology can be offered. In a similar analogy, to support PLC/RF mesh with cellular smart meters, a cellular connection is proposed at aggregator level in RF and PLC.

iii. **Application-level interoperability**:
Application-level interoperability is achieved when data can be exchanged seamlessly between MDMS and the Discom enterprise IT applications. It is expected that the different HES and MDMS systems should be able to seamlessly communicate without changing their system/ business configurations, by complying with defined standards.

In India, application-level interoperability is achievable. The Discoms, in the tenders, have been mandating that the MDMS must be able to interface with both the HES and the utility systems by complying with standards like CIM-XML-IEC 61968 / IEC 61968-100 / Web Services / Multi Speak. CEA guidelines are also available for architecture of integration (SOA-Service Oriented architecture). In the Indian scenario, the MDM application should have the following features to achieve application-level interoperability for data integration:

- Easily scalable
- High flexibility to handle any data type/ data format & CAST the data (Cleaning, Augmenting, Shaping & Transforming)
- Easily integrable to any enterprise IT application
- Ability to be hosted on cloud, for enablement of use cases with analytical and visualisation tool.
- Ability to accommodate analytical engines for analysis on the stored data

To ensure seamless data collection, integration, and transfer at these different levels across the AMI, it is important to have common standards in place.

4. Assessing standards that facilitate interoperability

It is essential to define standards to ensure long-term viability of the smart meters. Common standards are important to make sure that smart meters, from different vendors, operate in tandem with each other and the rest of the network, so that they can fully interoperate.

Internationally, multiple standards are being continuously developed to maintain interoperability and cybersecurity and are being implemented to support needed technology deployment. Geographies like United States of America (USA) and Europe recognised and acknowledged the need for interoperability standards relatively earlier than India and established multiple standards bodies that develop and maintain standards to facilitate interoperability. Some of the renowned bodies include:

- Institute of Electrical and Electronics Engineers (IEEE)
- International Electrotechnical Commission (IEC)
- European Committee for Standardisation (CEN)
- European Electrotechnical Committee for Standardisation (CENELEC)
- European Telecommunications Standards Institute (ETSI)
- National Institute of Standards and Technology (NIST)

In India, smart meters are governed by standards that have been set by Bureau of Indian Standards (BIS). BIS is the National Standard Body of India established under the BIS Act 2016 for the harmonious development of the activities of standardisation, marking and quality certification of goods and for matters connected therewith or incidental thereto.

These organisations have developed some standards to facilitate interoperability in India and globally.

Table 2: Indian standards to facilitate interoperability

#	Standard	Overview
1.	**IS 16444**	i. Part 1 specification is for AC static direct connected watthour smart meter class 1 and 2 and was released in 2015 ii. Part 2 specification is for AC static transformer operated watthour and var-hour smart meters of accuracy class 0.2S, 0.5S and 1.0S and was released in 2017
2.	**IS 15959**	i. Data exchange for electricity meter reading, tariff and load control – Companion specification: Part 1 ii. Data exchange for electricity meter reading, tariff and load control – Companion specification: Part 2 for smart meter iii. Data exchange for electricity meter reading, tariff and load control – Companion Specification: Part 3 for smart meter (Transformer operated kWh and kVARh, Class 0.2 S, 0.5 S and 1.0 S)

Table 3: International standards to facilitate interoperability

S.No.	Standard	Overview
1.	IEEE 1547	**Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces** The 1547 standard provides the minimum functional technical requirements that are universally needed to help ensure a technically sound interconnection. The IEEE Std 1547–2003 is the first in the 1547 series of interconnection standards and provides interconnection technical specifications and requirements as well as interconnection test specifications and requirements. These standards are followed by additional complementary standards designed to expand upon or support the root standard.
2.	IEEE 2030	**Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads** The 2030 standard provides alternative approaches and best practices for achieving smart grid interoperability. It is the first of all IEEE standards on smart grid interoperability that provides a roadmap directed at establishing the framework in developing an IEEE national and international body of standards based on cross-cutting technical disciplines in power applications and information exchange and control through communications. The IEEE Std 2030 – 2011 is the base guide followed by three additional complementary standards to expand upon it.
3.	IEC 61850	**Communication networks and systems for power utility automation** IEC 61850 is an international standard that defines communication protocols to provide communication between different equipment located in a substation, such as protection, control, and measurement equipment, as well as (IEDs) intelligent electronic devices. IEC 61850 aims to provide interoperability, a key concept to allow for the integration and management of equipment from different manufacturers.
4.	IEC 62056	**Suite of standards for electricity metering data exchange** The IEC 62056 standard defines the communication protocols that are designed for electricity consumption measurements, data exchanges with electricity meters, controlling the tariffs and load regulation. These standards define DLMS/ COSEM protocol specifications for communication.

S.No.	Standard	Overview
5.	European Mandate M/441	**Standardisation Mandate to CEN, CENELEC and ETSI in the field of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability** This is used for the standardisation of smart metering functionalities and communication for usage in Europe for electricity, gas, heat, and water applications. These applications required a standardisation process to ensure the interoperability of technologies and applications within the European market.
6.	NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0 and Release 2.0	**This document aims to create a self-sustaining, ongoing standards process that supports continuous innovation as grid modernisation continues in the decades to come**. The document covers the following: • A high-level conceptual reference model for the Smart Grid • Existing standards that are applicable (or likely to be applicable) to the ongoing development of the Smart Grid • High-priority gaps and harmonisation issues for which new or revised standards and requirements are needed • Action plans with aggressive timelines by which designated standards development organisations (SDOs) and standards-setting organisations (SSOs) will address these gaps • Strategy to establish requirements and standards to help ensure Smart Grid cybersecurity

In addition to these, there exist certain open protocols, that are free for manufacturers to build into their equipment without having to pay royalties. They are not owned by any particular company and not limited to a particular company's products. The open protocols used in smart metering include:

- Common Information Model (CIM)
- Device Language Message Specification (DLMS)/ Companion Specification for Energy Metering (COSEM)
- Wireless Smart Ubiquitous Network (Wi-SUN)
- ModBUS
- Distributed Network Protocol (DNP3)

5. Analysing the smart meter testing ecosystem

To ensure quality and reliability of smart meters, it is imperative to ascertain their performance as per relevant standards. Testing of smart meters helps to ensure that they are accurate in recording the energy consumption and billing and further prevent their malfunctioning and failures. With a greater number of meter manufacturers coming forward to support the high target of smart meter installations in India, there exist different technologies, protocols and designs, posing interoperability issues. Hence, there is a greater need to define testing standards for smart meters and subsequently ramp up smart meter testing through testing facilities.

a. Testing standards

Internationally, the IEC body defines standards for testing of meters. The Working Group 11 (WG11) is responsible for defining type tests and acceptance tests for all kinds of metering equipment. The standard IEC 62052-11 defines general requirements, tests and test conditions for metering equipment.

Some tests that are specified in this standard include:

- Mechanical tests (spring hammer test, shock test, vibration test)
- Material test
- Impulse voltage test
- Climatic tests (resistance to heat and temperature, dust, water and solar radiation)
- Immunity to earth fault
- Electromagnetic compatibility (EMC) test

In India, smart meters must undergo testing in accordance with the standard IS 16444. This standard cross-references to IS 13779 and IS 15884 for testing requirements. The standard specifies the testing requirements for the following parameters:

1. Metrology
2. Load switching capability
3. Data exchange protocol
4. Smart meter communicability

b. Testing laboratories

Testing facilities for smart meters have been set up by meter manufacturers and state Discoms in addition to independent third parties in India. However, while the number of testing facilities has increased over the past few years, testing requirements have also increased, owing to the growing adoption of smart meters. Some organisations that have set up smart meter testing labs include:

- Central Power Research Institute (CPRI)
- Institute for Design of Electrical Measuring Instruments (IDEMI)
- Electrical Research and Development Association (ERDA)
- Tata Power Smart Meter Testing Labs
- Yadav Measurements

Challenges for scale-up

Post primary discussions with testing agencies and based on secondary research, the following roadblocks in the Indian testing landscape were identified:

- Existing capacity of third-party testing labs for smart meters in India is very less when compared to the high smart meter installation target set by GoI
- There is lack of funding/ grants by the Government to existing laboratories, or to set up new laboratories that would enable accelerating pace of smart meter testing in India
- There is lack of manpower with available specialised skillsets to conduct individual tests (for eg: combined expertise in IT and tele-communication is required for performing communication tests)

6. Key learnings from distribution companies

6.1. Insights from current status of Indian Discoms

As India is at the onset of the smart meter journey, it is presented with the ideal opportunity to ensure interoperability at the initial stages across the components of the AMI. This shall help during systems upgradation later and circumvent any undue dependence on any single vendor, as the technologies evolve, and number of service providers increase.

Thus, it becomes imperative for states to define end-to-end interoperability in smart metering well beforehand. REC, one of the nodal agencies for smart meter implementation under the Revamped Distribution Sector Scheme (RDSS), has released a Standard Bidding Document (SBD) for procurement of the AMI System, in alignment with which the Discoms are required to draft their tenders for AMI procurement. Along with this, a high focus is being laid on other enabling factors such as cybersecurity measures, customer awareness, capacity building, data privacy, data management and testing.

To get holistic and in-depth insights into the current smart meter deployment practices across the country, smart meter journeys of three Indian Discoms were studied:

i. South Bihar Power Distribution Company Ltd. (SBPDCL) and North Bihar Power Distribution Company Ltd. (NBPDCL)
ii. Uttar Haryana Bijli Vitran Nigam Limited (UHBVNL)
iii. CESC Ltd.

The objective of the study was to assess:

i. Smart meter deployment journey of the Discoms
ii. Current efforts taken to ensure interoperability across different layers
iii. On-ground challenges faced
iv. Key imperatives for achieving end-to-end interoperability

The following insights were gained from the study:

Table 4: Key insights from Discoms' analysis

S.No.	Parameter	Details
South Bihar Power Distribution Company Ltd. (SBPDCL) and North Bihar Power Distribution Company Ltd. (NBPDCL)		
1.	Current status	~6 lakhs smart meters installed
2.	Vendor ecosystem	• System integrator: EDF in partnership with Accenture • Communication network: BSNL (3G) and Jio (4G) • HES: Schneider • MDMS: Siemens • Smart meter: Genus and Schneider • Cloud services: ESDS
3.	Focus on interoperability	• Hardware-level meter to HES interoperability was attained as the RFP specified the requirement of the HES and the MDMS to be compatible with 5 different makes of meters.

S.No.	Parameter	Details
		• The utility specified that the meters should have interoperable plug and play communication module (4G, 5G, RF, PLC), which is to be chosen by the bidder. Any costs involved for upgradation of communication technology is to be borne by the AMISP.
4.	Technical standards as specified in the tender document	Some of the key specifications as set out in the tender document are as below: • **Smart meter:** ○ The meters shall comply with IS 16444 for all requirements. ○ The smart meters shall have a dedicated sealable slot for accommodating plug-in type bi-directional communication module which shall integrate the respective communication technology (RF/PLC/ Cellular) with the smart meters. ○ The NIC card should be integrated with at least 3 makes of meters to enable the respective meters to seamlessly integrate with proposed HES and/or MDM thus enabling interoperability of the system. • **Communication infrastructure:** ○ The communication infrastructure should either be based on RF / RF mesh network / PLCC/ cellular network or a combination of these. • **Head End System (HES):** ○ HES shall communicate with DCUs/access points using WAN technology. ○ HES shall be able to accept data according to IS 15959 part-2 /part 3 and latest amendments. • **Meter Data Management (MDM):** ○ MDM shall interface with other utility legacy systems as well as the HES on standard interfaces. The data exchange models and interfaces shall comply with CIM-XML-IEC 61968 / IEC 61968-100 / Web Services / Multi Speak.
5.	Key challenges and considerations	• There is a need for the OEMs to upgrade and update their devices/ technology as the assumptions evolve to serve the smart meter consumers better. • While communication has improved over the years, as the technology moved from 3G to 4G, there is still a requirement for uninterrupted network. A hybrid model where the meter supports 2 types of communication technologies will help tackle this better.

S.No.	Parameter	Details
		• There is a need for meters to be interoperable with different technologies, so that the meters are not rendered useless when a technology goes obsolete.
Uttar Haryana Bijli Vitran Nigam Limited (UHBVNL)		
1.	Current status	~2.45 lakhs smart meters installed
2.	Vendor ecosystem	• System integrator: L&T Construction • Communication network: VI (2G/3G) • HES: Trilliant • MDMS: Oracle • Smart meter: Genus, Schneider, ITI, AEW • Cloud services: ESDS
3.	Focus on interoperability	• Hardware-level meter to HES interoperability was attained; currently the HES is communicating with up to 5 different meters. • The utility is in the planning stage for deploying additional 20 lakh meters for which hybrid communication technology will be considered (cellular + RF Mesh), as opposed to the current cellular technology (3G).
4.	Technical standards as specified in the tender document	Some of the key specifications as set out in the tender document are as below: • **Smart meter:** The smart meters were procured through a separate RfP which specified the following requirements: o The meters shall comply with IS 16444 for all requirements. o The smart meter must have a GPRS communication module which shall be of pluggable-type and shall be capable of servicing technologies such as 2G, 3G and 4G • **Communication infrastructure:** o The communication infrastructure should be based on GPRS technology. The GPRS communication network shall be capable of servicing 3G technology compliant with IPv6. • **Head End System (HES) and Meter Data Management (MDM):** o The HES should be able to communicate with meters from minimum five meter manufacturers o HES shall preferably interface with MDMS on standard interfaces and the data exchange models and

S.No.	Parameter	Details
		interfaces shall comply with CIM / XML / IEC 61968 or any other open standard.
5.	Key challenges and considerations	• While interoperability is very important for the smart meter industry, the pros and cons must be evaluated in advance. For example: utilities deploying RF Mesh communication technology in addition to cellular, must evaluate factors like cost, requirement of specialised expertise, specific communication module, etc. • A strong focus on cyber security is key for a successful implementation. The utility mandated measures like meter key rotation which ensure robust security. While state tenders usually specify such requirements, they must mandate them to ensure compliance by vendors.
CESC Ltd.		
1.	Current status	~40,000 smart meters installed
2.	Vendor ecosystem	CESC conducted multiple pilots in small pockets and tested different vendors and technologies. The vendor details are as follows: • System integrator: CESC Ltd. • Communication network: RF Mesh, Cellular 4G • HES: Itron, Iskraemeco • Smart meter: Genus, Secure, Schneider, IIPL
3.	Focus on interoperability	• Hardware-level: For RF mesh communications, NICs from the communication solution provider were integrated with the multiple makes of smart meters and for cellular communication, multiple makes of smart meters are made reporting to a single HES to achieve interoperability. Also, multiple HES are integrated with CESC's different existing IT applications.
4.	Key challenges and considerations	• Interoperability at the network device level was not achievable. • With evolving technology, achieving communication interoperability is a key challenge.

The detailed case studies are provided in Annexure 4.

6.2. Best practices from International DSOs

As India scales up its smart meter implementation, many other countries across the globe are also undertaking significant smart meter rollout programmes, the analysis of which reveals certain interoperability challenges faced and good practices followed. These learnings can be imbibed by India to ensure a successful and smooth on-ground smart meter rollout. With this objective, four notable smart meter rollout programmes of DSOs from around the world were studied to gain practical insights:

- **UK Smart Meter Installation Programme (SMIP):**
  The UK SMIP aims to replace 53 million (30 million electric and 23 million gas) legacy meters with remotely managed Smart Meters covering about 30 million households[6] by 2025.

- **EDF-Enedis' Linky smart meter programme:**
  The Linky rollout in France is one of the largest smart meter rollouts in the world with installation of 35 million meters[7]. The Linky deployment is almost complete.

- **Advanced Grid Intelligence and Security (AGIS) of a North American utility:**
  The utility is undertaking AMI implementation over a period of five years from 2019 to 2024 with a target to deploy over one million resident smart meters in the area of Colorado.

- **Kansas City Power & Light (KCP&L) Smart Grid Demonstration Project (SGDP):**
  One of KCP&L Smart Grid Demonstration Project's key initiatives was to develop integrated Advanced Metering Infrastructure (AMI) and Meter Data Management (MDM) systems that support two-way communication with 14,000 smart meters in the SGDP area[8].

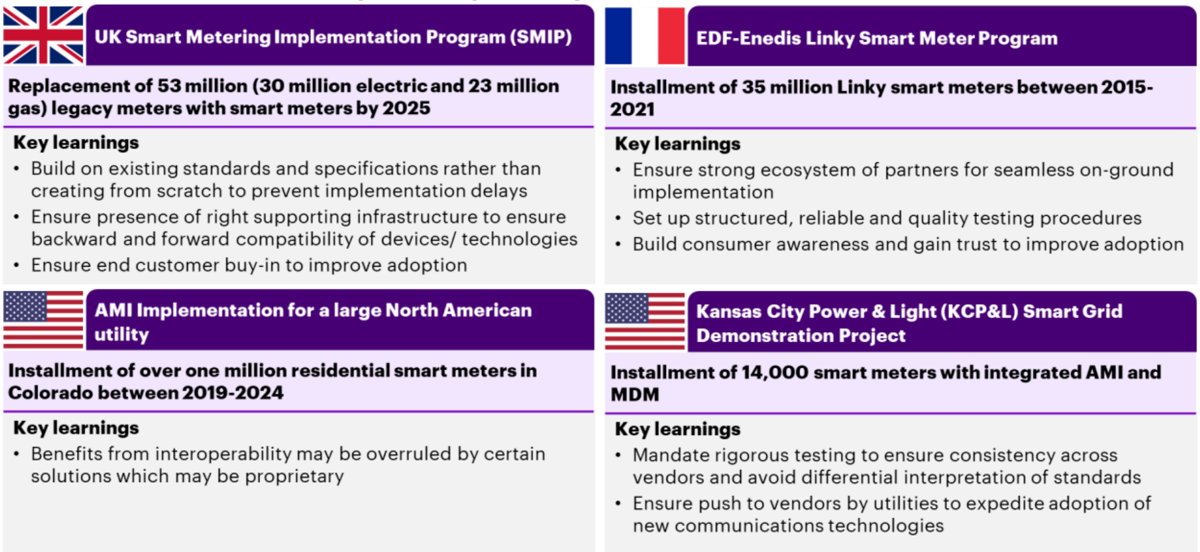
The objective of the study was to assess:

i. Smart meter deployment journey of the DSO
ii. Efforts taken to ensure interoperability
iii. Key learnings – challenges and best practices

Some of the key insights, which will be instrumental in ensuring a sustainable smart meter implementation, that emerged from the study of the above-mentioned programmes are as follows:

[6] Source: https://cyanconnode.com/uk-smip/
[7] Source: https://eu.landisgyr.com/blog/linky-project-france
[8] Source: https://www.energy.gov/sites/prod/files/2016/12/f34/OE0000221_KCPL_FinalRep_2015_04_0.pdf

Figure 8: Key learnings from international DSOs



- It is important to build on existing standards and specifications rather than creating them from scratch to prevent implementation delays.
- It is important to establish the right infrastructure to ensure backward and forward compatibility of devices and technologies.
- Ensuring customer buy-in by raising awareness is key to improving adoption of smart meters.
- A strong ecosystem of vendors is critical to ensure seamless on-ground implementation.
- It is vital to mandate rigorous testing through structured and quality testing procedures and labs to ensure consistency across vendors and avoid differential interpretation of standards.
- There may be times when benefits from interoperability may be overruled by certain solutions which may be proprietary.
- In a world where communication technologies are rapidly evolving, it is important that utilities push vendors to expedite adoption of these new technologies.

The detailed case studies are provided in Annexure 5.

