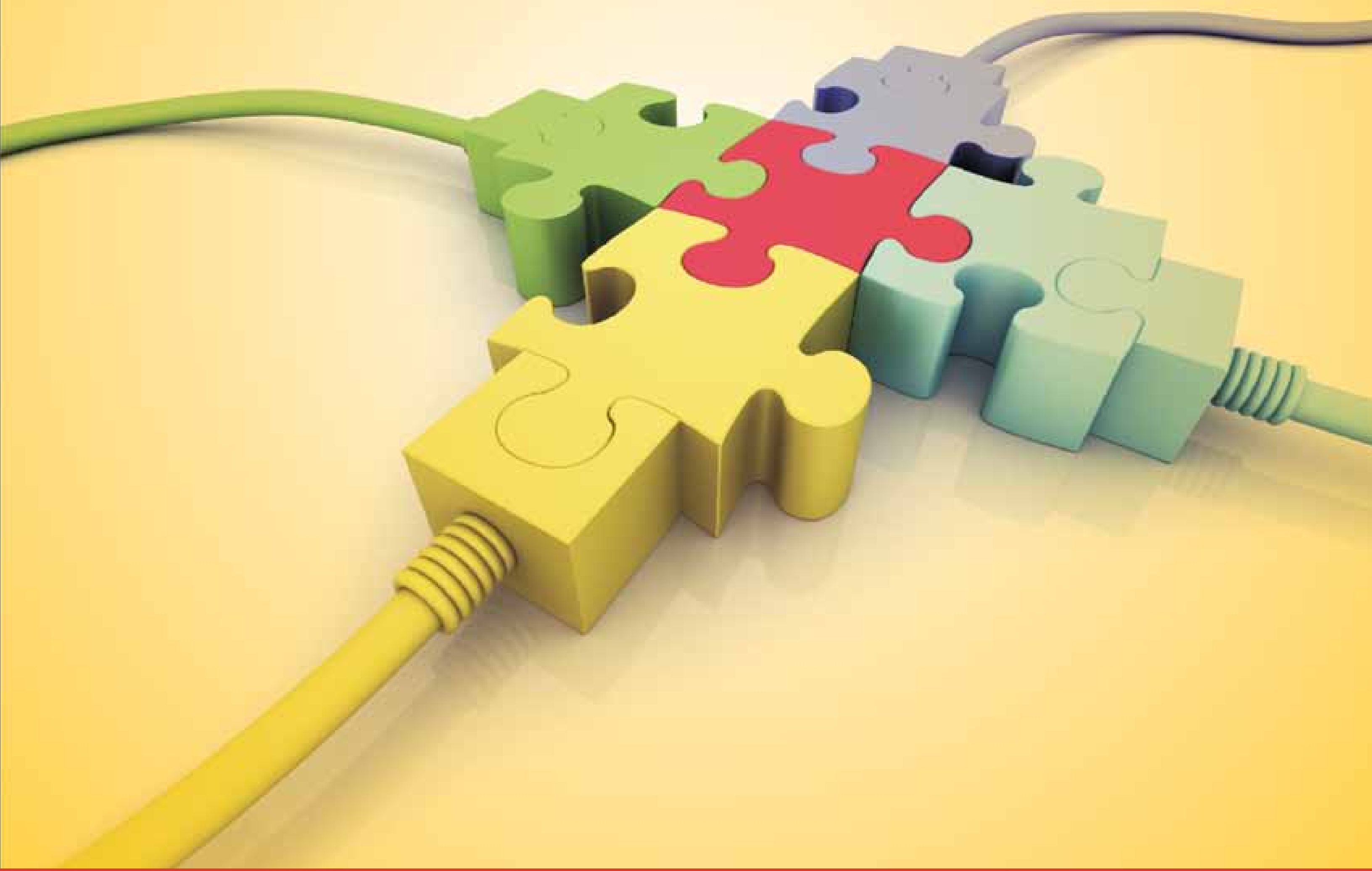
Partnership to Advance Clean Energy - Deployment (PACE - D)
Technical Assistance Program