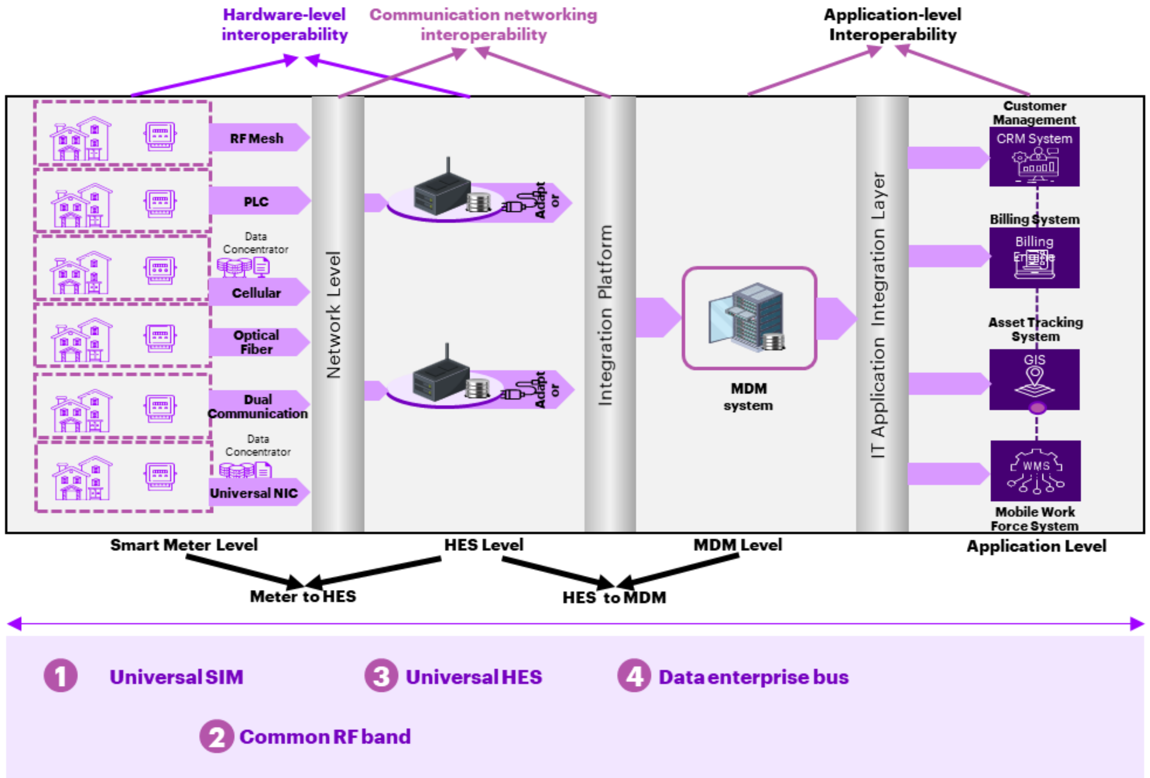
7. Way forward to facilitate AMI interoperability in India

Interoperability and interchangeability of the AMI infrastructure is desired to enable seamless integration of data across all systems and devices without making additional changes. In this regard, this section focuses on the way forward to facilitate interoperability and interchangeability across different layers of the AMI infrastructure, along with the enablers that will expedite the smart meter deployment journey in India.

7.1. Recommendations

To enable interoperability at all levels, different solutions are proposed across the different levels. The same has been depicted in the below figure:

Figure 9: AMI layer-wise interoperability



1. **Universal SIM card:**
   Universal SIM card is one of the solutions that can help in facilitating intra-network interoperability. The universal SIM can enable switching between network service providers, to the one which has better signal strength in a certain area. To enable smooth implementation of this concept and avoid any operational challenges, it is critical that the different telecom providers coordinate with each other. A central level policy/ guideline will be an imperative in operationalizing this.

2. **Common RF band:**
   A common RF mesh band for the utility sector at the national level is proposed. This implies that a frequency band is dedicated to the utility sector and the RF communication providers will be able to operate at any range within this band. This will ensure that there is no vendor lock-in for the RF mesh technology, in case the meters are changed.

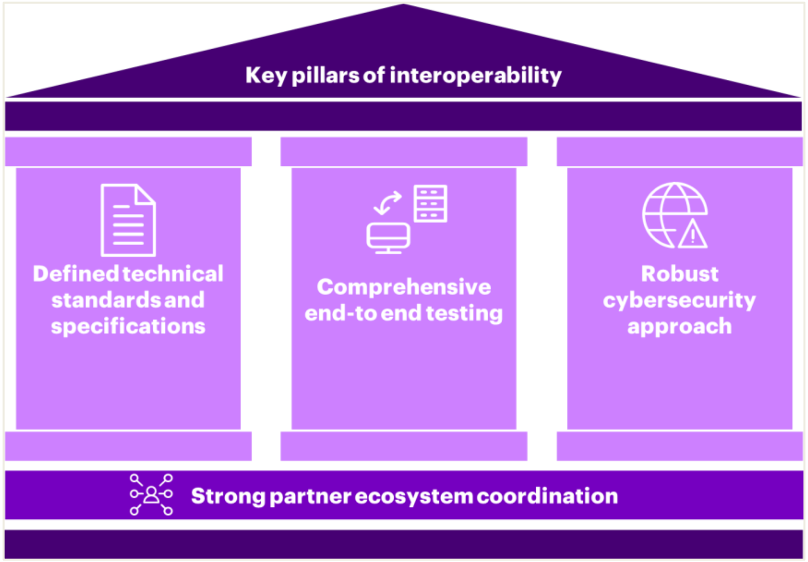
3. **Universal HES:**
   The universal HES can also help in facilitating network-level interoperability. The HES is designed to operate and support any networking systems, be it cellular, RF mesh or PLC. Since the universal HES provides options for multiple communication technologies, it will ensure that in the case where the primary network is unavailable, the network is not lost, and the HES falls back to the secondary communication technology.

4. **Data enterprise bus:**
   A data enterprise bus is an application that allows the MDM to communicate with different HES, irrespective of the communication technology on which the HES is operating. This is a vendor-agnostic solution that can help in facilitating interoperability between the HES and the MDM. In case the HES is replaced, the data enterprise bus will ensure that the MDM can continue to operate without being required to change.

7.2. Enablers

To enable interoperability at all levels, the following key pillars have been identified:

Figure 10: Key pillars to ensure interoperability



i. Well defined technical standards and specifications

Based on the standards defined in India and internationally, for smart meters, the following table identifies the areas of development for India standards to strengthen and ease the smart meter deployment. The detailed comparison between Indian and global standards is provided in Annexure 6.

Table 5: Areas of development for Indian standards

#	Attributes	Remarks
1.	**Device technical standards**	Indian Standards are well structured on device techno-functional aspects. These include: • IS 13779: AC Static Watt-hour Meter class 1 & 2 • IS 16444: A.C. Static Direct Connected Watt Hour Smart Meter Class 1 and 2- Specification. Power consumption guidelines as per IS16444 annexure K. • IS 15884: Alternating Current Direct Connected Static Prepayment Meters for Active Energy (Class 1 and 2)-Specification

#	Attributes	Remarks
		• IS 14697: Three phase transformer operated meters However, while basic interfacing guidelines have been provided by CA, there is a need to establish standards for the same. Global best practices have mandated device functionalities & interfacing feature standards (EU & US) such as: • IEC 60514: E-Mechanical Meter • IEC 61358: Static Meters • IEC 62053: Electromechanical kWh, Static kWh, Static kVARh meter • ANSI C12.22 – 2012: American National Standard Protocol Specification for Interfacing to Data Communication Networks
2.	**Data Exchange Standards**	India has already undertaken communication protocols such as DLMS/COSEM (IEC 62056, IS 15959). On the basis of these communication protocols, Indian standards are sufficient and well established. However, networking signal intensity benchmarking/standards are not defined as part of IEC 62056.Communication parameters testing (like time intervals, delay timing, frequencies etc.) are based on the utilities requirements and are not standardised.
3.	**Communication Infrastructure**	CEA guidelines specify that the vendor may choose any communication technology and architecture based on globally available open standards. Global standards, including US standards, are more specific to each communication sub-mechanisms. For example, ANSI C12.22 -2012 (American National Standard Protocol Specification for Interfacing to Data Communication Networks). This standard describes the process of transporting data over a variety of networks, with the intention of advancing interoperability among communication modules and meters. However, based on the current scenario of Indian smart meter projects & programmes, CEA guidelines and open standards are sufficient to move forward.
4.	**Head End System & Integration architecture standards**	HES guidelines for functionalities and configuration are available in India and have been provided in the CEA guidelines. (Note: Interoperable technologies have not been mentioned in the guidelines). Although, no specific standards are mandated globally. Integration infrastructure standards are mandated as CIM / XML / IEC 61968 or any other open standard for Indian distribution sector.

#	Attributes	Remarks
		Global standards are more specific to each layer of data integration architecture. Some standards specified by IEC include: • IEC 62056-42:Physical Layer • IEC 62056-46: Data Link Layer • IEC 62056-47: Transport layer for COSEM • IEC 62056-53: Application layer for COSEM • IEC 62056-51: DLMS based application layer+transport layer+data link layer
5.	**Networking & Architecture**	CEA guidelines are available for the Indian power system including distribution systems as per IS 16444 standards. For the current scenario of smart meter network and architecture systems in India, these guidelines are sufficient.
6.	**System Security Standards**	Security guidelines and standards are available for the Indian distribution sector. CEA guidelines provide the requirements for ensuring adequate cybersecurity measures. CEA also released guidelines on Cybersecurity in the power sector in 2021[9]. Global standards are more specific and well structured. Some key standards include: • ISO/IEC 61508: Functional Safety of Electrical / Electronic / Programmable Electronic Safety-related Systems • IEC 61850: Communication networks and systems for power utility automation • IEC 62351: Standards for Securing Power System Communications • IEC 62443: Cyber Security for Industrial Control Systems For the current Indian scenario, the Indian standards are sufficient. However, as India scales up the smart meters installation, it will lead to increase in volume of data and the subsequent use cases utilizing the data. It will also increase the vulnerability of data requiring more robust data protection. Hence, in the future, the system will require more specific and structured standards on networking, interfacing, cyber-attacks, data securities, interface securities etc.
7.	**Testing Standards**	**Interoperability & Security** Interoperability testing is standardised for communication protocol globally. However, Indian standards are not available.

[9] *CEA (Cyber Security in Power Sector) Guidelines*, Central Electricity Authority, 2021
Link to the guidelines: https://cea.nic.in/wp-content/uploads/notification/2021/10/Guidelines_on_Cyber_Security_in_Power_Sector_2021-2.pdf

#	Attributes	Remarks
		As per the current scenario in India, security standards are well structured. However, scaling up smart meter installation may necessitate revision to the current security testing standards. **Device & Interface Functionality** Indian Standards are well structured according to the current situation. However, Indian standards do not cover operational benchmarking of smart meters in certain electrical conditions. For example, the tolerance level of smart meters in low voltage conditions. **Communication & Networking** CEA guidelines for Indian distribution sector need to be strengthened with respect to data capturing frequency, intervals, delay time etc. Also, network signal intensity benchmarking and testing standards are not available as part of data exchange standards IEC 62056. Communication parameters testing are utility specific. Tolerance delay time, time intervals or frequency testing are tested as per utilities' requirement as DLMS/COSEM protocols give certain level of flexibility. In the future, these areas need to be well defined in communication standards. **DCU/NAP testing standards** Indian standards are available. End-to-end communication and device operability testing standards are required to be established as per the field conditions. These testing standards should include the overall data flow path testing from meter unit to MDMS through DCU and HES as applicable.

Thus, the areas of development for Indian standards can summarised as below:

Figure 11: Areas of development for Indian standards

ii. Comprehensive end-to-end testing

Testing of smart meters is a critical activity and India needs to ensure a robust testing ecosystem, in line with defined standards, in order to facilitate a seamless implementation of the smart meter rollout across the nation. REC also released a Standard Bidding Document (Version

3) in 2022. The document lays out the requirements for testing, inspections and management of the Quality Assurance/ Quality Control (QA/QC) program for the AMISP and its sub-vendors.

The following recommendations could help scaling up smart meter testing in India:

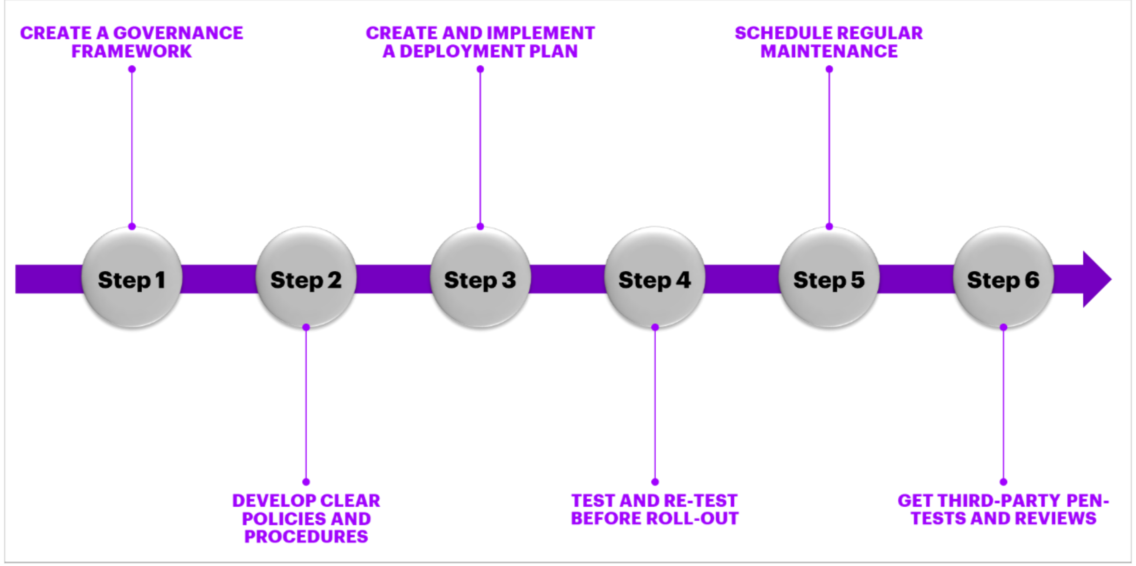
- Appoint a nodal agency responsible for managing the testing landscape in India and support with funding and infrastructure
  - In the short-term, there is a need to support existing energy meter testing laboratories with equipment required for communication and load switch testing capabilities
  - In the long-term, it will be critical to take initiatives for funding new laboratories (region-wise/state-wise) for allowing testing of larger number of smart meters
- Organise initiatives for training new people/ upskilling existing people to operate equipment in laboratories
- Collaborate with existing laboratories for conducting training & awareness programmes

iii. Robust cybersecurity approach

As adoption of smart meters is increasing, their vulnerability to cyberattacks also increases. Despite all the advantages of smart meters, they are exposed to the risk of cyber-attacks as they are physically exposed to hackers. There is a risk that the data collected by smart meters could be intercepted or altered posing a threat not only to vendors, but also to the consumers. Thus, it becomes vital to address concerns related to cybersecurity to increase consumer confidence leading to higher adoption of smart meters, especially in an interoperable framework.

Ensuring that steps are taken to secure the Discom’s network and protect customer’s data should be paramount when implementing an AMI. Regardless of the AMI vendor, the following cybersecurity measures should be part of any AMI implementation:

Figure 12: Measures to ensure cybersecurity in Discoms for AMI implementation



Step 1: Create a governance framework

The Discom has to ensure that the roles, responsibilities, and accountability are clearly defined. In addition, proper auditing and reporting functions needs to be allowed for adequate risk management. Senior management must set the tone that requires every employee, contractor, vendor, etc. to comply with the organisations security policies. Security governance and security management programmes help to align information security strategy with business objectives and compliance requirements, while helping manage risk. This will leave less room for malicious actors to find an alternate route into the system or for employees to make innocent mistakes that can harm the security of the AMI network.

Step 2: Develop clear policies and procedures

Once the strategic oversight through the governance and management framework is put in place, controls are to be developed that will cover all aspects of the AMI system security. It is imperative that high level policies clearly defining roles and responsibilities for security management and listing the rules and controls required for network access are developed. The policies also need to be supported with standards and guidelines that detail mandatory and non-mandatory controls. These are supported by procedures that cover step by step instructions for implementation, for example specific operational steps for setting up firewalls, handling the encryption keys or performing backups. A security awareness and training programme rounds this out. These steps will help protect the organisation, and in the event of a problem, the solutions to address the issue is easily found out.

Step 3: Create and implement a deployment plan

Proper planning is required to make sure that deploying security controls during AMI deployment goes smoothly. Working with the AMI vendor, a security assessment helps to identify all assets that need protection, as well as potential threats to the network. For each threat, risk assessment and risk prioritization will lead to the development of an actionable plan for secure deployment. The following technologies if implemented will help in the design and deployment of a layered defense for an AMI network:

- **Demilitarised Zone (DMZ):**
  DMZs with dual firewall architecture provide a layer of security to the organization's network by tightly regulating traffic entering and exiting the network. A DMZ network usually contains three zones, a trusted zone (Internal), a DMZ (Less Trusted) and an External Zone (Untrusted). When deploying AMI servers, they can be integrated with the existing DMZ network. Typically, the AMI head-end server(s) resides in the DMZ behind the perimeter firewall, while the AMI database and other AMI components reside in a more trusted zone that is separated from the DMZ by the back-end firewall. Other remote components of the AMI system such as Collector/Gateways may be configured to securely communicate with the AMI head-end server over virtual private networks (VPN).

- **Role-based access control:**
  It needs to be ensured that access to servers that will be part of the AMI network is controlled through role-based access control (RBAC). This is an approach to restricting access to authorised users based on the role of the individual. Operations on the AMI servers are assigned to specific roles, and the RBAC restricts access based on permissions associated with each role. For example, different roles may be assigned for users responsible for managing smart meters versus administrators.

- **Secure remote access with multifactor authentication:**
  Administrators and other users may require remote access to AMI systems. It is to be ensured that multifactor authentication (MFA) is utilised for remote access. MFA is a security system that requires more than one method of authentication from varying categories of credentials to verify a user's identity. For example, remote users may be prompted to use an entry code generated on a security token to access the system in addition to their username and password. This is a more secure method for remote access and can greatly reduce the attack surface compared to using only username and passwords.

- **IDS and IPS for your AMI:**

Creating a properly protected network, including careful placement of intrusion detection systems (IDS), and Intrusion Prevention systems (IPS), is critical to safeguarding against cyberattacks. These technologies should be placed at critical ingress or egress points within the network to ensure maximum coverage of traffic. In addition to network protections, Host Based IDS/IPS software should be deployed on AMI systems to provide additional layers of security against local system threats. During the configuration all these technologies, the Discom is to make sure that the auditing and logging are properly enabled, along with continuous monitoring and recording of all events to alert on suspicious activity.

- **Encrypt AMI network traffic:**

  While deploying an AMI system, it is critical to enable encryption on all relevant portions of your network. Encryption is the process of encoding messages or information in a way that only authorised users with encryption keys can access it. If anyone breaks into the communication system, message encrypting prevents the interceptor from reading any information. By encrypting network traffic on all parts of the AMI network, Discom can protect its system all the way from the end points (i.e., smart electric meters) to the head-end system.

- **Create redundant communication channels:**

  In addition to enabling encryption on the communication network, Discoms need to make sure that the communication channels have built in redundancy with multiple paths. This protects from denial of service (DOS) type cyberattacks. The AMI communication networks should be designed so that all endpoints, such as smart meters, can communicate with more than one collector. This way, if a certain collector is taken down (either for regular maintenance or due to a cyber- attack), the endpoint communication with the head end system can continue without interruption.

- **Secure Configuration and Patching**

  From the very start of the AMI network deployment, Discoms need to make sure that all systems are properly configured to reduce exposure. During configuration, make sure that the underlying operating system, as well as any applications and additional software is securely configured and hardened to prevent intruders from accessing AMI information. In addition, these systems also need be continuously updated with latest software patches and hot fixes from the operating system and application vendors.