Smart Grids: A Roadmap for Communication and Application Interoperability in India



November 2013

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ISGTF
India Smart Grid Task Force

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Acknowledgements

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EXECUTIVE SUMMARY

The Indian power sector consists of diverse participants including generation, transmission, and distribution utilities, and system and market operators. For efficient functioning of the sector, effective communication between these entities is of vital importance. The power sector can be seen as a logical information network where nodes, representing information sources and sinks, are interconnected with information links. Information travels from source nodes to destination nodes over information links across devices belonging to different systems, organizations, people, information representation formats, and communication protocols. To facilitate seamless communication between these nodes, a set of Interoperability Standards are required. The Open Knowledge Initiative defines interoperability as "the measure of ease of integration between two systems or software components to achieve a functional goal. A highly interoperable integration is one that can be easily achieved by the individual who requires the result."

This report compiles, analyses, and refines the different approaches to interoperability and standardization in the field of power distribution networks. It defines an analysis framework or "Interoperability Matrix", and uses this to categorize and compare the different existing approaches. The report breaks down the "Smart Grid Interoperability" problem into a more manageable set of individual "Interoperabilities" between a defined list of "Entities and Applications" and infers the need for open standards to drive interoperability at the interfaces between all such entities and applications. The approach undertaken for "Smart Grid Interoperability" is described below.

The first step is to define a Context Setting Framework for the Indian scenario. This framework maps out the different entities or nodes that participate in the electric power grid, and shows the communication links between the entities that are required to effectively manage three main functions of the power grid: (i) scheduling; (ii) operations; and (iii) commercial settlements. This context setting framework is then extended to include specific requirements of the modern smart grid; first, the inclusion of the consumer node into the framework with the necessary communication links; and second, an abstraction of the different nodes into common classes of entities, and then development of a matrix that aligns the entities with different grid applications[1] (e.g., advance metering response, demand response, and cyber security).

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[1] The technical term for these applications in the context of power system distribution is "application domains", and this is the term used throughout the report.

The report takes the generic definitions of "interoperability" and "smart grid" and adapts them to the Indian context, in order to develop a definition of "interoperability" that is specific to India.

The output is a set of tables (an Interoperability Matrix), which essentially provides a guideline for mapping grid applications (application domains) against the various entities involved in the power grid (entities). Such a matrix is essential for proper operation of a smart grid: it is necessary to have agreed guidelines that define the standards used for each case of interaction (for each entity, and for each application domain). The interoperability matrix has been developed for various application domains such as automated meter reading (AMR)/automated metering infrastructure (AMI), demand response (DR), data management system (DMS), network communication, wide area measurement systems (WAMS), electric transport and cyber security.

Additionally, the report details national initiatives and international experience (U.S., Japan, Ireland, Germany, China, Denmark, Canada and Australia) with respect to interoperability. A gap analysis is also carried out to bring out best practices suited to the Indian scenario.

The report concludes by providing a road map for achieving a high degree of interoperability between communication entities and applications. Key points that emerged from the analysis are as follows:

- Need for enterprise layer standards for communication of meter originated data between the head end systems (HES) and all enterprise applications.
- Additional enhancements that could be considered for communication between HES and data concentrator unit (DCU).
- Developments required to be undertaken for localized communication networks i.e. from DCU to all meters.

In addition to the above, the report also proposes institutional capacity development, and regulatory and training measures that need to be undertaken to promote communication and application interoperability.

1 BACKGROUND

This report compiles, analyzes, and refines the different approaches to interoperability and standardization in the field of power distribution networks. It defines an analysis framework or 'Interoperability Matrix', against which the different existing approaches are categorized and compared. The report takes into consideration the methods, standards, and the differing goals and objectives of the various interoperability approaches that exist in the market. The Interoperability Matrix explained later in the report provides a benchmark, conducts a comprehensive gap analysis, and assists in the development of a roadmap to help achieve the goals of the future smart grid in India.

1.1 INTEROPERABILITY

Interoperability is crucial to ensure a return on investment and prevent vendor lock-in of any distributed system consisting of different entities or applications that need to work together to achieve a common objective. Interoperability is even more important in the context of smart grids, where the sheer number of entities that need to work together can be enormous.

The Institute of Electrical and Electronics Engineers (IEEE) defines interoperability as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged". Note that this definition is about two decades old and pre-dates the concept of smart grids. A more recent definition from Open Knowledge Initiative[2] defines interoperability as "the measure of ease of integration between two systems or software components to achieve a functional goal. A highly interoperable integration is one that can be easily achieved by the individual who requires the result." However, because interoperability is an intangible quantity, its measurement poses a major challenge. Therefore, this report presents various possibilities/parameters to measure interoperability.

1.2 SMART GRID DEFINITION – U.S. DEPARTMENT OF ENERGY (DOE)

Beginning in 2005, the U.S. DOE convened seven regional workshops across the United States involving regulators, utilities, vendors, legislators, research institutions, universities, and other stakeholders to forge a common vision and scope for the smart grid. This two-year effort resulted in

[2] http://www.okiproject.org/view/html/site/oki/node/2916

the identification of the following functional characteristics of a smart grid, which now comprise the foundation of DOE's smart grid program:

- Self-healing from power disturbance events
- Enabling active participation by consumers in demand response
- Operating resiliently against physical and cyber attack
- Providing power quality for 21st century needs
- Accommodating all generation and storage options
- Enabling new products, services, and markets
- Optimizing assets and operating efficiently

The DOE's vision for a smart grid includes the use of digital technology to improve reliability, resiliency, flexibility, and efficiency (both economic and energy) of the electric delivery system. The strategy to achieve this vision hinges on activities that directly address the technical, business, and institutional challenges to realizing a smarter grid. Furthermore, the DOE states:

"Interoperability and Standards activities ensure that new devices will interoperate in a secure environment as innovative digital technologies are implemented throughout the electricity delivery system, advancing the economic and energy security of the United States. The on-going smart grid interoperability process promises to lead to flexible, uniform, and technology-neutral standards that enable innovation, improve consumer choice, and yield economies of scale. Interoperability and standards activities are not limited to technical information standards; they must be advanced in conjunction with business processes, markets and the regulatory environment."

In this chapter, a model is presented which depicts the "logical" information network of the Indian power sector. The logical information network is essentially a graph with nodes, representing information sources and sinks, which are interconnected with information links. Information travels from source nodes to destination nodes over the information links across devices belonging to different systems, organizations, people, information representation formats, and communication protocols. For example, the National Load Despatch Centre (NLDC) and Regional Load Despatch Centre (RLDC) are two nodes in the network that share information over a communication link. The details of the underlying physical network are not covered in the model. The objective of mapping this information network is to identify all the participants and the types of information that is being exchanged between these participants. The network model is as comprehensive as possible, covering all aspects of power system scheduling, operation, control, and commercial settlement practices.

1.3 PARTICIPANTS OF THE INFORMATION NETWORK

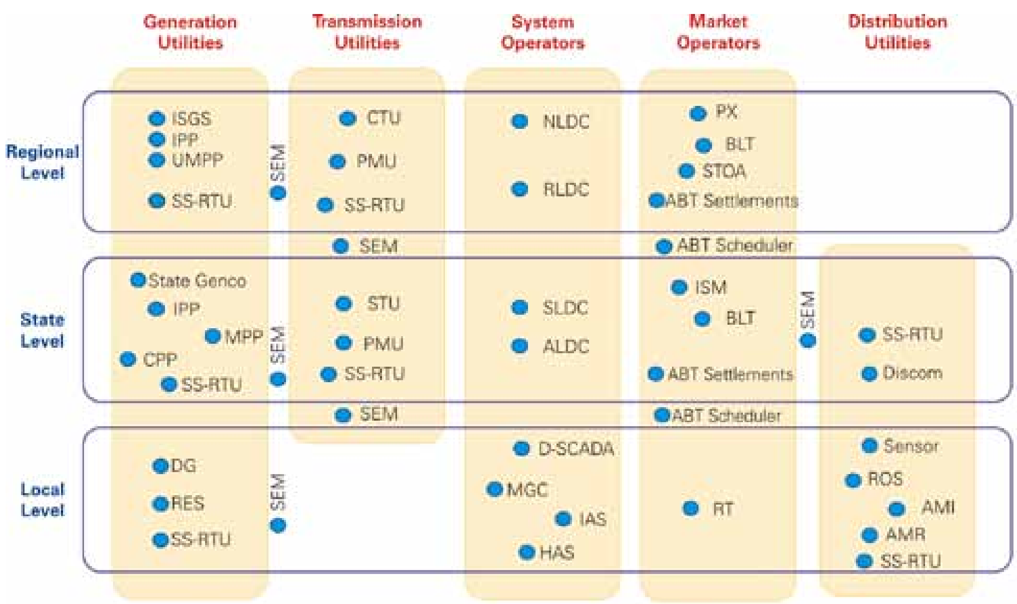
Figure 1.1 presents the nodes participating in the information network. The nodes are categorized into different kinds of utilities/agencies.