Step 4: Test and re-test before roll-out

Implement a testing programme to ensure that systems are tested before they are implemented on the secure AMI production network and/or to customers. This will allow for the remediation of bugs and errors during the testing phase. Also, it is recommended that implementation of new software/systems in the production environment be done in phases; a pilot of a few endpoints at first to test software/system in production before doing systemwide rollout can be implemented.

Step 5: Schedule regular maintenance

The Discoms need to schedule time for regular maintenance and patching to maintain a secure AMI system. An operations team whose sole job is to maintain the security of the AMI system conduct routine maintenance checks should be deployed. To derive maximum benefits out of the technology investment, regular updates along with patching and maintenance is to be scheduled.

Step 6: Get third-party pen-tests and reviews

It is important to get a second or even third pair of eyes to review the internal work. There are third-party reviewers and penetration-test vendors who specialise in checking the security of the system. The Discom should consider conducting an annual or bi-annual pen-test, especially if it is undergoing any major system changes. These experts can look at the system security to identify weaknesses and give recommendations on ways to improve upon the program.

To summarise, a checklist of security best practices and controls that the Discoms should consider while implementing for an interoperable AMI system is provided below:

- Ask the software and hardware (with embedded software) vendors for evidence (e.g., third-party assessment) that their software is free of security weaknesses.
- Perform remote attestation of smart meters to ensure that their firmware has not been modified.
- Make use of the communication protocol security extensions (e.g., MultiSpeak security extensions) to ascertain the data and origin integrity of smart meter data.
- Establish and maintain secure configuration management processes (e.g., when servicing field devices or updating the firmware).
- Ensure that all software (developed internally or procured from a third-party) is developed using security aware SDLC[10].
- Apply a qualified third-party security penetration testing to test all hardware and software components prior to live deployment.
- Decouple identifying end-user information (e.g., household address, global positioning system [GPS] coordinates, etc.) and use a unique identifier instead.
- Implement physical security controls and detection mechanisms when tampering occurs.
- Ensure that a reliable source of network time is maintained.

[10] Software Development Life Cycle

- Disable the remote disconnect feature that allows electricity to be remotely shut down using a smart meter.

Additionally, the Discom should ensure the following security requirements and controls for the MDM:

- Data arriving to be stored in the MDM system does not come from a compromised meter.
- Data arriving to be stored in the MDM system is syntactically and semantically valid.
- The system parsing the data arriving in the MDM system should make use of all the appropriate data validation and exception-handling techniques.
- The MDM system has been designed and implemented using security aware SDLC.
- The MDM system has passed a security penetration test by a qualified third-party.
- Denial-of-service attempts (from compromised meters) are handled gracefully.
- Data stored in the MDM system should be cleansed from all private information.

iv. Strong ecosystem coordination

There exist a host of reasons why implementing interoperability, specifically network interoperability, successfully is considered difficult. Fundamental to all those problems is the correct balance and coordination between the stakeholders.

For network interoperability, it is vital to have the right coordination between telecom operator’s liabilities (such as inadequate indoor network coverage, enabling charging methodology for different technologies, interconnection with HES, etc.) and benefits associated with these activities. Also, to enable inclusion of dual technology, at the meter design level, there needs to be vetting by the stakeholders to commercialise the same. In order to achieve hardware-level interoperability (for smart meters & HES) the Discoms need to define & communicate the techno-functional features of the physical devices to the device manufacturers and vendors. Respective manufacturers of the physical devices need to work collectively to come up with a standard technical design of the respective devices which can support dual communication.

Thus, for high operational efficiency of AMI, it is important that the devices and systems (smart meters, communication modules, HES, MDMS), provided by different vendors, are compatible with each other, in terms of communication capabilities, data reception and management. This will not only allow a seamless end-to-end communication through network interoperability but also ensure that the system does not fail to operate in case the components/ vendors are required to be changed in the future. Therefore, a strong ecosystem collaboration is an imperative to achieve interoperability at all levels.

7.2. Roadmap

Keeping in mind the current level of interoperability across different layers in India (as explained in Section 3.2), a phased implementation plan must be followed with defined roles for each stakeholder involved in the AMI ecosystem. Since AMI interoperability is still an evolving subject in India as well as globally, a prescriptive approach involving distinct interventions will not be feasible currently. Therefore, we propose a collaborative, guided, and stepwise approach which will be instrumental in facilitating interoperability, as India scales up smart meter deployment. The following table aims at designing an implementation roadmap to achieve this objective.

Table 6: Proposed roadmap to facilitate AMI interoperability

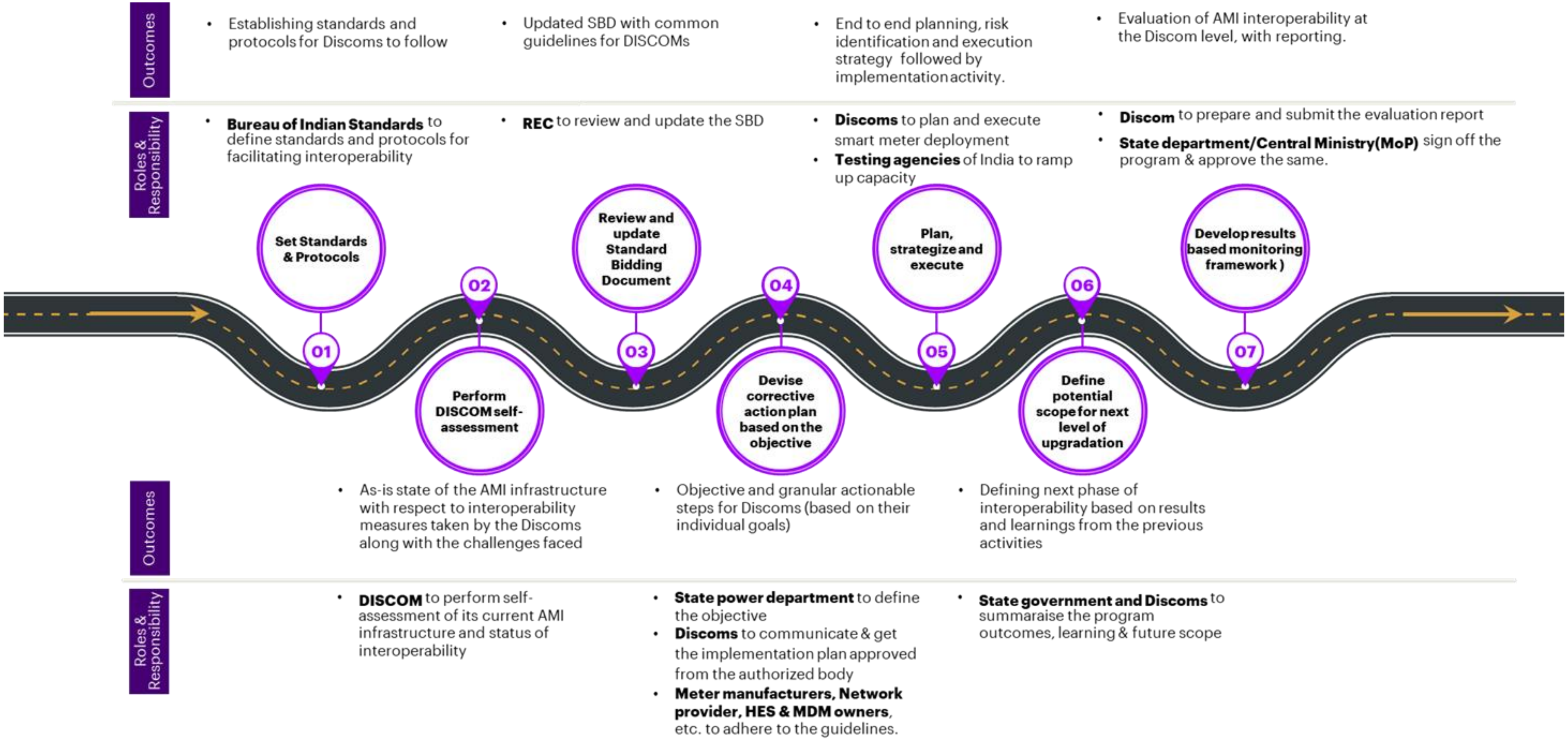
#	Phase	Description	Outcome	Roles & Responsibility
1.	**Set standards & protocols**	The regulatory bodies may choose to either create new standards and protocols or opt for the best practices from the international standards/protocols on the basis of the requirements of Indian Discoms, for the areas where standards are currently not defined in India. For example, standards and protocols for smart meter & HES interoperability, operational technologies, working principle, device calibration, MDM operation specifications, data flow mechanism guidelines, IT infrastructure integration, system security and recourse/ process management are some areas that could be enhanced further with respect to development of standards.	Establishing standards and protocols for Discoms to follow	**Bureau of Indian Standards** to define standards and protocols for facilitating interoperability
2.	**Perform DISCOM self-assessment**	DISCOMs to perform a self-assessment of the current as-is situation of the different AMI components and the techno-functional AMI interoperability at various levels. For example, end-to-end interoperability is expected to be demonstrated by the AMISP as per the recent test bed circular by REC. In this case, it is important for the DISCOM to assess the current availability of its MDM system, which will need to be interoperable with the new AMISP's HES systems. In case it is not, a data enterprise bus, as suggested above, will need to be considered to ensure that replacement of existing MDM is not required, which is a cost-intensive process.	As-is state of the AMI infrastructure with respect to interoperability measures taken by the Discoms along with the challenges faced (For example, communication failure, difficulties in data integration with own systems, etc.)	**DISCOM** to perform self-assessment of its current AMI infrastructure and status of interoperability

#	Phase	Description	Outcome	Roles & Responsibility
3.	**Review and update Standard Bidding Document**	Based on the identified areas of development for enabling interoperability across different components of the AMI architecture, REC to update the Standard Bidding Document (SBD) to include the recommended solutions.	Updated SBD with common guidelines for DISCOMs	**REC** to review and update the SBD
4.	**Devise corrective action plan based on the objective**	State power departments, in collaboration with SERCs, to define objectives for their respective Discoms, based on the current state, the target they wish to achieve and the prescribed time period for the implementation phase. Subsequently, on the basis of the guidelines of the State authorities and schemes if any, each Discom to establish its action plan at a more granular level by identifying the implementation priorities based on criticality and cost benefit assessment. For example, if a Discom wants to replace a certain number of non-communicative smart meters, which are currently operating with existing infrastructure, the Discom can broadly go through the below steps to define the action plan. *Step 1: Identify the root cause of the communication failure. (for example: legacy HES system is unable to support the data formats and capture & process the data further)* *Step 2: Identify scope of troubleshooting (for example: Discom can make certain number of meters operable by changing the configuration of the existing HES data processing algorithms*) *Step 3: If troubleshooting is not possible, Discom may need to replace or upgrade some part of the HES system as per CEA guidelines of HES configuration.* Additionally, actionable items could be defined for other stakeholders in the AMI ecosystem such as meter manufacturers, network providers, HES and MDMS service providers, other OEMs, in line with the implementation guidelines in the tender document for future rollouts. This phase can begin in parallel with the previous phase of setting the standards and protocols.	Objective and granular actionable steps for Discoms (based on their individual goals)	**State power departments** to define the action plan **Discoms** to communicate & get the implementation plan approved from the authorised body **Meter manufacturers, Network provider, HES & MDM owners, etc.** to adhere to the guidelines

#	Phase	Description	Outcome	Roles & Responsibility
5.	**Plan, strategise and execute**	The Discoms to strategise the overall implementation plan focusing on investment, resource planning and risk analysis along with identification of bottlenecks with respect to interoperability (based on OEMs' operations, the current techno-functional as-is model of the manufacturer and cost benefit analysis). It is extremely critical for the implementation plan to include the integration strategy, which is a key requirement to facilitate interoperability. Finally, the Discoms to undertake adequate testing of the equipment as per the standards before the start of smart meter deployment. The Discoms to also undertake training sessions to upskill their employees for seamless implementation. It will also be critical to ramp up testing facilities with respect to availability of testing equipment and skilled manpower to enable end-to-end testing for smooth scale-up.	End-to-end planning, risk identification and execution strategy	**Discoms** to plan and execute smart meter deployment **Testing agencies of India** to ramp up capacity
6.	**Define potential scope for next level of upgradation**	Based on the results, bottlenecks and challenges of interoperability enablement program, Discom will summarise the scope and requirement of interoperability enhancement for future rollouts. Discoms to document the challenges, outcomes and learnings from the programme, next phase of action plan if required for future rollouts and submit the same to state government authority.	Defining next phase of interoperability based on results and learnings from the previous activities	**Discoms** to summarise the programme outcomes, learning & future scope.
7.	**Develop results-based monitoring framework**	Discoms to track the completeness of the programme undertaken in each phase, as defined in Phase 5. Discoms to create the evaluation report at the end of the interoperability programme or at the completion of each stage (as defined in its individual action plan) as applicable. The Discom may be submit the report to the State Department/ MoP for approval.	Evaluation of AMI interoperability at the Discom level, with reporting.	**Discom** to prepare and submit the evaluation report **State department/ Central Ministry (MoP)** to provide approval on the same

The above table can be summarised as below:

Figure 13: Proposed roadmap to facilitate AMI interoperability



8. Annexures

Annexure 1: Universal HES

Smart meters capture OT data of various energy consumption parameters & supply line/meter performances. This OT data is categorised as real time unstructured data. This data needs to be communicated with DCU (data concentration unit)/ HES (Head end system) through wireless communication technologies (like cellular, RF modules, PLCs etc.). A universal HES is one which can support and be compatible with different communication technologies, for example: cellular (2G, 3G, 4G, 5G), RF mesh, power line communication (PLC), etc.

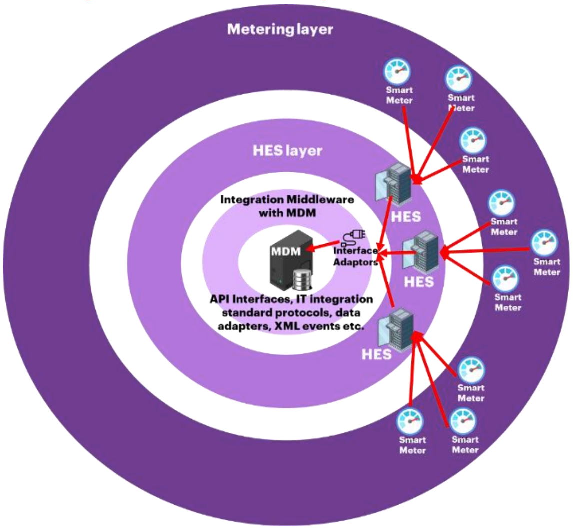
Meter data communication system:

A meter data communication system can be structured by different layers.

- The outer layer is the physical layer of analog data capturing units (like smart meters to capture energy consumption data). This layer can be called the metering layer.
- The intermediate layer is to consolidate & concentrate the data with HES system, which is the HES layer (which would comprise of multiple HES that receive data from the smart meters).
- The MDMS integration layer (standard data integration system/middleware system to transfer semi structured digitalised data to MDM from the HES layer). This layer may consist of various IT data integration protocols and methodologies like API interfacing, XML event logger, scheduled push mechanisms or any other standard IT integration methods as per the Discoms requirements. Generally, these integration mechanisms are called interfacing adaptors of MDM.

In essence, the meter data system architecture could be represented in the following manner:

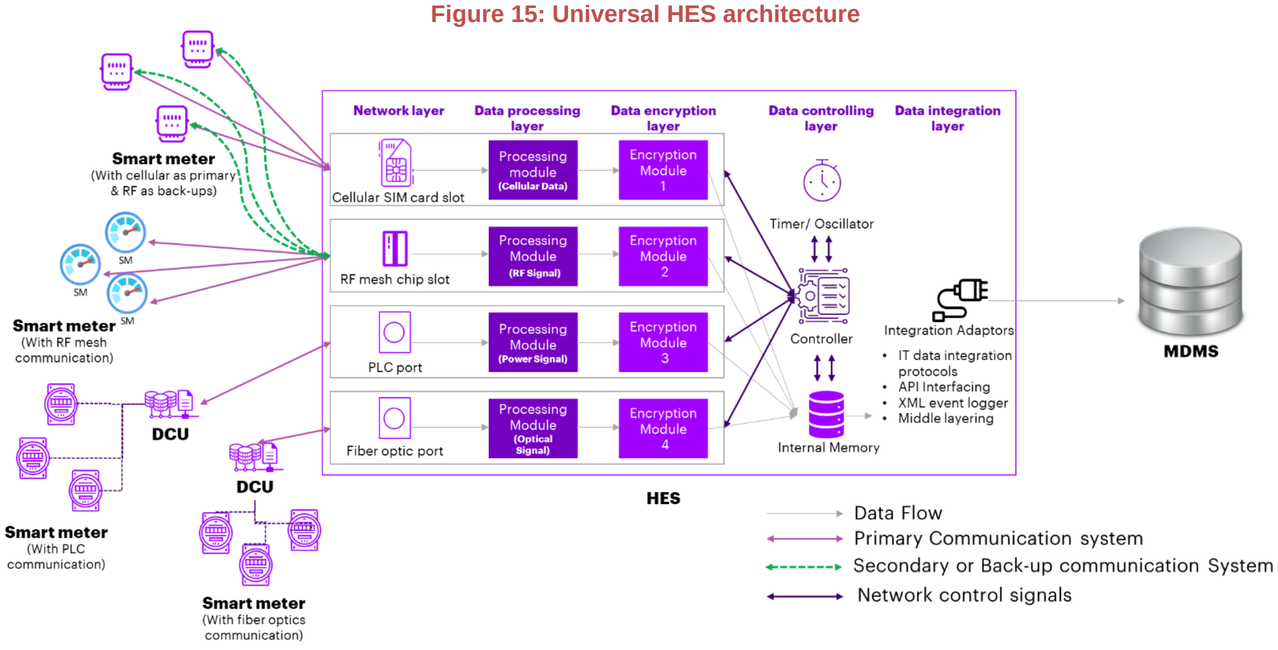
Figure 14: Meter data system architecture



Universal HES architecture:

The universal HES functionalities include networking technology level interoperability. The HES is designed to operate and support any networking systems, be it cellular mechanism, RF mesh or PLC. The below diagram describes a generic architecture of a universal HES system:

Figure 15: Universal HES architecture



A universal HES architecture can be divided into the following layers:

1. **Network layer:** This layer includes several networking mechanisms like RF modules, cellular, PLCs & fiber optics etc. This layer is responsible to receive the data from smart meters irrespective of the communication technologies, within a defined time interval.
2. **Data processing layer:** This layer consists of different processing modules to process incoming data using different communication/ networking technologies.
3. **Data encryption layer:** This layer encrypts the processed data.
4. **Data controlling layer:** This layer broadly consists of three main components: controller, internal memory & time synchroniser. This layer operates with pre-defined algorithms to control the processing modules with a synchronised timer system and stores the data in the internal memory.
5. **Data integration layer :** This layer is responsible for connecting the internal data servers to the MDM using the required integration adaptors.

Functional working principle:

The data from the smart meter will be received by the HES in the network layer using the primary communication technology. Here the communication technology could be anything as supported by the HES system. One particular meter may have one or more than one communication technologies (for example: cellular as primary communication technology & RF module as back-up) deployed. If, for a certain period of time, a particular meter experiences interruptions/ breakdown in the primary networking system, then the back-up system can automatically be triggered. The respective HES controller can help enable communication with the respective meter data & processing system. The data will then be sent through the processor to decode, process/translate & encode to a further processable format. Subsequently, the data is sent to the encryptor for ensuring security of the data.

Post data encryption, the data will be sent to the internal memory system of controlling layer. The controller's job is to enable data communication and processing systems as required by the primary or secondary/backup communication technology, manage data storage & synchronize internal timer mechanisms.
The internal storage (internal data server) has the middleware integration (as per the Discoms' requirements) adaptors connected with MDMS. Further the data is sent to the MDMS through integration adaptors.

Note: Since the universal HES provides options for multiple communication technologies, it will ensure that in the case where the primary network is unavailable, the network is not lost and the HES falls back to the secondary communication technology. The controller is responsible for ensuring this.