1.3.1 Generation Utilities

Generation utilities in India exist at both a regional and local level. At the regional level, there are centrally owned interstate generation stations (ISGS); for example, the NTPC, National Hydro Power Corporation (NHPC), and Nuclear Power Corporation (NPC) plants. There are private generating units at the regional level in the form of ultra-mega power plants and independent power producers. The generation companies at the regional level supply their power in the regional power pool through the central transmission utilities. Correspondingly, at the state level there are state-owned generation companies, independent power producers, merchant power producers, and captive power producers who supply their power into the state power pools via the state transmission utilities. The local level comprises all the sources of distributed generation and renewable energy.

Every generator has an associated substation where the power is stepped up and evacuated to the grid. The real-time operational information on all these generators is measured and is available at these substations via their remote terminal units (RTUs). Thus, the substation RTU forms important source nodes in the information network. The RTUs report to the control centres as shown in Figure 1.1.

Figure 1.1: Information Ecosystem of Indian Power Sector – Participating Nodes in the Information Network



Acronym: ISGS – Inter State Generating Station; UMPP – Utra Mega Power Plant; SSRTU – Substation Remote Terminal Unit; IPP – Independent Power Producer; MPP – Merchant Power Producer; CPP – Captive Power Producer; DG – Distributed Generation; RES – Renewable Energy Sources; CTU – Central Transmission Unit; PMU – Phasor Measurement Unit; SEM – Special Energy Meter for Intra and Inter State Availability Based Tariff (ABT); NLDC – National Load Despatch Centre; RLDC – Regional LDC; SLDC – State LDC; ALDC – Area LDC; DSCADA – Distribution Supervisory Control And Data Acquisition System; MGC – MicroGrid Controller; IAS – Industrial Automation System; HAS – Home Automation System; PX – Power Exchange; BLT – Bilateral Trader; STOA – Short Term Open Access; ISM – Intra State Markets; RT – Retail Trader; ROS – Remote Operated Switch; AMI – Automated Metering Infrastructure; AMR – Automated Meter Reader

1.3.2 Transmission Utilities

The transmission utilities in India are also hierarchical. Power Grid Corporation of India Limited (PGCIL) is the central transmission utility at the regional and national level, while there are independent state transmission utilities (STUs) for each state. These central transmission utilities and STUs form sources and sinks of information. The information on availability, maintenance, and scheduling of the entire transmission infrastructure is exchanged frequently between the transmission utility and its respective system operator. Similarly, real-time operational data on the entire transmission grid is obtained from substation remote terminal units (SS-RTUs). Additionally, phasor measurement units (PMUs) and phasor data concentrators (PDCs) are also being installed at various locations in India, which form a separate path for real-time phasor information reaching the control centres. The commercial settlements in India are done on the basis of data retrieved weekly from the special energy meters installed at the interfaces of the constituent power networks. All of these information nodes are depicted in Figure 1.1.

1.3.3 System Operators

In India, the unified load dispatch and communications scheme is used as a structure for organizational coordination and to monitor, operate, and control the regional power grid in a unified, consistent, and coordinated manner. The unified load dispatch and communications scheme has improved grid reliability by ensuring data availability, visibility, and transparency. Under the unified load dispatch and communications scheme, the entire power system is operated by a hierarchy of control centres with well-defined roles and responsibilities assigned to each level of system operation. Control centres form the major part of system operation, participating heavily in the information network.

1.3.4 Market Operators

The role of market operators is gradually increasing in India. Bilateral power traders and power exchanges are involved in carrying out power market operations. These markets participate in the information network as shown in Figure 1.1. Participation occurs namely through: energy only, physical delivery, voluntary participation, double-sided bidding, uniform pricing, day-ahead exchange, hourly bids, congestion management by market splitting, and multiple exchanges – competition amongst exchanges.

1.3.5 Distribution Utilities

Following the restructuring of the Indian State Electricity Boards, many public and private distribution utilities have emerged in India. Distribution utilities are at the forefront of advancing the role of information technology in their operations and are already reaping the benefits of lower losses, faster outage responses, higher reliability, and higher customer satisfaction. Distribution utilities also need a well-connected interoperable network to achieve remote operation capability and automated billing via deploying AMI and AMR.

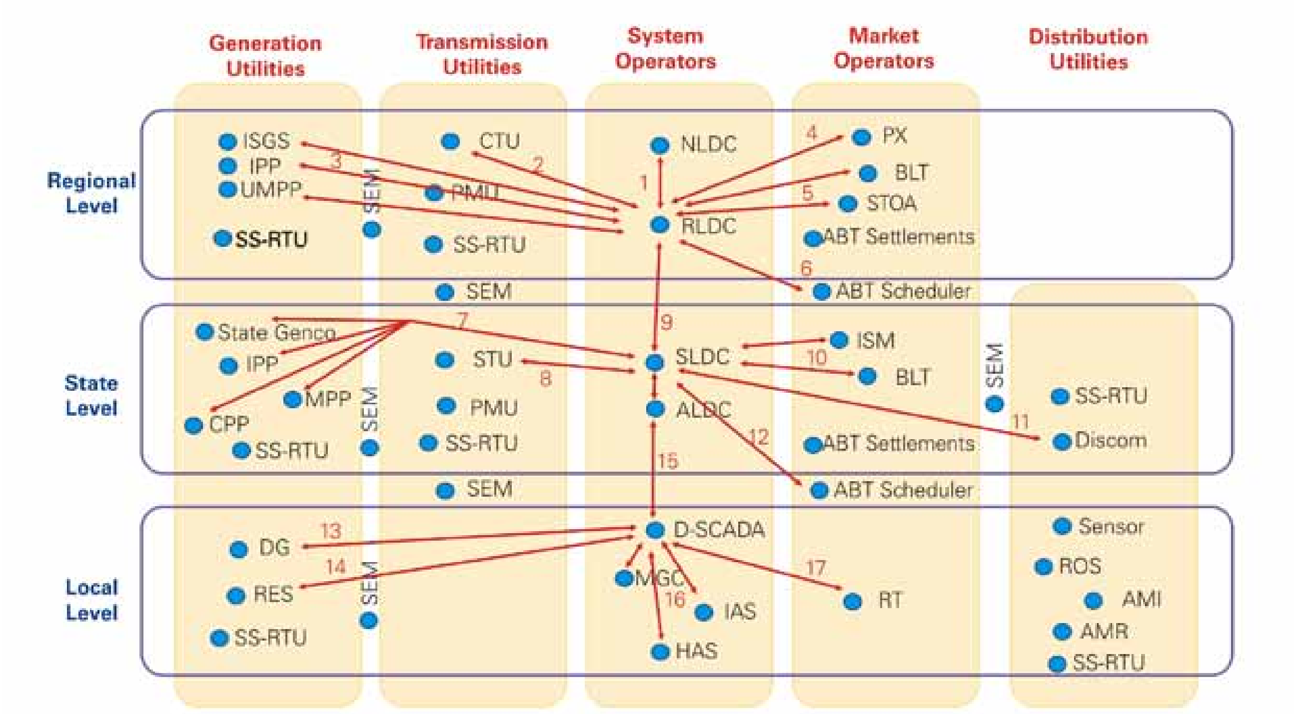
1.4 INFORMATION NETWORKS

This chapter connects the nodes described above to form data flow diagrams. All the data exchanges have been broadly classified into three categories, based on the content being exchanged, as defined below.