The suggested functions of HES (not exhaustive) may be:

- Acquisition of meter data on demand & at user selectable periodicity
- Two-way communication with meter/ DCU
- Signals for connect & disconnect of switches present in end points like meter
- Audit trail and event & alarm logging
- Encryption of data for secure communication
- Maintaining time sync with DCU/ meter
- Storing raw data for defined duration
- Handling of control signals/ event messages on priority
- Setting of smart meter configurable parameters
- Communication device status and history
- Network information & automatic network technology switching/ controlling system in case more than one technology is deployed in field between the two devices
- Critical and non-critical reporting functionality. The suggestive critical events may be alarms and event log for meter events like tamper/power failures etc., if data is not received from DCU/Meter, if relay does not operate for connect / disconnect or there is communication link failure with DCU/Meter or network failure while noncritical events may be retried attempts on communication failure, periodic reading missing and failure to connect etc.

Benefits:

- The support for multiple communication technologies enables a reliable and cost-effective solution for both rural and densely populated areas
- The user has the option to choose between different communication technology based on the network presence in that area
- The ability to fall back on the secondary technology ensures uninterrupted connection and also enables interoperability across technologies

Challenges:

- The cost of the HES goes up significantly as it provisions for multiple communication technologies
- It is difficult to scale up the HES to accommodate 250 million meters

Case study:
An example of an HES that supports multiple communication technologies is Landis+Gyr HES[11]. It provides ideal communication options for all customer segments and network areas. Landis+Gyr HES offers a wide range of communication options.

For example, the following options can be used:

- Low voltage PLC network
- GPRS, 3G, NB-IoT/M1
- IP networks (LAN, WAN)

All combinations of the offered communication media are possible. The most commonly used options include PLC and GPRS/3G either separately or as a combination.

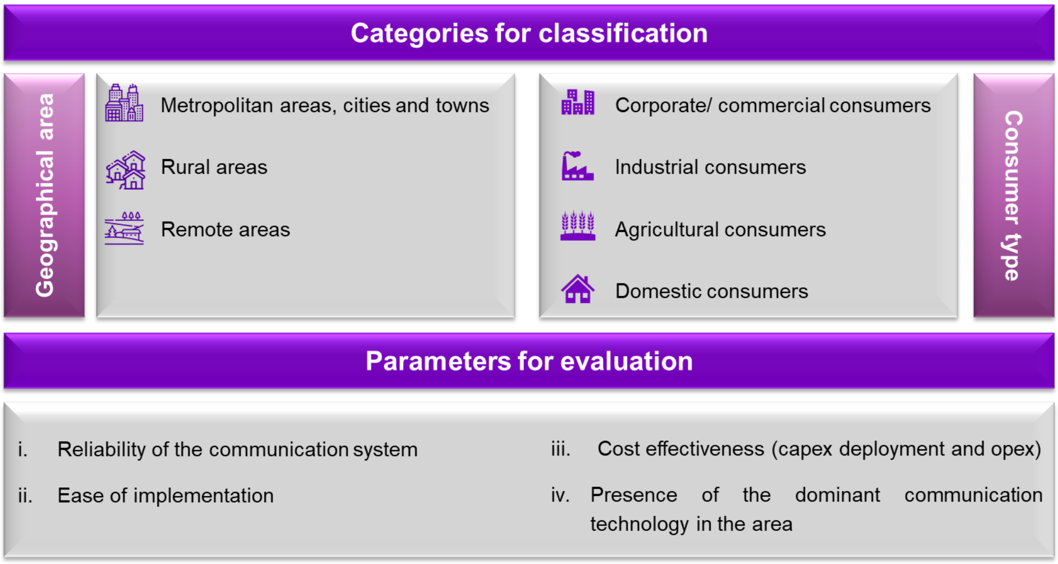
- PLC communication shows its strengths in large-scale transmission areas. It provides cost efficiency due to lower investment and communication costs. When PLC is used with concentrators, it also offers operational efficiency because the concentrator can operate as a single communication interface for several metering devices.
- GPRS/3G communication is the optimal communication media in rural areas. It also enables additional functionality, such as SMS alarms, data push functionalities from the meter to Landis+Gyr HES, and a variety of wake-up functionalities.
- NB-IoT/M1 communication provides robust data transfer and reliable operations with higher range and better building penetration. It also offers additional functionalities like active notifications and alarms based on events as well as last gasp for power outages.

[11] Source: landisgyr.com/webfoo/wp-content/uploads/2012/09/LandisGyr-HES_Product-Description.pdf

Annexure 2: Optimal combination of dual communication technologies by area

To achieve interoperability/ interchangeability on the network-level, smart meters equipped with a dual communication system can be a potential solution. However, this increases the overall costs. Currently, in India, a dual communication system for AMI has not been implemented on a large-scale. Based on the current scenario of the Indian distribution sector, a combination of RF Mesh communication, PLC, cellular network & fiber optics (in some areas) has been identified as the best way forward to achieve a reliable and cost-effective communication system. To achieve network-level interoperability, a dual communication system (primary & secondary/back-up) with a combination of the above four communication technologies has been studied based on the following framework:

Figure 16: Framework for selection of communication technologies



To enable interchangeability for dual communication technologies, a combination of technologies which poses the maximum reliability for different areas, based on the above framework, is provided below.

Evaluation of the parameters are rated as follows:

Very High
High
Moderate
Low

i. Metropolitan areas, cities & towns

Table 7: Combination of dual communication technologies for metro cities & towns

#	Consumer Type	Metering Point to DCU/Gateway	DCU/Gateway to HES	HES design	Remarks	
1	Corporate/ Commercial (Offices, community areas, schools, markets, government institutions etc.)	**Primary Networking System**: RF Mesh **Secondary/ back-up**: PLC/Fiber Optics	GPRS/Fiber Optics	Interoperable with RF Mesh, PLC & Optical fiber	**1. RF Mesh + PL C** Reliability: Ease of implementation: Cost Effective: **2. RF Mesh + Fiber Optics** Reliability: Ease of implementation: Cost Effective:	 ● ◕ ◕ ● ◑ ◑
2	Industrial	Primary Networking System: RF Mesh/Cellular Secondary/back-up: Cellular/Fiber Optics	GPRS/Fiber Optics	Interoperable with RF Mesh, Cellular & Optical fiber	**1. RF Mesh + Cellular:** Reliability: Ease of implementation: Cost Effective: **2. RF Mesh + Fiber Optics:** Reliability: Ease of implementation: Cost Effective:	 ● ◑ ◕ ● ◑ ◑

#	Consumer Type	Metering Point to DCU/Gateway	DCU/Gateway to HES	HES design	Remarks	
					3. Cellular + Fiber Optics: Reliability: Ease of implementation: Cost Effective:	 ● ◑ ◔
3	Domestic	Primary Networking System: RF Mesh/Cellular Secondary/back-up: PLC/Cellular	GPRS/Fiber Optics	Interoperable with RF Mesh, Cellular & PLC	**1. RF + PLC:** Reliability: Ease of implementation: Cost Effective: **2. RF + Cellular:** Reliability: Ease of implementation: Cost Effective: **3. Cellular + PLC:** Reliability: Ease of implementation: Cost Effective:	 ● ● ● ● ◑ ◕ ● ◑ ◑

ii. **Rural areas**

Table 8: Combination of dual communication technologies for rural areas

#	Consumer Type	Metering Point to DCU/Gateway	DCU/Gateway to HES	HES design	Remarks
1	Agricultural and Commercial (Offices, community areas, schools, markets, government institutions etc.)	**Primary Networking:** PLC/RF Mesh **Secondary/ back-up:** RF Mesh/Cellular/PLC	GPRS	Interoperable with RF Mesh, PLC & Cellular	**1. RF + PLC:** Reliability: ● Ease of implementation: ● Cost Effective: ● **2. PLC + RF:** Reliability: ● Ease of implementation: ● Cost Effective: ● **3. RF + Cellular:** Reliability: ● Ease of implementation: ◑ Cost Effective: ◕ **4. PLC + Cellular:** Reliability: ● Ease of implementation: ◑ Cost Effective: ◑

#	Consumer Type	Metering Point to DCU/Gateway	DCU/Gateway to HES	HES design	Remarks
2	Industrial	**Primary Networking:** RF Mesh **Secondary/back-up:** PLC/Fiber optics/Cellular	GPRS/Fiber Optics	Interoperable with RF Mesh, PLC, Cellular/ Fiber Optics	**1. RF + PLC:** Reliability: ● Ease of implementation: ● Cost Effective: ● **2. RF + Cellular:** Reliability: ● Ease of implementation: ◑ Cost Effective: ◕ **3. RF + Fiber:** Reliability: ● Ease of implementation: ◑ Cost Effective: ◔
3	Domestic	**Primary Networking:** PLC **Secondary/back-up:** RF Mesh	GPRS/Fiber Optics	Interoperable with RF Mesh, PLC,	**1. PLC + RF:** Reliability: ● Ease of implementation: ● Cost Effective: ●

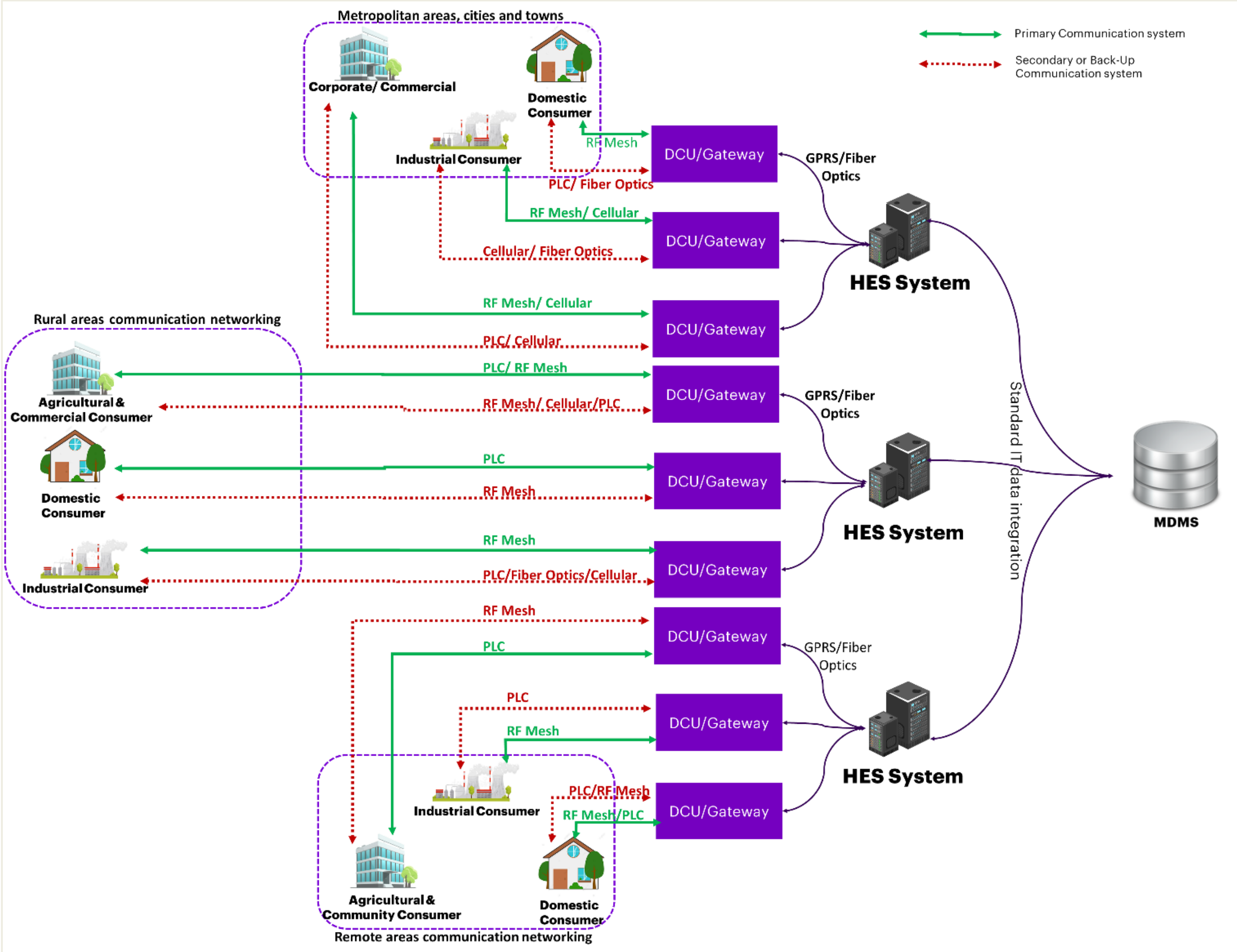
iii. Remote areas

Table 9: Combination of dual communication technologies for remote areas

#	Consumer Type	Metering Point to DCU/Gateway	DCU/Gateway to HES	HES design	Remarks	
1	Agricultural & Community Consumer (Community areas, schools, markets, government institutions etc.)	**Primary Networking**: PLC **Secondary/ back-up:** RF Mesh	GPRS	Interoperable with RF Mesh,	**1. PLC + RF:** Reliability: Ease of implementation: Cost Effective:	 ● ● ●
2	Industrial	**Primary Networking:** RF Mesh **Secondary/ back-up:** PLC	GPRS/Fiber Optics	Interoperable with RF Mesh,	**1. RF + PLC:** Reliability: Ease of implementation: Cost Effective:	 ● ● ●
3	Domestic	**Primary Networking:** PLC/RF Mesh **Secondary/ back-up**: RF Mesh/PLC	GPRS	Interoperable with RF Mesh,	**1. PLC + RF:** Reliability: Ease of implementation: Cost Effective: **2. RF + PLC:** Reliability: Ease of implementation: Cost Effective:	 ● ● ● ● ● ●

The below figure illustrates the network architecture with smart meters equipped with dual communication technologies:

Figure 17: Dual communication network architecture



There is already a push from the Government of India to replace conventional electricity meters with smart meters under the National Smart Grid Mission. In some of the urban, areas, Discoms have already implemented some networking technologies, like cellular, RF mesh & PLC. Based on the current networking system of each area and the categories of the consumers, Discoms as well as the government authorities need to evaluate the pre-requisites to achieve dual networking systems.

A general approach to evaluate the pre-requisite is given below:

Evaluation of site condition:

- Discoms need to identify the best possible networking solutions available in the target zones along with the consumer type, their economic condition and their electricity usage pattern. Accordingly, the best alternatives with respect to primary & secondary networking systems available in each zone will need to be identified[12].

Defining RFP:

- Discoms need to define the RFP based on the evaluation of the site condition. Specifically, Discoms need to define the primary and secondary communication system that can be opted for each consumer base. Technical specifications with broad functional specifications and guidelines need to be included in the RFP as well.
- Discoms need to encourage all the manufacturers and service providers to share information of the designing approach and implementation plan.

Meter technical & operation design:

- Interested smart meter manufacturers need to come together to provide the specific design of the meter with dual networking system. Manufacturers need to maintain the Discoms guideline and meter manufacturing standards as well while designing dual communication modules.

Testing and deployment:

- Government authorities need to standardise the technical and functional specifications and guidelines of communication network along with the testing standards and guidelines.
- Deployment guidelines and standards also need to be established for these dual communication systems by responsible government bodies, state electricity distribution authorities & Discoms.

Additionally, a next generation architecture can be proposed that suggests connectivity with the internet seamlessly over current network infrastructure, forming a synergy with telecom operators in a service provider space as a necessary development at the smart meter network module (NIC) level to register, switch between different networks technologies.

[12] For example: One distribution circle/zone may have a well-established cellular network and also a good optical fiber network. The users of this circle are large industrial electricity consumers with more focus on reliability of power supply. Then the primary network could be taken as cellular and secondary/backup as fiber optics. On other hand, if the distribution circle includes domestic rural consumers, then the consumption of electricity may be less for such areas. Here, Discoms may opt for a combination of RF mesh and PLC as primary and secondary to connect the last mile with reliable communication system.

Annexure 3: International use cases for smart meter communication

In smart metering communication module, the key elements are Data Concentrator Units (DCU), aggregators and gateways. These devices contribute the most to the total cost, reliability, scalability, and interoperability of last mile connectivity. Experiences from around the globe show that none of the solutions individually offer 100% reliable connectivity at all times. The best range of reliability offered is between 95-98%; and in many cases it is well below 90%.

Some of the popular communication architectures deployed for AMI worldwide are:

Figure 18: Architecture deployed by ENEL (Italy)

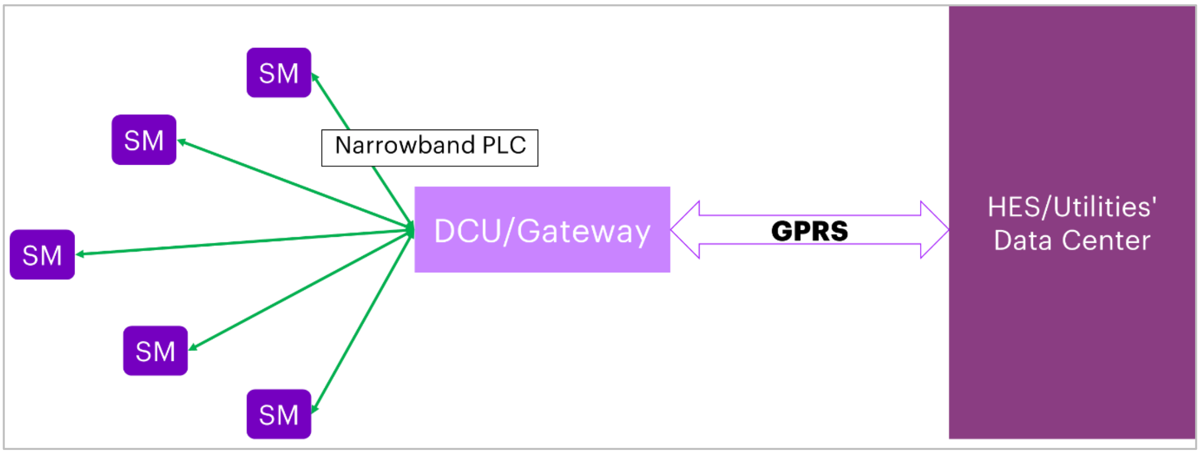


Figure 19: Architecture deployed by CenterPoint Energy (Houston, USA)