1.4.1 Scheduling Data Flow

Scheduling data refers to data that is exchanged prior to the transfer of electrical energy and comprises information about the amount of power to be generated, transmitted, and consumed by all the participants of the power network. The schedule is typically done a day before the actual electricity transfer, referred as (D-1) or before. In India, the schedule is ultimately derived out of superposition of various contracts, such as long-term open access, short-term open access, availability-based tariff mechanisms power purchase agreements, bilateral transactions, and power exchange transactions. The nodal agency at each of the levels (regional, state, and local), is responsible for preparation of the schedule. The scheduling data flow network is shown in Figure 1.2.

Figure 1.2: Information Ecosystem of Indian Power Sector – Scheduling Data Flow



1.4.2 Operational Data Flow

Operational data refers to data that is exchanged during the transfer of electrical energy and comprises information about the amount of power actually generated, transmitted, and consumed by all the participants of the power network. It is typically measured by instruments in substations and transmitted by RTU during the transfer event, and thus described as "real-time" data. The direction of operational data is bottom-up, flowing to higher levels of hierarchy, while being collected, aggregated, and summarized at each level. The operational data flow network is shown in Figure 1.3.

1.4.3 Commercial Data Flow

Commercial data refers to data that is exchanged after the transfer of electrical energy that allows calculation and dissemination of information on commercial settlements to all participants of the power network. Commercial settlements are usually carried out the day after the actual electricity transfer, referred as (D+1) or later. The commercial data flow network is shown in Figure 1.4.

Figure 1.3: Information Ecosystem of Indian Power Sector – Operational Data Flow

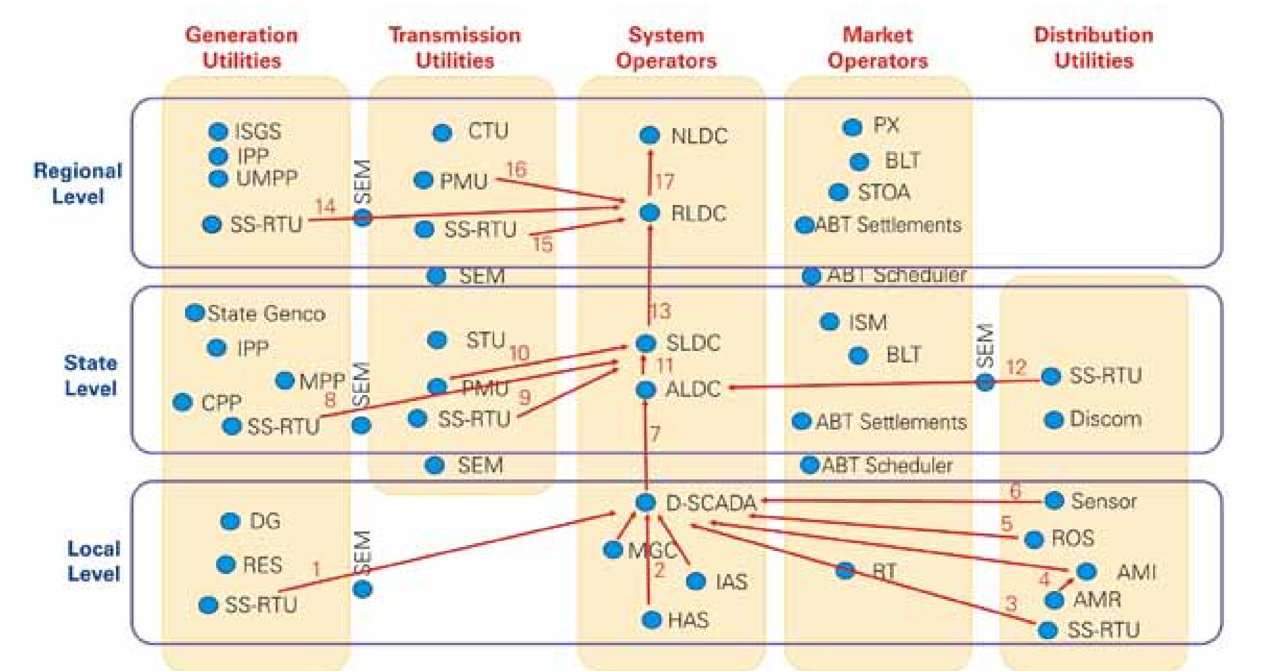
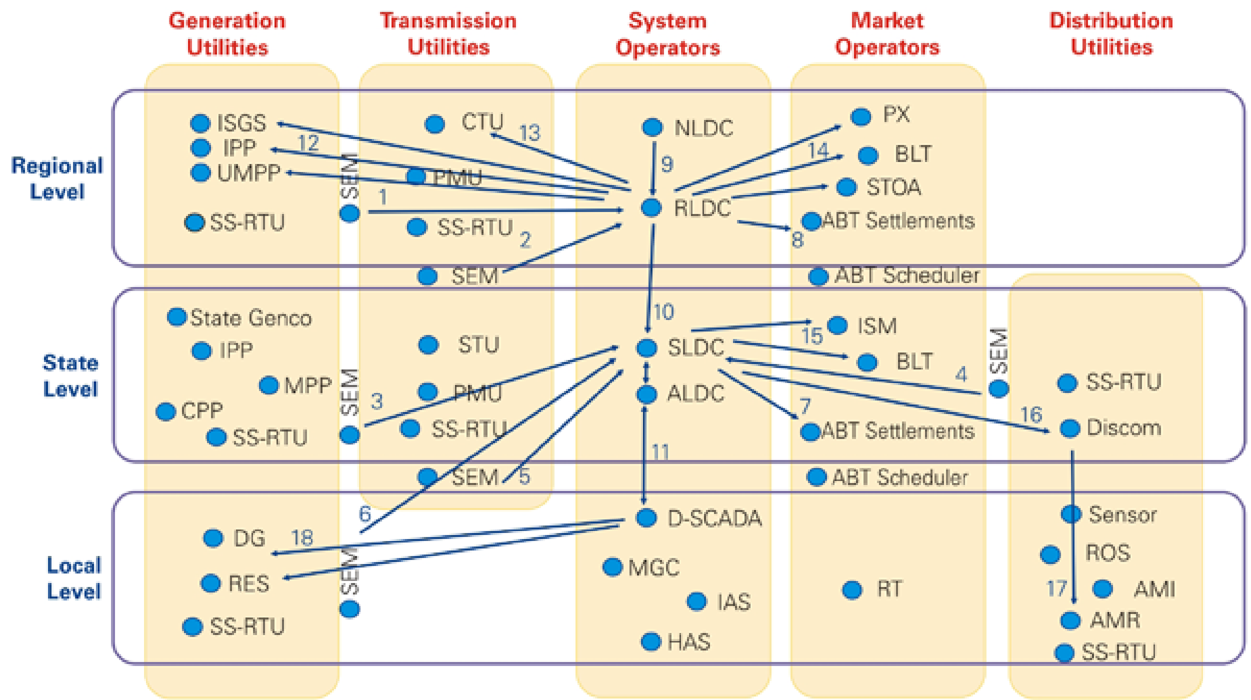


Figure 1.4: Information Ecosystem of Indian Power Sector – Commercial Data Flow



1.5 OBSERVATIONS

At an organization level, the roles and responsibilities of India's various utilities are well defined. This creates a hierarchical network of utilities involved in operating the power network which communicate over the information network. Every link in the communication is backed by a specific business context and reason for the communication. Following the restructuring of the power sector and under the active oversight of India's regulatory agencies, the public and private utilities are evolving in a dynamic environment. Based on the data flow networks presented above, it is generally understood that information flow is radial tree-like in structure.