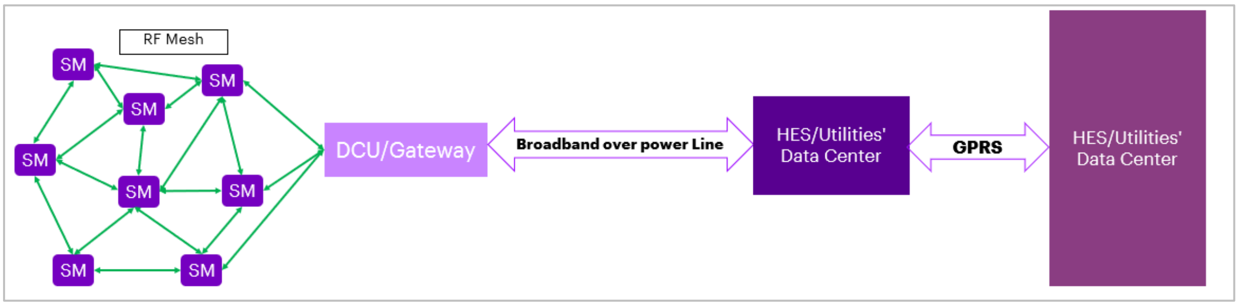
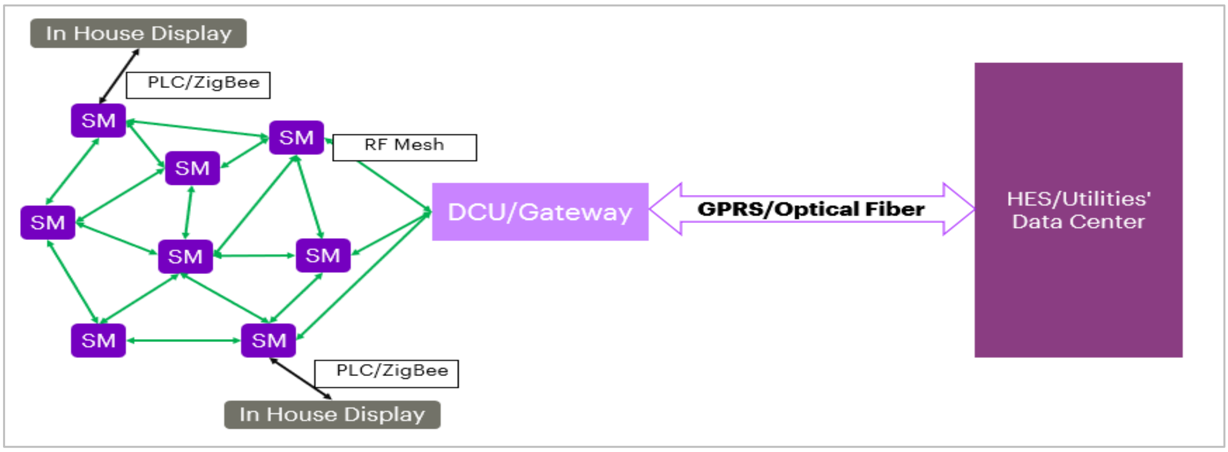
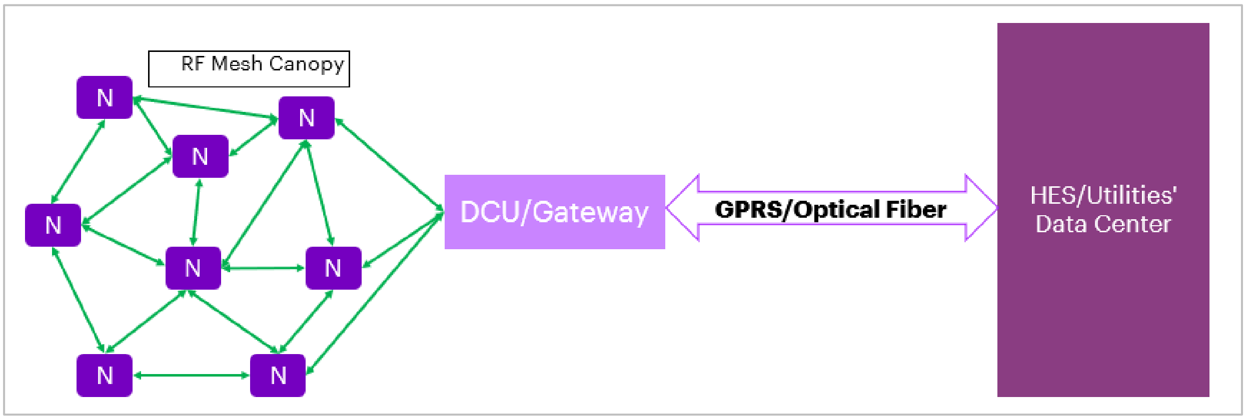


Figure 20: Typical AMI architecture with RF mesh as last mile



This has emerged as a popular solution amongst utilities in many geographies.

Figure 21: Emerging architecture for smart grid and smart city applications



**N = Node for any application (AMI, Street Lights, Traffic Signals etc.)

Also, RF mesh canopy network is emerging as the latest trend.

Annexure 4: Case studies of Indian Discoms

To understand the smart metering landscape of Indian Discoms, a multi-pronged approach was followed:

i. Perform secondary research to get an overview of the Discoms and their operations
ii. Analyze tender documents for procurement of smart meters to analyze the key conditions set out with respect to vendor technical requirements and focus on interoperability
iii. Conduct primary interviews with the concerned officials from the Discoms to get insights into their smart meter journey

A questionnaire was designed to help structure the discussions with Discoms and reap maximum insights:

Table 10: Questionnaire for Indian Discoms

#	Question
1	What is the current status of smart meter deployment in your organization? • Name of the SI/ partners (incl, meter manufacturers, communication provider, HES/ MDM/ Cloud service provider, etc.) implementing the project • Funding scheme • Status and timeline
2	If any of the vendors mentioned above is unable to fulfill its commitment due to any unforeseen circumstances, what are the risks envisaged to your overall planning of smart meter rollout?
3	What are the major challenges (during planning and approval, procurement, implementation phase etc.) faced during smart meter deployment?
4	What are the standards and specifications used for AMI (smart meter/ communication/ HES/ MDM)? What are the challenges and barriers specifically related to availability of standards and specifications?
5	What are the communication technologies you use for AMI system and how do you strategize to build a cohesive communication network to ensure last mile connectivity? Do you use any software like Network management system (NMS) and etc. for monitoring and managing the AMI communication network
6	Do you think interoperability is an important characteristic to keep in mind while designing the smart metering infrastructure? What is the major objective of Discoms to ensure interoperability? Are there any disadvantages of interoperability?
7	Are there any alternate method to ensure benefits of interoperability?
8	Were there any specific standards/ specifications used for ensuring AMI (smart meter/ communication/ HES/ MDM) interoperability?

#	Question
9	Do you have the ability to do remote firmware upgradation to avoid any service disruption and to reduce billing errors
10	How are the interoperability conditions for AMI ensured during the RFP/ procurement stage? Were there any specific requirements in the RFP?
11	What are the challenges and requirements for implementation of AMI interoperability?
12	Which smart metering system testing agencies are empaneled by your organization?
13	What are the standards and specifications used for smart meter testing?
14	Have you observed any delay in the smart meter deployment owing to delay in testing?
15	What has been the measures taken to mitigate cybersecurity concerns during the procurement and the operation phase?
16	How did you train your employees for-? • Smart meter deployment on field • Smart meter data management and usage for control centers/ corporate office
17	What has been the feedback from the consumers?

The insights gained are documented below:

1. SBPDCL and NBPDCL (Bihar)

Overview of SBPDCL and NBPDCL

In Bihar, there are 2 functionally independent state-owned companies, South Bihar Power Distribution Company Ltd. (SBPDCL) and North Bihar Power Distribution Company Ltd. (NBPDCL) that have been given the status of a Distribution License. SBPDCL is serving consumers in 17 districts of South Bihar with a total consumer base of ~62 lakhs and NBPDCL is covering 21 districts of North Bihar with a total consumer base of more than 100 lakhs.

The distribution losses at both Discoms are currently higher than the approved loss trajectory and stood at 26.19% for SBPDCL[13] and 23.04% for NBPDCL[14] in FY 2020-21, as opposed to the approved 15%. However, both SBPDCL and NBPDCL had been able to bring down the AT&C losses by ~14% in a span of 3 years (FY 2016-17 to FY 2018-19). This has been made possible through multitude of initiatives on improving the network performance as well as on

[13] Source: https://www.sbpdcl.co.in/(S(nfpppzx2pnqaugortcfncruk))/Tariff_Regulation_PDF/211/K.%201862/SBPDCL%20PETITION_15112021%20_V2.PDF

[14] Source: https://nbpdcl.co.in/(S(eqorzqlpabzudlmgvr55qkok))/Tariff_Regulation_PDF/202/K.%203915/NBPDCL%20PETITION_15112021_V4.PDF

the services side to enhance billing and collection efficiency. Smart metering played a significant role here. However, due to the impact of COVID-19 from the last quarter of FY 2019-20 and onwards, the AT&C loss has seen a slight increase due to impact on billing and collection efficiency. The AT&C losses stood at 37.02% and 25.93% respectively for SBPDCL and NBPDCL for FY 2020-21.

Smart metering initiative

Bihar aims to install 23.5 lakh smart meters from February 2021 to July 2022, out of which ~6 lakh smart meters have already been installed[15]. The utilities have an MoU with EESL, that is funding the project based on OPEX model. After handling O&M for 8 years, EESL will hand over the project to the utility.

During the implementation phase, EESL has the responsibility to select the meter manufacturer and specify the communication technology.

Table 11: Smart meter implementation partners in Bihar

System/ Activity	Partners
Smart meter supplier	Genus and Schneider
System integrator	EDF in partnership with Accenture
Communication network	3G – BSNL 4G – Jio
HES	Schneider
MDMS system	Siemens
Cloud service provider	ESDS
Mobility solution	SEW (Smart Energy Water)

Focus on interoperability:

- The utility specified that the meters should have interoperable plug and play communication module (4G, 5G, RF, PLC), which is to be chosen by the bidder. Any costs involved for upgradation of communication technology is to be borne by the AMISP.
- Hardware-level meter to HES interoperability was attained as the RFP specified the requirement of the HES and the MDMS to be compatible with 5 different makes of meters.
- During the implementation period, it was observed that in case of poor network, the meter was unable to fall back on a different network, showcasing lack of interoperability at the communication level.

Risks and challenges:

- The smart meter programme is fairly new in India with no prior experience. It is being designed and developed under assumptions which may not be completely correct/exhaustive. There is a need for the OEMs to upgrade and update their devices/ technology as the assumptions evolve to serve the smart meter consumers better.

[15] Source: NSGM; accessed on 30th March 2022

- While communication has improved over the years, as the technology moved from 3G to 4G, there is still a requirement for uninterrupted network. A hybrid model where the meter supports 2 types of communication technologies will help tackle this better.
- There is a need for meters to be interoperable with different technologies, so that the meters are not rendered useless when a technology goes obsolete. Currently, the communication module is not interoperable and there is a need for a plug and play communication module so that a meter device can support multiple communication technologies.

Tender analysis

SBPDCL and NBPDCL both released Requests for Proposal (RFP) in 2021 for "Appointment of AMISP including design of AMI system with supply, installation and commissioning of Smart Prepaid Meter with corresponding DT Meter along with DT level energy accounting with FMS in area specified by the Discom under DBFOOT model (Hybrid model, CAPEX plus OPEX)". SBPDCL RFP was for installation of 10 lakhs smart meters and NBPDCL was for 26 lakhs smart meters.

The tenders lay out all the minimum requirements of the features for the smart meter. The bidder must comply with minimum requirement from the existing BIS standards (primarily IS15959 and IS16444).

Some key conditions for the AMI components include:

- **Smart meter**
  - The smart meters shall have a dedicated sealable slot for accommodating plug-in type bi-directional communication module which shall integrate the respective communication technology (RF/PLC/ Cellular) with the smart meters, leading to easy adaptability for network interfaces (WAN/NAN). The plug-in module shall be field swappable/ replaceable.
  - The communication module is to be chosen by the bidder. Any cost involved for upgradation of communication technology shall be borne by the AMISP through the entire contract period.
  - The Network Interface Card (NIC) / Communication Module should be integrated with at least 3 (three) makes of meters in India to enable the respective meters to seamlessly integrate with proposed HES and/or MDM thus enabling interoperability of the system. In future, it would be AMISP's responsibility to integrate new meter in consultation with Utility or facilitate integration of other application.
- **Communication infrastructure:**
  - The communication infrastructure should either be based on RF / RF mesh network / PLC/ cellular network or a combination of these.
- **Head End System (HES):**
  - HES shall communicate with DCUs/access points using WAN technology.
  - HES shall be able to accept data according to IS 15959 part-2 /part 3 and latest amendments.

- **System applications:**
  - The system shall be designed for hardware independence and operation in a network environment that facilitates interoperability and integration of third-party applications. AMI applications should support multiple Relational Database Management Systems (RDBMS) including Oracle, Microsoft SQL Server and MySQL.

Other important conditions that were laid out to ensure smooth on-ground implementation include:

- **AMI system integration**
  - The MDM will act as the bridge to integrate the AMI system with other utility IT/OT systems. These IT/OT systems may be already existing or those which the Utility have planned. For those IT/OT systems which the Utility have planned in future, the AMISP shall publish document on available standard interfaces to enable their integration.
  - MDM shall interface with other utility legacy systems as well as the HES on standard interfaces. The data exchange models and interfaces shall comply with CIM-XML-IEC 61968 / IEC 61968-100 / Web Services / Multi Speak.
  - The HES shall follow the integration protocol established by IS 15959 (DLMS-COSEM) and make use of ACSE and DLMS services to communicate with southbound field devices (DCUs and Smart Meters) irrespective of the physical communication layer.
- **Data management**
  - The AMISP shall provide all necessary software tools for the development and maintenance of the databases required for AMI application.
  - The database development tool shall facilitate exchange of both incremental and full data in standard exchange format. The product should have facility to export and import databases from different vendors applications.
- **Cybersecurity**
  - For establishing secure and resilient smart meter systems, a standardized cybersecurity framework should be adopted by the AMISP in consultation with the Utility and relevant stakeholders. The key elements of the cyber security framework are also specified in detail.
  - The guidelines/strategies detailed out in the tender document shall be taken care of by the AMISP for making the entire AMI system immune to cyberattacks.
- **Data privacy**
  - AMISP should describe ensure that the system is compliant with the applicable provisions of the "Reasonable security practices and procedures and sensitive personal data or information Rules, 2011 (IT Act)" as well as shall be committed to work with Utility for compliance to Personal Data Protection requirements.
- **Consumer engagement**
  - AMISP shall develop a consumer engagement plan for smooth implementation of AMI system. The plan should include educating consumers about the pre-paid

recharge mechanism, benefits of pre-paid meters, potential usage of Smart Meters data for consumers, etc.

    - The Utility shall implement consumer engagement plan with support of AMISP. This would include running media campaign to raise awareness and counter myths around smart metering prior to installation, etc.

- **Training requirements**
    - Professional Training for the for the core group of implementation team (business functions and IT functions) of the Utility. It is the responsibility of AMISP to deliver this training. Standard curriculum designed and agreed by the Utility for hardware, software and network preferably shall be arranged by the AMISP for each group.
    - End User Training by the trained utility's team to the end users. The training sessions could have courses on Business Process Automation software fundamentals, business process overview, job activity training, etc.

- **Testing**
    - Test and inspections are in the complete purview of the AMISP and its sub-vendors.
    - The following tests will need to be performed:
        - In-Process Inspection (Type testing, Quality Assurance and Quality Control Programme, Factory Acceptance Test)
        - Field Installation and Integration Test (FIIT)
        - Site Acceptance Test (SAT)
        - System Availability Test

For evaluation of the bidder, the following criteria have been specified in the tender document:

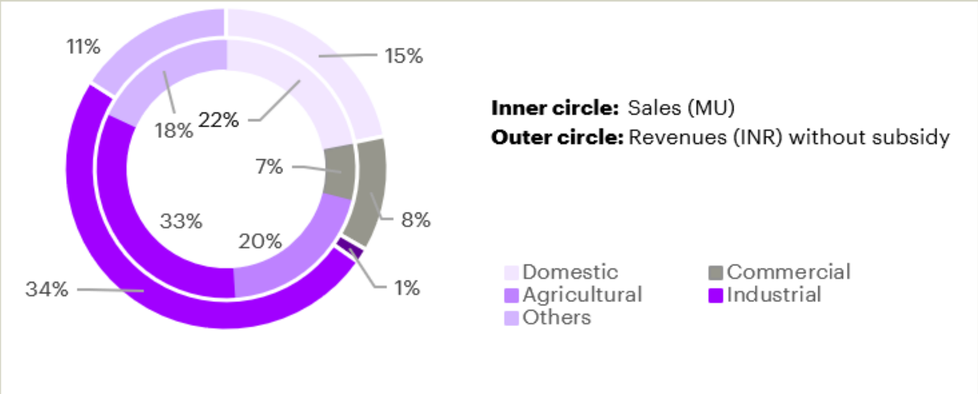
- Firstly, the Technical Bid will be evaluated 'clause by clause' to check for compliance with the RFP document and the AMISP Contract including the technical specifications and functional requirements.
- The bidders who fulfil the Eligibility and the Qualification Requirement along with the specifications mentioned in the RFP will qualify for the opening of the Financial Bid/ Proposal.
- The price as per the Financial Proposal/ Bid of all technically qualified bidders, shall be the basis for determination of the successful bidder.
- The technically qualified bidder with the lowest Financial Bid shall be considered as the successful bidder and shall be considered for award of the AMISP Contract.

2. UHBVNL (Haryana)

Overview of UHBVNL

Uttar Haryana Bijli Vitran Nigam Limited (UHBVNL) is one of the two Discoms in the state of Haryana and provides services to approximately 33,09,729 consumers in Northern Haryana. UHBVNL procures power through Haryana Power Purchase Center (HPPC), which is a joint forum of UHBVNL & DHBVNL[16]. UHBVNL has a good consumer mix with high industrial consumers as illustrated in the graph[17] below:

Figure 22: Consumer mix of UHBVN



UHBVNL has been taking various initiatives to contain its AT&C losses and distribution losses and has been able to reduce the losses drastically over the past year. In FY 2019-20, UHBVN has achieved distribution losses of 19.01% and AT&C loss of 19.61% with collection efficiency of 99.26%[18].

One of the key initiatives for managing losses and improving efficiency includes deployment of smart meters.

Smart metering initiative

UHBVNL is undertaking implementation of 5 lakhs smart meters on OPEX model as a part of the utility-owned scheme by EESL under the smart grid movement of the GOI. The project is a part of the Revamped Distribution Sector Scheme (RDSS) under the Ministry of Power. UHBVNL has already undertaken implementation of 2.45 lakh smart meters until March 2022[19]. The Discom has created a strong ecosystem of implementation partners to ensure on-ground success of the project.

Table 12: Smart meter implementation partners of UHVBN

System/ Activity	OEM
System integrator (Civil infrastructure implementation)	L&T Construction
Communication network (2G/3G)	VI
HES	Trilliant
MDMS system	Oracle Data Base 11.2.0.4
Smart meter supplier	Genus, Schneider, ITI, AEW
Cloud services	ESDS

[16] Source: https://uhbvn.org.in/about-uhbvn
[17] Source: True up FY20, HERC report
[18] Source: https://www.uhbvn.org.in/staticContent/documents/APR_2020_21_01ZS.pdf
[19] Source: NSGM; accessed on 30th March 2022

The electronic energy meters provided, are IS16444 compliant and are equipped with pluggable network interface cards. The smart meters have prepaid, postpaid & net metering capabilities.

Presently, the utility has completed the whole IT implementation (includes HES, MDM, integration with billing, etc.) and the User Acceptance Test (UAT) is in progress.

Focus on interoperability:

- UHBVNL believes that interoperability is a must. The utility has achieved meter to HES interoperability; currently the HES is communicating with up to 5 different meters.
- The utility is in the planning stage for deploying additional 20 lakh meters for which hybrid communication technology will be considered (cellular + RF Mesh), as opposed to the current cellular technology (3G).

Key considerations:

- While interoperability is very important for the smart meter industry, the pros and cons must be evaluated in advance. For example: utilities deploying RF Mesh communication technology in addition to cellular, must evaluate factors like cost, requirement of specialized expertise, specific communication module, etc.
- A strong focus on cyber security is key for a successful implementation. The utility mandated measures like meter key rotation (the ability to rotate meters´ keys and credentials over the air, mitigating the risk of hackers deciphering the key over long periods), which ensure robust security. While state tenders usually specify such requirements, they must mandate them to ensure compliance by vendors.

Tender analysis

EESL released a Request for Proposal (RfP) in 2017 for “International Competitive Bidding (ICB) for Design, Supply, Installation, Integration, Commissioning, Operation and Maintenance/FMS Support of Advanced Metering Infrastructure (AMI) Solution for 5-million Smart Electricity Meters with GPRS-based Communication Module for Haryana and Uttar Pradesh.”

The project scope for EESL AMI solution comprises of design, supply, install, commission, integrate and maintain the AMI for 50 lakhs smart meters for both states. Out of this, 10 lakh smart meters are targeted to be installed for Haryana.

The following design considerations have been specified in the tender document:

- The AMI Implementing Partner has to design and implement an end-to-end Integrated AMI solution and interoperable architecture clearly depicting integration between electricity meters, HES, MDMS and other supporting applications.
- The proposed solution must have the highest degree of interoperability and the solution components shall be standard-based and adopt an open approach rather than support a specific technology or vendor.
- Smart meter to HES communication:

  - The AMI implementing partner must ensure implementation and configuration of functional APIs from meter manufacturers and configuration of head end system.
  - Interoperability must be achieved at the meter level i.e., the AMI implementing partner must integrate the proposed AMI solution with at least 5 smart meter manufacturers to exchange meter data.
  - The smart meters supplied by the bidder(s) shall communicate with the HES using GPRS networks module. The communications module shall be of pluggable-type and shall be capable of servicing 3G technology compliant with Ipv6.

- Integration of MDMS with other systems
  - MDMS shall preferably interface with other systems on standard interfaces and the data exchange models and interfaces shall comply with CIM / XML / IEC 61968/IS15959/ Indian Companion Specification/ any other open standard.
  - MDMS solution shall be Service Oriented Architecture (SOA) enabled.

The contract will be awarded to the bidder with the lowest evaluated technically accepted bid or the bid offering the highest returns to EESL. This is further to the condition that the bidder is determined to be qualified to perform the contract satisfactorily.

3. CESC Limited

Overview of CESC

CESC Limited is a flagship company of the RP-Sanjiv Goenka Group. CESC is a fully integrated power utility with its operations spanning from generation to distribution of power. CESC is presently serving more than 3.4 million customers which includes domestic, industrial and commercial users, across 567 sq. km area.

CESC operations include both generation & distribution of electricity in its licensed area across Kolkata, Howrah, Hooghly, North and South 24 Parganas. CESC also operates a 600 MW plant in Haldia through its 100% owned subsidiary – Haldia Energy Limited. The operational thermal and renewable capacity of CESC is ~800 MW.

CESC has been continuously upgrading its distribution infrastructure to enhance the quality and reliability of its power supply. CESC is actively pursuing its efforts to contain its distribution losses and has brought it down to a single digit figure. CESC's deployment of advanced technology has been a key contributor in this. The utility leveraged smart meters in order to bring down the loss figure in specific loss-prone pockets.

Smart metering initiative

Over the last ~10 years, CESC has been deploying smart meters in the quest to provide better customer experience and achieve higher operational efficiencies. Till date, CESC has deployed ~40,000 smart meters spanning across Kolkata. Instead of large-scale deployments, CEC has deployed smart meters only at some high loss areas and also as per the need.

(i) Smart meter PoCs (Proof of Concept):

Various PoCs of smart meters have been undertaken using different communication technologies, each with their own advantages and disadvantages. The key observations emerging from each technology are as below:

a) Cellular (2G):

To ease the process of collecting meter readings from meters with disparate billing cycles and different spread-out locations, CESC deployed smart meters with cellular technology. However, some issues were faced such as:

- Lack of service-level agreements (SLAs) in the cellular segment
- Cellular requires point-to-point connectivity. Hence, poor connection due to placement of meters in remote areas, was a roadblock in smooth functioning. The high billing reading success rate of 99.6% dropped to ~90%, in case of this segment, requiring 10% of these meters to be read manually.
- High rental charges of cellular sim cards

b) PLC:

25 Echelon (European vendor) meters were deployed for 3 different scenarios on PoC (Proof of Concept) – underground, overhead, and clustered environment using PLC communication technology. The key issues faced during deployment were:

- In the underground scenario, disturbances were experienced due to noise of transformers. Later, the DCU was relocated away from the transformer and near to the meters for better performance.
- With the overhead electricity joints being poor, the performance of PLC network for overhead meters was not satisfactory.
- While the performance of PLC was good for cluster deployment (housing complex), it was not for scattered consumers.

c) RF Mesh:
To overcome the issues faced while deploying cellular and PLC technology, CESC decided to deploy RF Mesh in pilot mode. The pilot was funded through a USTDA grant and an EOI was floated in 2014 for installation of smart meters using RF mesh communication technology.

While RF Mesh posed issues of vendor lock-in, it has been accepted to be the most preferred communication technology.

(ii) Focus on interoperability

CESC follows standard IS16444 to support interoperability across different levels. During the smart meter deployment process, CESC placed high focus on interoperability and made conscious efforts for ensuring it. The following was observed during the implementation process:

- Hardware-level: Interoperability from meter to HES was achievable and was demonstrated during PoC.
- Application-level: Application-level interoperability also exists as multiple HES are able to communicate with CESC's own applications.
- Network-level: Interoperability at the communication network-level was observed as a key impediment as moving from one communication technology to another was a challenge.

Annexure 5: Case studies of international DSOs

To understand the international smart metering landscape, the team followed the following approach:

i. Conducted in-depth secondary research
ii. Held discussions with the Accenture experts engaged with the DSOs on their smart meter implementation programmes

A questionnaire was designed to help structure the discussions with the international experts and reap maximum insights:

Table 13: Questionnaire for international Discoms

#	Question
1.	What is the current status of smart meter deployment in your organization?
2.	What are the major challenges (during planning and approval, procurement, implementation phase etc.) faced during smart meter deployment?
3.	Do you think component-level interoperability is important to be kept in mind while designing the smart metering infrastructure? Interoperability across which components is ensured/ should be ensured by DSOs? What are the DSOs' major reasons/ motivations for ensuring interoperability? Are there any disadvantages of interoperability?
4.	In your opinion, what are the benefits achieved from interoperability?
5.	What are the major standards/ specifications that mandates interoperability for one or more layers of AMI (smart meter/ communication/ HES/ MDM), if any?
6.	What are the challenges and requirements for implementation of AMI interoperability?
7.	Which are the major testing laboratories authorized by Government/ Regulator for testing of AMI system?
8.	What has been the measures taken to mitigate cybersecurity concerns during the procurement and the operation phase?
9.	What do you think are the major challenges for change management and capacity building within the organization post smart meter deployment?
10.	What has been the feedback from the consumers?

The detailed case studies are documented below:

1. UK Smart Meter Rollout

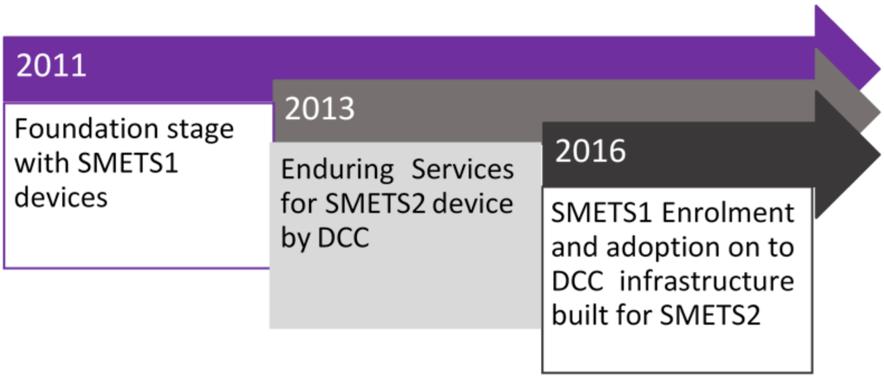
A. Background

The ongoing Smart Metering Rollout in UK, or UK Smart Metering Implementation Programme (SMIP), as it is commonly called, aims to replace 53 million (30 million electric and 23 million gas) legacy meters with remotely managed Smart Meters covering about 30 million households. The rollout currently involves only the 'residential customer segment' in the UK Power and Gas Utilities sector.

B. AMI implementation

The AMI implementation in the UK is being delivered in three stages – the Foundation Stage, which began in 2011, transitioning into the Enduring Services phase and finally into the Main Installation Stage, which commenced in November 2016.

Figure 23: Stages of UK SMIP



(i) Foundation stage (2011)

With an aim to replace legacy meters with smart meters, the UK Government initiated the Foundation Stage of the Smart Meter Rollout in 2011, which involved installation of SMETS1 meters i.e., Smart Metering Equipment Technical Specification version 1 meters, which were based on the initial Metering Standards created by the Government. The Foundation Stage was designed to enable Energy Suppliers to build learning and experience of installing and operating smart meters, accelerate customer benefits and bring forward industry savings.

The Energy Suppliers who rolled out SMETS1 smart meters used to provide services via their own combination of Communication Service Providers (CSP) and data services providing entities which were called as Smart Metering System Operators (SMSO). Each of the SMSOs had their own set of specifications and functionalities which were enabled in their individual systems.

The following were some of the salient features and limitations of the Foundation Stage:

- Many of the Energy Suppliers had contracted with different CSPs and the communication between the SMSO and the SMETS1 meters was tied to the CSP, i.e., each set of meters communicated in different standards
- Each SMSO used to support different functionalities and features of the metering system
- Each SMSO had their own unique message formats and interface specifications
- The metering authentication certificate and the communication devices (sim cards) were aligned to the requirements of the SMSO and the CSP contracted with the SMSO

Due to the above-mentioned features, there was lack of interoperability between systems of two different SMSOs/ supplier. This led to an issue during the customer switching process, as sometimes the SMETS1 smart meter installed at the premises used to be incompatible with the communications and data systems of the new supplier/ SMSO – thereby temporarily making the SMETS1 meter unable to communicate (going dormant) with backend systems. This essentially meant that all the ‘smart features’ of the meter would be lost, and it would work like a legacy meter.

Thus, the lack of interoperability which resulted in the SMETS1 smart meters going dumb, necessitated the setting up of a centralized entity which could prevent such issues in the future.

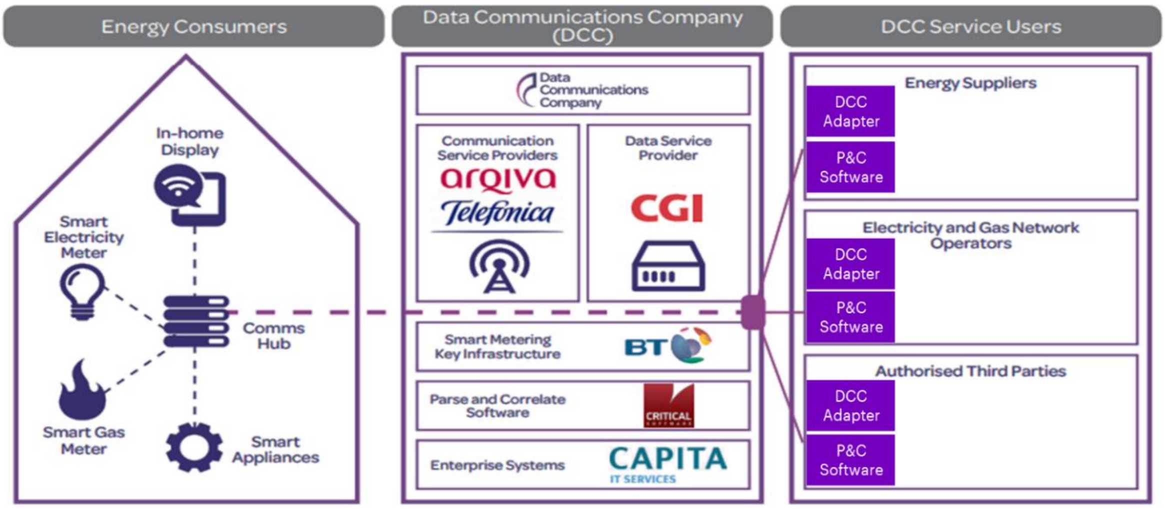
(ii) Enduring services (2013)

During this stage, a centralized entity named the Smart DCC (Data Communications Company) was created in 2013. DCC was required to provide a test environment and support to SEC Parties on an enduring basis for ensuring compatibility and systems assurance for SMETS2 during this period.

DCC is operated by Capita plc under a license regulated by the Office of Gas and Electricity Markets (OFGEM). The role of the DCC is to provide the shared infrastructure necessary for smart meters to operate consistently for all consumers, regardless of their Energy Supplier. The DCC is intended to act as a central nationwide body with the responsibility to contract the data and communication services needed to deliver smart metering data (and control) to Energy Suppliers. It is responsible for linking smart meters in homes and small businesses with energy suppliers, network operators and energy service companies.

The DCC is needed to ensure that full benefits from smart meters are realized lifelong, and that the smart metering system as a whole works smoothly once many millions of smart meters have been installed. It acts as a gateway between the various smart metering systems and the various market participants such as Distribution Network Operators (DNOs), suppliers and other relevant entities such as regulators, nominated agents etc.

Figure 24: DCC stakeholder landscape



DCC was granted the license to build and manage the Smart Metering network in 2013 by the erstwhile Department for Energy and Climate Change (DECC), now part of the Department of Business, Energy and Industrial Strategy (BEIS). The DCC communications network is being delivered on the ground by two Communications Service Providers, Arqiva and Telefonica, and a single Data Service Provider, CGI. Arqiva is installing the network infrastructure in the north of England and Scotland while Telefonica is installing across central and southern England and Wales.

(iii) Main installation stage (2016)

The main installation stage of the smart meters commenced in the year 2016 which was also around the time when the Centralized DCC Systems had become fully operational. This stage involved the installation of the new generation of smart meter i.e., SMETS2 meters which had advanced features.

All the SMETS2 meters which were being installed by the Energy Suppliers communicated via the systems of the Centralized DCC i.e., the Communication Service Providers (CSP) and the Digital Service Providers (DSP) systems.

SMETS 1 onboarding onto DCC (2019)

To overcome the issue of the SMETS1 meters going dormant post change of supplier, the UK Government mandated the DCC to enable their systems in such a way that SMETS1 meters could be onboarded as well onto the Centralized DCC Systems. The process of moving the SMETS1 meters onto the DCC Systems is called as the 'Enrolment and Adoption' process and commenced from 2019 in multiple cohorts/ tranches based on the meter makes which include Aclara, EDMI, Honeywell Elster, Itron, Landis+Gyr, and Secure Meters. The entire process of migration is over-the-air and does not require a field visit. This is a highly challenging and technical process and represents one of the largest IT migrations in a live environment.

Current status

At the end of 2021, there were 27.8 million smart and advanced meters installed in Great Britain[22]. Of these, 23.6 million were smart meters operating in smart mode and advanced meters and the rest in traditional mode[23].

C. Key learnings

Following were the key learnings from the UK Smart Metering Implementation Programme:

[22] Source: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1035290/Q3_2021_Smart_Meters_Statistics_Report.pdf

Figure 25: Key learnings from SMIP

i. **Define the key objectives, drivers and use cases clearly**

Although most of the relevant use cases were included right from the beginning, there were some important use cases of Smart Metering which were missed out during the planning phase. Some of the functionalities were –

- Ability to provide Auxiliary Control of in-home appliances – This is a very important feature especially from the perspective of Grid Demand Response – this feature was missed during the planning phase and now changes are being made to incorporate the same
- Similarly, the provision to upgrade the firmware of the In-home display (IHD) was also missed out which is being incorporated now

Such late additions and changes to the functionalities and specifications add to the timelines and cost as well as postponed the benefits in some cases.

ii. **Build on existing industry standards and specifications**

The specifications for the various components of the SMIP, such as smart meters, communication hubs, key infrastructures, message specifications and formats etc. were all written from scratch over a long period of almost 3 years. This resulted in overall delays in the programme as well as prevented the early detection of programme issues such as lack of interoperability of SMETS1 meters etc.

iii. **Ensure presence of right supporting infrastructure before commencing meter rollout**

The Foundation Stage allowed the rollout of smart meter in the field before having a centralized mechanism in place to manage the rollout. This resulted in varying types of incompatible technologies to be rolled out and subsequent interoperability issues. Hence, it is very important to have the supporting infrastructure such as the CSP and DSP and standardized specifications and protocols which allow interoperability before commencing rollout.

iv. **Ensure end customer buy-in**

The business case for the SMIP assumes that the smart meters would be rolled out within a certain time span and the benefits will start accruing from a specific year. This whole Cost Benefit Analysis (CBA) becomes redundant if the timelines are delayed. Hence, apart from technical issues, it is also important to parallelly build up consensus amongst the 'end customer community' to ensure adoption and faster rollouts. In UK there was some amount of opposition to the smart meter rollout due to fears of loss of privacy as well as due to presumed ill effects of radio frequency radiation and cellular networks radiation on human health. Due to these concerns, Public Health England (PHE), a government agency, conducted an extensive programme of research to assess exposures from smart meters to conclude that exposures to the radio waves produced by smart meters do not pose a risk to health. This learning was then widely advocated through public announcements and advisories that busted such myths.

2. EDF-Enedis Smart Meter Programme

A. Background

Enedis is a French grid operator and a 100% subsidiary of EDF, an electricity supplier in France. The country's largest grid operator, Enedis manages 95% of the operations, maintenance and development of France's public electricity distribution network.

B. AMI implementation

In 2015, Enedis initiated the Linky programme in France. The Linky programme is one of the largest smart meter rollouts in the world, which targeted to install 35 million smart meters by 2021. This is in line with a European Commission directive that all member states must change to at least 80% smart meters by 2021. The French programme is estimated to cost €5.7 billion.

Under this programme, Enedis is installing Linky smart meters, a new generation of smart meters across the country. The aim of the programme is to optimise operations through improved grid management, reduce non-technical energy losses and ensure remote operations and meter reading.

The Linky programme is considered to be one of the largest and most successful smart meter rollouts in the world, with the country already being very close to achieving 100% installation target.

C. Key learnings

Several factors contribute to France being able to successfully deploy smart meters within the decided time frame.

- **Strong partner ecosystem:**
  Enedis ensured to bring the best partners onboard for the project implementation. The programme had 6 main partners for manufacturing of the smart meters and DCUs:
  i. Sagemcom
  ii. Itron
  iii. Landis+Gyr
  iv. Honeywell
  v. Alfanar
  vi. Cahors

- **Structured reliability and quality testing:**
  Enedis set up an Enedis Qualification Centre to ensure that no quality and reliability issues occurred during implementation. The centre helped to ensure that the equipment has a

20-year lifetime, device interoperability for meters and DCUs, technological innovations and tackle issues of tight deadlines for design and qualification of devices, complex purchasing strategy and large volumes of devices.

Being the largest smart meter system in Europe, this centre has ~400 test racks and ~50 engineers and technicians working daily at the lab, who are experts in design and testing with detailed knowledge of electronics, mechanics, software, telecoms and cyber security technology.

- **Consumer awareness:**
  The importance of consumer awareness was realized later on in the programme, when the programme received certain consumer resistance. Thousands of people across France had been refusing the mandatory installation of the Linky meters. The consumers were concerned about the potential health issues that could arise from the electromagnetic waves such as sleep disorders and headaches. To clear the misinformation, the national frequency agency (ANFR) studied wave exposure and concluded the transmission does not significantly increase the ambient electromagnetic field.

  Additionally, some consumers were also worried about data security and how their energy usage data might be used by the grid operator. This makes it very important to build trust within the consumers for facilitating seamless adoption of smart meters and thus necessitates a robust planning for awareness creation within consumers.

3. A large North American utility

A. Background

This is an American utility based in Minneapolis, Minnesota, and powers millions of homes in the United States. It is an industry leader with great focus on producing and delivering clean and reliable energy solutions. With an aim to improve power reliability, allow for better grid integration and provide customers with more information to track their energy usage, the utility initiated the implementation of smart and advanced grid, with a key focus on Advanced Metering Infrastructure (AMI).

In Colorado, the utility is working with the Colorado Public Utilities Commission (CPUC) to undertake AMI implementation over a period of five years from 2019 to 2024 with installment of over one million residential smart meters. For this implementation, they inked an agreement with Itron to secure smart meters which will be integrated with innovative customer apps to improve their energy efficiency. The utility leveraged the existing standards-based, interoperable network from Itron along with Itron's comprehensive distributed intelligence platform to manage edge applications from an open ecosystem of solution providers.

B. AMI implementation

Since the advent of the AMI implementation journey, interoperability was a key consideration. The utility was looking at interoperability at various levels, i.e., within the meter and especially within the FAN network and the meter Network Interface Card (NIC) to AMI head-end solution. They also looked at how much interoperability they could achieve in the back-office systems from the AMI Head-End System (HES) through the AMI Meter Data Management System (MDMS) to the customer system and some of the integrations to other systems like OMS in distribution operations.

The key considerations to ensure interoperability included:

- Adherence to standards for metrology like C12.29 or COSEM/DLMS
- Adherence to network protocol standards such as COSEM/DLMS, IPv6, and TCP

While finalizing the vendor, the utility decided on Itron as the Itron UtilityIQ (AMI head-end solution) supported these interoperability standards and also provided a meter NIC that would be compatible with multiple meters from other vendor meters and not just the Itron meters. To ensure this, a pilot was conducted where some Landis+Gyr meters were operated with an Itron NIC.

Soon after, they encountered Itron's Distributed Intelligence (DI) solution. The DI solution enables applications to be developed and installed on the meter itself. These applications have access to the meter's data, which is used to implement algorithms. The results of these computations, that are done on the meter itself, are then sent to a backend server for further analysis and/or display. The DI meters are capable of providing sub-second sampling rates, in addition to still providing 5-minute and 15-minute interval data every four hours. They also have capabilities to provide one second usage data and 1/30th second power factor data but not across the FAN/WAN networks. However, the DI solution could only be used with Itron DI meters.

The utility was convinced that the benefits of DI outweighed the benefits from other meters from multiple vendors, as well as the benefits from interoperability and hence went ahead with it. The DI meters also made the utility move away from the Zigbee standard and the Smart Energy Profile (SEP) 1.0 standard to the IEEE 2030.5 standard and SEP 2.0 for home area networking support. However, they still support interoperability in the FAN/WAN protocol stack, the HAN networking stack and the back-office systems in the cloud and data center.

C. Key learnings

While interoperability had been a focus area, the utility took a conscious decision of overruling benefits from interoperability for the benefits achieved from the DI meters, which would improve customer experience and utility operations using the distributed intelligence capabilities.

4. Kansas City Power & Light (KCP&L) Smart Grid Demonstration Project

A. Background

Kansas City Power & Light (KCP&L) is a leading energy provider headquartered in Kansas City, Missouri. KCP&L was awarded a Regional Smart Grid Demonstration Project (SGDP) cooperative agreement by the US Department of Energy (DOE) to deploy a fully integrated Smart Grid Demonstration in an economically challenged area of Kansas City, Missouri. The project was awarded a funding of over $58 million. As part of this programme, KCP&L is deploying an end-to-end smart grid that will include advanced renewable generation, storage resources, leading edge substation and distribution automation and controls, energy management interfaces, and innovative customer programmes and tariffs.

The overarching objective of this programme was to demonstrate the feasibility of integrating the existing and emerging smart grid technologies and solutions to build innovative smart grid solutions and report its financial and business model viability.

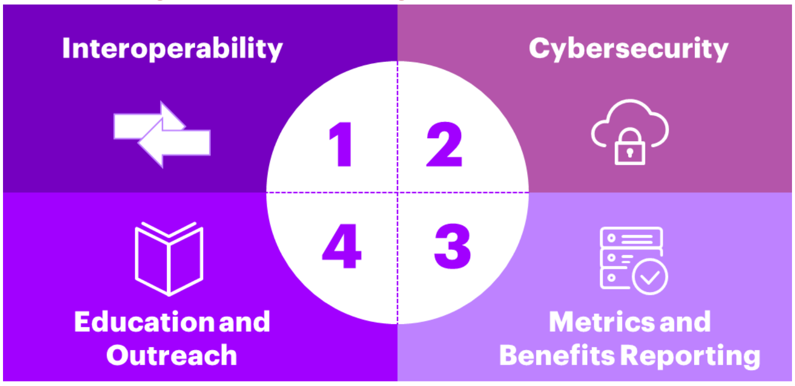
To achieve the objectives, a strong network of stakeholders was brought together to leverage their capabilities and deliver cutting-edge solutions.

Smart metering
One of the key initiatives/subprojects under this programme was of smart metering. The objective of this project was to develop integrated AMI and Meter Data Management (MDM) systems that support two-way communication with 14,000 smart meters in the SGDP area. The AMI and MDM would also be required to be integrated with other enterprise systems such as Customer Information System (CIS), Distribution Management System (DMS), Outage Management System (OMS), and Distributed Energy Resource Management (DERM) system, etc.

B. Smart Grid implementation

To enable smooth on-ground implementation, the project team focused on defining key themes which are critical to execution of any smart grid/ meter project. The team identified these cross-cutting themes early on and published them as individual series.

Figure 26: Cross-cutting themes for the SGDP



i. Interoperability Plan

This plan detailed out the smart grid system interoperability strategy and approach. This plan was charted out to ensure interoperability at the overall smart grid level, as interoperability becomes a key consideration when trying to combine legacy components and products from multiple vendors. Interoperability at the smart meters level also becomes important, as they are one of the key components of a smart grid. During the integration, the following challenges are envisaged, which this interoperability plan aims to mitigate:

- Communication between legacy systems and devices
- Communication between open standards and proprietary components
- Identification of failure, followed by upgradation and maintenance of components so that the overall system operation is highly reliable
- Supporting interacting parties' anticipated response to failure scenarios, particularly loss of communications

The interoperability strategy lays out some key points to address these challenges:

- Consider emerging standards for distribution grid management such as IEC 61968 and IEC 61850 while selecting the products
- Select open and modular architectural approaches that emphasize vendor-independent integration mechanisms (e.g., Service-Oriented Architecture)
- Invest in ongoing integration test-bed capability to provide for agile component integration, interoperability testing and means for managing technical and security risks through hands-on application and integration of new technologies
- Continue to collaborate with stakeholders including public and private industry players and special interest groups (such as SGIP, EPRI, IEC, IEEE, UCAIug and the GridWise Alliance) to work together for refinement of interoperability standards
- Perform regular review of current implementation and architecture versus current industry standards and emerging integration models

The strategy plan involves adoption of frameworks to derive architectures that satisfy interoperability requirements for smart grid systems. Some of these frameworks are as below:

- NIST Framework and Roadmap for Smart Grid Interoperability
- GridWise Architectural Council Interoperability Context-Setting Framework
- NIST Smart Grid Cyber Security Strategy and Requirements
- EPRI IntelliGrid Methodology (Business Use Cases)
- AMI-SEC AMI Security Profile & Distribution Security Profile

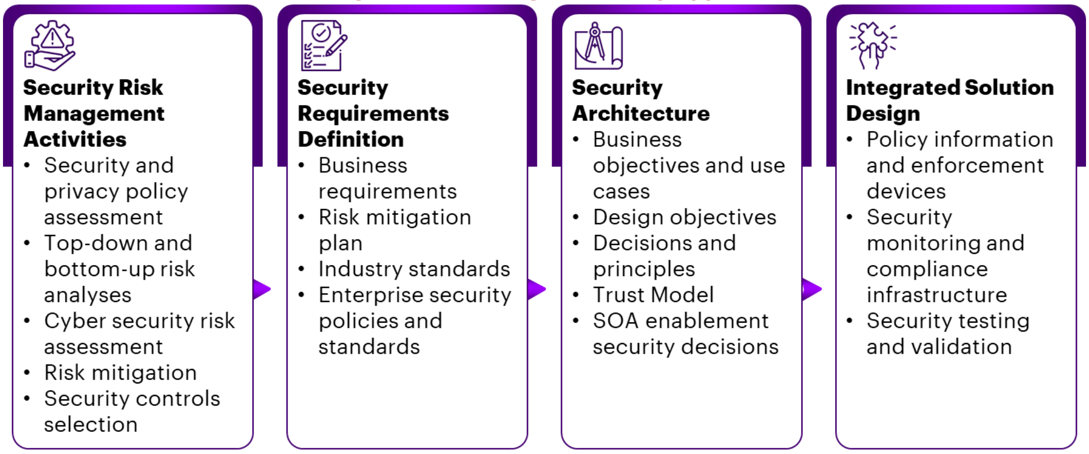
ii. Cybersecurity Plan

The team designed a "Smart Grid Cybersecurity Plan" with a detailed strategy and approach for implementing cybersecurity in the SGDP. The challenges associated with cybersecurity were identified as below:

- Increased potential points of attacks across the grid
- Increased risk of compromise due to IT-oriented threats, which affect control systems within the grid
- Impact of security controls on reliability and availability of the grid
- Lack of quick response to security challenges by vendors, utilities and standards bodies and subsequent incorporation of cyber security mechanisms into their products
- Immature mechanisms to detect anomalous behavior within the grid indicating that a cyber-attack on control systems is underway

To address the above challenges, the team designed a cyber-security controls framework, design, architecture, and infrastructure to ensure that technologies, polices, processes and procedures result in adherence to existing cyber security regulations, evolving smart grid security requirements and KCP&L's business requirements. The approach followed is summarised below:

Figure 27: Smart grid security approach



iii. Education and Outreach Plan

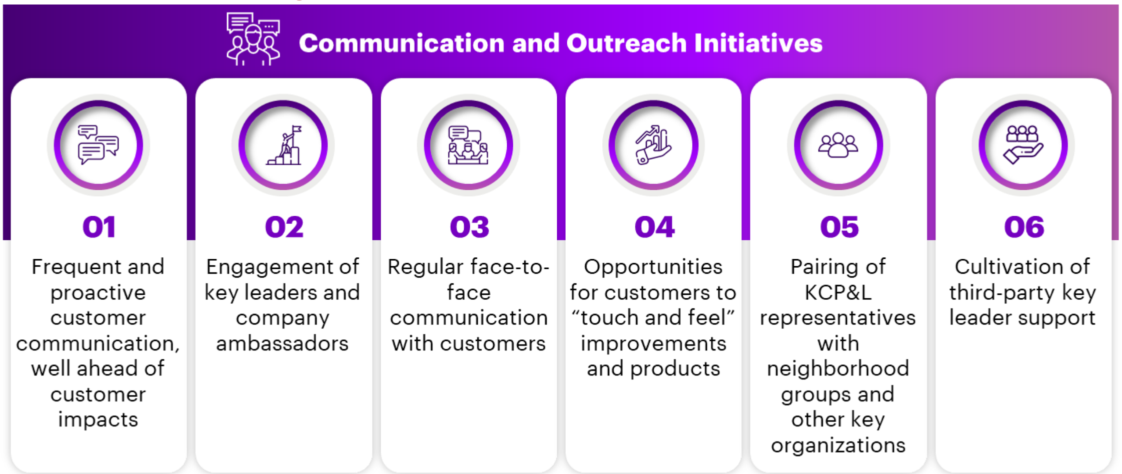
The overall success of a smart grid project is closely tied to the overall success of the utility's public education and outreach plan. KCP&L designed a highly target education and outreach plan to raise awareness and improve adoption of smart grids. KCP&L collaborated with its vendor partners and a wide range of community groups to deliver this. Additionally, the success and lessons learned over the deployment period will help while creating the plan for future deployment.

The plan aimed to target multiple audiences including:

- Smart Grid Demonstration Area Customers (customers, neighborhood groups, schools, community leaders, elected leaders, etc.)
- All KCP&L customers (residential, commercial, industrial)
- All KCP&L employees (departments: customer care, engineering and operating)
- State Agencies, Legislators and Regulators
- Utilities and Smart Grid Industry (Department of Energy, National Energy Technology Laboratory, National Institute of Standards and Technology, Smart Grid Interoperability Panel, etc.)

A structured approach was designed to engage and educate the stakeholders using variety of initiatives through multiple channels.

Figure 28: Communication and Outreach initiatives



iv. Metrics and Benefits Reporting Plan

The Metrics and Benefits Reporting Plan lays down the expected benefits, build and impact metrics, data collection and analysis methodologies, etc. The metrics will be reported by KCP&L to DOE using a reporting framework developed by DOE.

The benefits will be evaluated under four major benefit categories:

i. Economic
ii. Reliability
iii. Environmental
iv. Security

The benefits accrued across various smart grid technologies will be compared with appropriate baseline data.

C. Key learnings

Interoperability was a key focus area during the SGDP. Some key lessons learnt while facilitating interoperability can be summarised as below:

- The process of developing standards is slow. If the interoperability standards are not complete, the vendors will need to make assumptions, thereby making it unfeasible. To avoid this, project vendors could come up with a common working version of the standard.
- There exists possibility of different interpretation of standards by different vendors. This must be overcome by rigorous testing by established testing bodies to ensure consistency across vendors
- Meter manufacturers can be slow to adopt new communication technologies. Even if a standard is fully vetted, the time to develop, test, and bring the devices to market is quite long. Utilities need to push vendors to expedite adoption of new communications technologies.

To ensure stability for all the back-office systems, a holistic monitoring system is necessary. This system should alarm when a critical event on a particular server, device, interface, or communication path occurs for appropriate troubleshooting and resolution.

Annexure 6: Comparison between Indian and global standards

Based on the standards defined in India and internationally, for smart meters, the following table identifies the areas of development for India standards to strengthen and ease the smart meter deployment.

Table 14: Areas of development for Indian standards

#	Attributes	Global best practices	Indian standards	Remarks
1.	**Device technical standards**	**Mandated EU standards:** • NTA 8130: 2007 (Netherland): Minimum set of functions for metering of electricity • DSMR (Dutch Smart meter requirement): companion standard for an Automatic Meter Reading (AMR) system for electricity • SM-2g (2nd generation of smart meter) standard. • IEC 60514: E-Mechanical Meter • IEC 61358: Static Meters • IEC 62053: Electromechanical kWh, Static kWh, Static kVARh meter **Mandated US standards:** Physical aspects standards • ANSI American National Standard for Electricity Meters C12.20 – 2015: This standard establishes the physical aspects and acceptable performance criteria on electricity smart meters. Interfacing standards: • ANSI C12.21 – 2006: Protocol Specification for Telephone Modem Communication.	**Physical Standards** Single phase whole current & three phase whole current meters operation and construction/make standards: • IS 13779: AC Static Watt-hour Meter class 1& 2 • IS 16444: A.C. Static Direct Connected Watt Hour Smart Meter Class 1 and 2- Specification. Power consumption guidelines as per IS16444 annexure K. • IS 15884: Alternating Current Direct Connected Static Prepayment Meters for Active Energy (Class 1 and 2)- Specification • IS 14697: Three phase transformer operated meters	Indian standards are well structured on device techno functional aspects. However, while basic interfacing requirements have been provided in the CEA guidelines, there is a need to establish standards for the same. Global best practices have also mandated device functionalities & interfacing feature standards (EU & US)

#	Attributes	Global best practices	Indian standards	Remarks
		• ANSI C12.22 – 2012: American National Standard Protocol Specification for Interfacing to Data Communication Networks		
2.	**Data Exchange Standards**	• IEC 62051 Electricity metering - Data exchange for meter reading, tariff and load control • IEC 62056: Local data exchange, data exchange based on DLMS /COSEM.IES-61334: extended version of DLMS.	• IS 15959: Data Exchange for Electricity Meter Reading, Tariff and Load Control- Companion Standards. • IEC 62056 DLMS/COSEM Data exchange protocol	India has already undertaken communication protocols such as DLMS/COSEM. On the basis of these communication protocols, Indian standards are sufficient and well established. **Networking signal intensity benchmarking/standards are not defined as part of IEC-62056. **Communication parameters testing (like: time intervals, delay timing, frequencies etc.) are based on the utilities' requirements and not standardized.
3.	**Communication Infrastructure**	**World Standards:**	**CEA Guidelines:** The communication infrastructure	CEA guidelines specify that the vendor may

#	Attributes	Global best practices	Indian standards	Remarks
		• IEC-62357 Power systems management and associated information exchange • IEC -61850 international standard defining communication protocols for intelligent electronic devices at electrical substations • IEC 62746 Systems interface between customer energy management system and the power management system **US standards:** ANSI C12.22 -2012: American National Standard Protocol Specification for Interfacing to Data Communication Networks: This standard describes the process of transporting data over a variety of networks, with the intention of advancing interoperability among communication modules and meters. Some other specific standards under (ANSI C12)	should either be based on RF mesh network / PLC or cellular network or a combination of these. The communication network shall be based on suitable standards from ITU/IEC/IEEE/CEN/ CENELEC/ ETSI for NAN and WAN network. Communication network shall provide reliable medium for two-way communication between various nodes (smart meter) & HES. RF based network should use license free frequency band available in India. The engagement of cellular operator would be in the scope of AMI Implementing Agency to meet the performance level as given in the document.	choose any communication technology and architecture based on globally available open standards. Global standards & US standards are more specific to each communication sub-mechanisms. Based on the current scenarios of Indian smart meter projects & programmes CEA guidelines and open standards are sufficient to move forward.
4.	**Head end system & Integration architecture standards**	**HES:** Global best practice on HES functionalities: • Establishment capabilities: Establish user file in the AMI system • VEE Validation, Estimation, Edit • Storage: Save the validation results and the original data in the database • Analysis: Statistics of the collected data **Integration Standards:**	**HES:** CEA guidelines on suggested functionalities & configuration is available. **Integration Standards:** CIM / XML / IEC 61968 or any other open standard. The solution shall be Service	HES guidelines for the functionalities and configuration are available in the Indian distribution sector. (Note: Interoperable technologies have not been mentioned in the guidelines). Although no

#	Attributes	Global best practices	Indian standards	Remarks
		• IEC 62056-42: Physical Layer • IEC 62056-46: Data Link Layer • IEC 62056-47: Transport layer for COSEM • IEC 62056-53: Application layer for COSEM • IEC 62056-51: DLMS based application layer+transport layer+data link layer • Open integration standard: IEC 619	Oriented Architecture (SOA) enabled.	specific standards are mandated globally. Integration infrastructure standards are mandated as CIM / XML / IEC 61968 or any other open standard for Indian distribution sector. Global standards are more specific to each layer of data integration architecture.
5.	**Networking & Architecture**	**Networking & Protocols Standards:** ANSI/CEA 709: Control Network Protocol Specification for interoperability. Network Technical specification and topologies. ANSI/CEA 852: Enhanced Protocol for Tunneling Component Network Protocols over Internet Protocol Channels **ISGFCEN-CENELEC-ETSI CG** (EU standard): Open architecture for utility meters involving communication protocols enabling interoperability (smart metering). **Networking technologies & respective protocols can be broadly divided into wired and wireless connection technologies under three main categories	**CEA Guidelines:** Meter shall have ability to communicate with DCU/Access Point/HES on any one of the technologies mentioned in IS16444 in a secure manner, as per the site conditions and as per design requirement of AMI Implementing agency. In case of GPRS/3G/4G based meter, the meter shall accommodate SIM card of any service provider. In case of Plug-in type communication module, the meter shall log communication	CEA guidelines are available for the Indian power system including distribution systems as per IS 16444 standards. For current scenarios of smart meter network and architecture systems, these guidelines are sufficient.

#	Attributes	Global best practices	Indian standards	Remarks
		1. Last mile communication, NAN, FAN. 2. Home area networks (HAN) 3. Backhaul/WAN and Backbone	module removal /nonresponsive event with snapshot. It shall support the networking layer protocol IPv4 / IPv6 network addressing of OSI architecture model	
6.	**System Security Standards**	Globally, one of the best practices to prevent regular attacks on electric utilities includes in-depth focus on the utility's day to day functioning. A layered security approach across functions will help strengthen its cyber security posture. The layers are: • Anti-Malware • Patch Management • Account Management • System Policies • Firewalls & Architecture • Policies & Procedures • Physical Security **US standards & guidelines on security mechanisms** • ANSI C12.22-2012: American National Standard Protocol Specification for Interfacing to Data Communication Networks. • **Department of Homeland Security (DHS): Cyber Security Procurement Language for Control Systems** This document summarises security principles that should be considered when designing and procuring	**CEA Guidelines:** The Network shall have adequate cyber security measures. The network security would be extended to all the interfaces also. Guidelines are on following security parameters: • Secure Access Controls • Authorization Controls • Logging • Hardening • Malicious Software Prevention • Network Security **CEA (Cyber Security in Power Sector) Guidelines, 2021**: provides the guidelines on below areas • Cyber Security Policy.	Security guidelines and standards are available for Indian power distribution sector. Global standards are more specific and well structured. For current smart meter projects, these standards are sufficient. However, scaling up of smart meters in Indian distribution sector may need more specific and structured standards on networking, interfacing, cyber-attacks, data securities, interface securities etc.

#	Attributes	Global best practices	Indian standards	Remarks
		control systems products and services (software, systems, maintenance, and networks), and provides example language to incorporate into procurement specifications. The guidance is offered as a resource for informative use. It is not intended to be a policy or standard. • **DHS National Communications System (NCS) Catalog of control systems security: recommendation for standard developers.** This catalogue presents a compilation of practices that various industry bodies have recommended to increase the security of control systems from both physical and cyberattacks. • **Framework for Improving Critical Infrastructure Cybersecurity V1.1 April,16, 2018** The Framework focuses on using business drivers to guide cybersecurity activities and considering cybersecurity risks as part of the organization's risk management processes. The Framework consists of three parts: the Framework Core, the Framework Profile, and the Framework Implementation Tiers. • IEC TR 61850-90-12:2015 Communication networks and systems for power utility automation - Part 90-12: Wide area network engineering guidelines. • IEC 62351-1:2007 Power systems management and associated information exchange - Data and communications security - Part 1: Communication network and system security - Introduction to security issues	• Identification of Critical Information Infrastructure (CII). • Electronic Security Perimeter • Cyber Security Requirements • Cyber Risk Assessment and Mitigation Plan • Phasing out of Legacy System • Cyber Security Training • Cyber Security Training • Cyber Security Incident Report and Response Plan • Cyber Crisis Management Plan(C-CMP) • Sabotage Reporting% • Security and Testing of Cyber Assets • Cyber Security Audit **Respective standards:** • ISO/IEC 15408: Common Criteria Certification Standard • ISO/IEC 17011: General requirements for accreditation bodies accrediting conformity assessment bodies • ISO/IEC 17025: General requirements for the	

#	Attributes	Global best practices	Indian standards	Remarks
		• IEC 62351-3:2014+AMD1:2018 CSV Consolidated version Power systems management and associated information exchange - Data and communications security - Part 3: Communication network and system security - Profiles including TCP/IP • **IEC 62351-4:2007 Part 4: Security for any profiles including MMS (e.g., ICCP-based IEC 60870-6, IEC 61850, etc.).** This standard specifies procedures, protocol extensions, and algorithms to facilitate securing ISO 9506 • **IEC 62351-5:2013 Part 5: Security for any profiles including IEC 60870-5** This standard specifies messages, procedures, and algorithms for securing the operation of all protocols based on or derived from IEC 60870-5 • **IEC 62351-6:2007 Security for IEC 61850 profiles Part 6: Security for IEC 61850 profiles** This standard specifies messages, procedures, and algorithms for securing the operation of all protocols based on or derived from the standard IEC 61850. Applies to at least those protocols of IEC 61850-8-1, IEC 61850-9-2, and IEC 61850-6. • IEC 62351-7:2017 Security through network and system management Part 7: Security through network and system management • IEC 62351-8:2011 Power systems management and associated information exchange - Data and	competence of testing and calibration laboratories • ISO/IEC 21827: Systems Security Engineering - Capability Maturity Model (SSE-CMM) • ISO/IEC 24748-1: Systems and software engineering — Life cycle management — Part 1: Guidelines for life cycle management. • ISO 27001/2: Information Security Management • ISO/ IEC 27019: Information technology — Security techniques — Information Security controls for the energy utility industry • ISO/IEC 61508: Functional Safety of Electrical / Electronic / Programmable Electronic Safety-related Systems • IEC 61850: Communication networks and systems for power utility automation • IEC 62351: Standards for Securing Power System Communications	

#	Attributes	Global best practices	Indian standards	Remarks
		communications security - Part 8: Role-based access control • IEC 62351-9:2017 Power systems management and associated information exchange - Data and communications security - Part 9: Cyber security key management for power system equipment. • IEC TR 62351-10:2012 Power systems management and associated information exchange - Data and communications security - Part 10: Security architecture guidelines. • IEC 62351-11:2016 Power systems management and associated information exchange - Data and communications security - Part 11: Security for XML documents. • IEC TR 62351-12:2016 Power systems management and associated information exchange - Data and communications security - Part 12: Resilience and security recommendations for power systems with distributed energy resources (DER) cyber-physical systems. • IEC TR 62351-13:2016 Power systems management and associated information exchange - Data and communications security - Part 13: Guidelines on security topics to be covered in standards and specifications. • IEC TR 62357-1:2016 Power systems management and associated information exchange - Part 1: Reference architecture • IEC 62541-2:2016 OPC unified architecture - Part 2: Security Model.	• IEC 62443: Cyber Security for Industrial Control Systems IS 16335: Power Control Systems – Security Requirements.	

#	Attributes	Global best practices	Indian standards	Remarks
		• IEC 62541-6:2015 OPC unified architecture - Part 6: Mappings. • IEEE 1686-2013: Standard for Intelligent Electronic Devices Cyber Security Capabilities • IEEE 1701-2011: Standard for Optical Port Communication Protocol to Complement the Utility Industry End Device Data Tables • IEEE 1702-2011: Standard for Telephone Modem Communication Protocol to Complement the Utility Industry End Device Data Tables • IEEE 1815-2012: Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3). • IEEE 2030.5 (SEP 2)-2013: IEEE Adoption of Smart Energy Profile 2.0 Application Protocol Standard • MultiSpeak Security-V1.0 • NAESB REQ.21 Energy Services Provider Interface Model Business Practices (MBPs) • **NAESB RMQ.26 OpenFMB:** The OpenFM framework provides a specification for power systems field devices to leverage a non-proprietary and standards-based reference architecture, which consists of internet protocol (IP) networking and Internet of Things (IoT) messaging protocols. The framework supports Distributed Energy Resources that communicate based on a common schematic definition and then can process the data locally for action (control, reporting). • **NEMA SG-AMI 1-2009 (R2015) Requirements for Smart Meter Upgradeability**:		

#	Attributes	Global best practices	Indian standards	Remarks
		This standard will be used by smart meter suppliers, utility customers, and key constituents, such as regulators, to guide both development and decision making as related to smart meter upgradeability. This standard serves as a key set of requirements for smart meter upgradeability. These requirements should be used by smart meter suppliers, utility customers, and key constituents, such as regulators, to guide both development and decision making as related to smart meter upgradeability. • **NERC Critical Infrastructure Protection (CIP) 002-009**: These standards cover organizational, processes, physical, and cybersecurity standards for the bulk power system. • **NIST SP 800-53-Rev 5-2017 Security and Privacy Controls for Information Systems and Organizations.:** This publication provides a catalogue of security and privacy controls for federal information systems and organizations to protect organizational operations and assets, individuals, other organizations, and the Nation from a diverse set of threats including hostile attacks, natural disasters, structural failures, human errors, and privacy risks. • **Security Profile for Advanced Metering Infrastructure, v 1.0, December 10, 2009** The scope of this work extends from the meter data management system (MDMS) up to and including the		

#	Attributes		Global best practices	Indian standards	Remarks
			home area network (HAN) interface of the smart meter. Informative security guidance may be provided for systems and components relevant but beyond the explicitly designated scope.		
7.	**Testing Standards**	**Interoperability & Security**	**Interoperability testing standards** (only communication protocol interoperability standards are available globally) • Sm-2g (2nd generation of smart meter) standard • **CEN-CENELEC-ETSI CG:** Open architecture for utility meters involving communication protocols enabling interoperability (smart metering). **Security Testing standards:** • Test of the security measures based on ISO/IEC: 27001 • Security Profile for Advanced Metering Infrastructure, v 1.0, December 10, 2009 (US AMI metering security standards) • NEMA SG-AMI 1-2009 (R2015) Requirements for Smart Meter Upgradeability (US AMI metering security standards) • IEEE 1686-2013: Standard for Intelligent Electronic Devices Cyber Security Capabilities	No interoperability testing standards of technologies/ protocols/ methodologies are adopted in India. **Security Testing standards currently used:** Basic Security Test Guideline as per IS: 15959 • Lowest level security secret • Low level security (LLS) secret • High level security (HLS) secret CEA (Cyber Security in Power Sector) Guidelines, 2021: • Article 13 Security and Testing of Cyber Assets as per the standard listed on MoP Order No. 12/13/2020-T&R dated 8th June 2021(Annexure-B). • Article 14 Cyber Security Audit: The Cyber Security	Interoperability testing is standardized for communication protocol globally. However, Indian standards are not available. As per the current scenario in India, security standards are well structured. However, scaling up smart meter installation may necessitate revision to the current security testing standards.

#	Attributes	Global best practices	Indian standards	Remarks
			Audit shall be as per ISO/IEC 27001 along with sector specific standard ISO/IEC 27019, IS 16335 and other guidelines issued by appropriate Authority if any	
	Device & Interface Functionality	**Mandated EU standards:** Type Tests: • IES 62052: Metering Equipment, Ripple controls, Time switches tests • IEC 62053: Power consumption, Symbols, Pulse output, Static & electromechanical meter functionalities tests. Acceptance Tests: • IEC 60514: Electromechanical meter tests • IEC 61358: Static Meter Test • IEC 62058: General requirements. **Mandated US standards:** • ANSI American National Standard for Electricity Meters C12.20 – 2015: This standard establishes the physical aspects and acceptable performance criteria on electricity smart meters. Interfacing standards (including testing standards): • ANSI C12.21 – 2006: Protocol Specification for Telephone Modem Communication.	**Device functionality & mandatory interfacing features:** • Meter Shall be BIS marked as per IS 16444. • The manufacturer shall have NABL accredited laboratory to ensure accurate testing calibration as per IS 13779 for acceptance test. • CEA Guidelines for theft or tamper condition: The meter shall continue recording energy under any tamper condition and would log the event and send alarm at Head End System after detection of the defined theft features as per IS 15959 Part 2. • CEA Guidelines on the user interface performance testing. (Update, Display,	Indian standards are well structured according to the current situation. However, Indian standards do not cover operational benchmarking of smart meters in certain electrical conditions. For example, the tolerance level of smart meters in low voltage conditions.

#	Attributes	Global best practices	Indian standards	Remarks
		• ANSI C12.22 – 2012: American National Standard Protocol Specification for Interfacing to Data Communication Networks	Printing, Alarms need to be responded within 1-2 sec) (Optional test as per requirement of utility: The Meter shall be immune under external magnetic influences as per CBIP 325. Meter shall be tested for high voltage discharge (Spark) up to 35 KV as per CBIP 325.)	
	Communication & Networking	**Communication & Networking Standard of US:** ANSI C12.22 -2012: American National Standard Protocol Specification for Interfacing to Data Communication Networks: This standard describes the process of transporting data over a variety of networks, with the intention of advancing interoperability among communication modules and meters	**CEA Guidelines:** Meter shall have ability to communicate with DCU/Access Point/HES on any one of the technologies mentioned in IS16444 in a secure manner, as per the site conditions and as per design requirement of AMI Implementing agency.	CEA guidelines for Indian distribution sector need to be strengthened with respect to data capturing frequency, intervals, delay time etc. Also, network signal intensity benchmarking and testing standards are not available as part of data exchange standards IEC 62056. Communication parameters testing are utility specific. Tolerance delay time, time intervals or frequency testing are tested as per utilities' requirement as DLMS/COSEM

#	Attributes	Global best practices	Indian standards	Remarks
				protocols give certain level of flexibility. In the future, these areas need to be well defined in communication standards.
	DCU/NAP testing standards	• Radio interference measurement (CIS PR 22) • Surge test (IEC 61000-4-5) • Fast transient burst test (IEC 61000-4-4) • Test of immunity to electrostatic discharges (IEC 61000-4-2) • Test of immunity to electromagnetic HF field (IEC 61000-4-3)	• Radio interference measurement (CIS PR 22) • Surge test (IEC 61000-4-5) • Fast transient burst test (IEC 61000-4-4) • Test of immunity to electrostatic discharges (IEC 61000-4-2) • Test of immunity to electromagnetic HF field (IEC 61000-4-3) • The bidder of the network services shall provide IP-55 compliance test certificate for DCU/Access Point.	Indian standards are available. End-to-end communication and device operability testing standards are required to be established as per the field conditions. These testing standards should include the overall data flow path testing from meter unit to MDMS through DCU and HES as applicable.

Annexure 7: List of abbreviations

Abbreviation	Full Form
3GPP	3rd Generation Partnership Project
ACS	Average Cost of Supply
AGIS	Advanced Grid Intelligence and Security
ALT	Accelerated Life Testing
AMI	Advanced Metering Infrastructure
AMISP	Advanced Metering Infrastructure Service Provider
API	Application Programming Interface
ARR	Average Revenue Realized
AT&C	Aggregate Technical & Commercial
BEIS	Department of Business, Energy and Industrial Strategy
BIS	Bureau of Indian Standards
BPL	Broadband Powerline
BTS	Base Transceiver Station
BU	Billion Units
C&I	Commercial and Industrial
CAGR	Compounded Annual Growth Rate
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CDMA	Code Division Multiple Access
CE	Coverage Enhancement
CEA	Central Electricity Authority
CEN	European Committee for Standardization
CENELEC	European Electrotechnical Committee for Standardization
CIM	Common Information Model
CIS	Customer Information Systems
CMC	Cell Max Coverage
COSEM	Companion Specification for Energy Management
COVID	Coronavirus Disease
CPRI	Central Power Research Institute
CPUC	Colorado Public Utilities Commission
Cr	Crore
CSP	Communication Service Providers
CTT	Conformance Test Tool
DBFOOT	Design Build Finance Own Operate Transfer
DCC	Data Communications Company
DCU	Data Concentrator Unit
DECC	Department for Energy and Climate Change
DERM	Distributed Energy Resource Management

Abbreviation	Full Form
DF	Distribution Franchisees
DI	Distributed Intelligence
Discom	Distribution Company
Discoms	Distribution Companies
DLMS	Device Language Message Specification
DMS	Distribution Management System
DMTF	Distributed Management Task Force
DMZ	Demilitarized Zone
DNO	Distribution Network Operators
DNP	Distributed Network Protocol
DOE	Department of Energy
DOS	Denial of Service
DoT	Department of Telecommunications
DSL	Digital Subscriber Line
DSO	Distribution Service Operator
DSP	Digital Service Providers
DT	Distribution Transformer
E2E	Exchange to Exchange
EESL	Energy Efficiency Services Limited
EFT	Electrical Fast Transient
EFTA	European Free Trade Association
EHPLMN	Equivalent Home Public Land Mobile Network
e-MBB	Enhanced Mobile Broadband
EMC	Electro Magnetic Compatibility
EMI	Electro Magnetic Interference
EMTL	Energy Meter Testing Laboratory
EOI	Expression of Interest
EPA	Enhanced Performance Architecture
EPRI	Electric Power Research Institute
EPS	Electric Power System
ERDA	Electrical Research and Development Association
ESD	Electro Static Discharge
ETSI	European Telecommunications Standards Institute
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FAN	Field Area Networks
FAT	Factory Acceptance Test
FIIT	Field Installation and Integration Test
FMS	Financial Management System
FY	Financial Year
GBPS	Gigabits per Second
GenCos	Generation Companies

Abbreviation	Full Form
GIS	Geographic Information System
GOI	Government of India
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GW	Gigawatt
HALT	Highly Accelerated Life Testing
HAN	Home Area Network
HES	Head End System
HLR	Home Location Register
HPPC	Haryana Power Purchase Center
HSS	Home Subscriber Server
IDEMI	Institute for Design of Electrical Measuring Instruments
IDS	Intrusion Detection Systems
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IHD	In-home Display
ILC	Inter-Laboratory Comparison
INR	Indian Rupee
IOT	Internet of Things
IPS	Intrusion Prevention Systems
IPv6	Internet Protocol version 6
IT	Information Technology
JUTA	Japan Utility Telemetering Association
KBPS	Kilobits per Second
KCP&L	Kansas City Power & Light
kHz	Kilo Hertz
KM	Kilometres
KPI	Key Performance Indicator
kVARh	Kilo Volt Amps Reactive Hours
kWh	Kilo Watt Hour
LOA	Letter of Award
LOI	Letter of Intent
LoRa	Long Range
LPWAN	Low Power Wide Area Network
LTE	Long Term Evolution
LTE-M	Long Term Evolution - Category M
M2M	Machine to Machine
MDM	Metering Data Management
MDMS	Meter Data Management System

Abbreviation	Full Form
MFA	Multifactor Authentication
MHz	Mega Hertz
MME	Mobile Management Entity
MoP	Ministry of Power
MoU	Memorandum of Understanding
MPBS	Megabits per Second
MPPKVVCL	M. P. Paschim Kshetra Vidyut Vitaran Co. Ltd
MQTT	MQ Telemetry Transport
MU	Million Unit
MW	Mega Watt
NABL	National Accreditation Board for Testing and Calibration Laboratories
NAN	Neighborhood Area Network
NB-IOT	Narrowband - Internet of Things
NBPDCL	North Bihar Power Distribution Company Limited
NIC	Network Interface Card
NIST	National Institute of Standards and Technology
NMIS	Network Management Information System
NMS	Network Management System
NOC	Network Operations Centre
Node-B	Radio base station for UMTS networks
NPRACH	Narrowband Physical Random-Access Channel
NSGM	National Smart Grid Mission
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
OFC	Optical Fiber Communications
OFGEM	Office of Gas and Electricity Markets
OMS	Outage Management System
OPA-DM	Open Mobile Alliance Device Management
OPEX	Operating Expenditure
OT	Operational Technology
PAN	Presence Across Nation
PCRF	Policy and Charging Rules Function
PDSN	Packet Data Serving Node
PEV	Plug-in Electric Vehicle
PFC	Power Finance Corporation
PGW	Packet Data Network Gateway
PHE	Public Health England
PLC	Power Line Communication
PLCC	Power-Line Carrier Communication
PLMN	Public Line Mobile Network
PoC	Proof of Concept

Abbreviation	Full Form
PV	Photovoltaic
R&D	Research and Development
RAT	Radio Access Technology
RBAC	Role-Based Access Control
RDBMS	Relational Database Management Systems
RDSS	Revamped Distribution Sector Scheme
RE	Renewable Energy
REC	Rural Electrification Corporation
RF	Radio Frequency
RFC	Request for Comments
RFP	Request for Proposal
ROI	Return on Interest
RPL	Routing Protocol for Low-Power and Lossy Networks
RPLMN	Rome Public Line Mobile Network
SAT	Site Acceptance Test
SBD	Standard Bidding Documents
SBPDCL	South Bihar Power Distribution Company Limited
SCADA	Supervisory Control and Data Acquisition
SDLC	Software Development Life Cycle
SDO	Standard Development Organization
SEP	Smart Energy Profile
SGDP	Smart Grid Demonstration Project
SGIP	Smart Grid Interoperability Panel
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SI	System Integrator
SIB2	System Information Block Type2
SLA	Service-Level Agreement
SMETS	Smart Metering Equipment Technical Specification
SMIP	Smart Meter Installation Programme
SMSO	Smart Metering System Operators
SOC	Service Operations Centre
SW	Software
Tbit/s	Terabits per Second
TCP	Transmission Control Protocol
THz	Tera Hertz
TSP	Telecommunications Service Priority
UAT	User Acceptance Test
UCAIug	UCA International Users Group
UE	User Equipment
UHBVNL	Uttar Haryana Bijli Vitran Nigam Limited

Abbreviation	Full Form
UK	United Kingdom
UL/DL	Upload/ Download
UMTS	Universal Mobile Telecommunications System
US	United States
USD	US Dollar
U-SIM	Universal Subscriber Identity Module
USTDA	United States Trade and Development Agency
UT	Union Territories
VPN	Virtual Private Networks
WAN	Wide Area Network
WBEM	Web-Based Enterprise Management
Wi-SUN	Wireless Smart Ubiquitous Network
WPC	Wireless Planning Committee

Imprint

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