Hereafter, it is assumed that the context setting framework described in this chapter is representative of the entities that collaborate to function as a smart grid. An analysis of the business case context for each communication link will drive the specific need for interoperability of the function performed by that link.

Applying the definitions of "interoperability" and "smart grid" to the Context Setting Framework, yields the term "Smart Grid Interoperability" and its definition: "the measure of ease of integration between all the defined pairs of entities and applications arising from the Indian Utility Context where a communication/integration link is shown between the two entities in the pair for achieving the functional goal of the shown link[3]".

To create the interoperability matrix, the following activities are performed to extend and align the Context Setting Framework for the purpose of this report:

a. The Context Setting Framework described earlier is comprehensive in so far as the utility/company nodes are identified. However, the smart grid brings new players into the equation that would not be normally covered; namely the consumer node and intra-consumer premise communicating nodes. Some classes of field-placed equipment like data concentrators and distribution transformer monitors are also not covered. An extension of the Context Setting Framework that includes these entities is required and is done in the next chapter.

b. An abstraction of the class of entity that is involved in the information flow can be made out of the Context Setting Framework, which provides the categorization necessary to apply the same inferences/suggested solutions to the same class of communication. For example, the context setting shows a number of different links for the same class of communication (e.g. "SS-RTU to Control Centre"). The nature of the communication makes it possible to apply the same standards for interoperability to the entire class. An exercise to "abstract" similar classes of entities to apply similar solutions for interoperability is required and performed in the following section.

The report goes on to abstract all the classes of entities (as described earlier), adds the missing classes of entities, and defines a reference matrix that takes into consideration:

1. The different classes of entities that communicate with each other.

2. The applications within these entities that communicate with each other – allied to the business context/application domain for the communication.

[3] AF Mercados EMI definition

2 INTEROPERABILITY ANALYSIS FRAMEWORK

This chapter presents a framework to analyze the requirements and current approaches to smart grid interoperability. The framework provides an essential structure for comparing different initiatives, providing benchmarks and conducting a comprehensive gap analysis.

The following sections list international standards against this framework and discuss their applicability and effectiveness.

2.1 INTEROPERABILITY MATRIX – ENTITIES AND COMMUNICATION

Interoperable systems require exquisite attention to detail. For the smart grid to work successfully, communications, management, security, and application execution messages must all be interpreted and executed by the interoperating equipment. Hence, interoperability should be achieved at the interfaces of different entities, while leaving the internal implementation of the monitoring and control mechanisms to each individual entity themselves. This chapter lists the different categories of entities that define the interfaces and participate in the distribution of energy using advanced smart grids. All the different entities are categorized at a suitable level of abstraction. The higher the level of abstraction, the better the modelling aspects brought out. The lower the level of abstraction, the more the modelling approaches real world conditions. This concept of modelling has been explained through an example in the following paragraph.

Communications between substations and the control centre are an important link with significant interoperability requirements. Substations and control centres are thus entities that can be considered as suitable entries in the interoperable entities list. However, at a deeper level of examination, an analysis of the communication links and devices within the substation presents two distinct communication buses: the station bus and the process bus. Enumerating these entities as "intra-substation-communication" would also be considered necessary from an interoperability point of view. Going further, within the station bus are a number of possible entities like disturbance fault recorders, protection relays, and bay controllers. However impact of interoperability at this level of granularity may not be worth the effort to quantify and analyse. Thus, extending the granularity of the analysis approaches the real state of the grid but makes it more complex to define interoperability requirements, as well as less rewarding since the interoperability (or lack of) within a unit like a substation bus has a smaller impact. Cutting off the level of granularity to a "manageable" level achieves the maximum impact to interoperability with the minimum effort. The expected result is a matrix of tangible entities that communicate with each other over distinct and identified interfaces to achieve the requirements of the smart grid at a suitable level of abstraction. Table 2.1 lists the entities identified as part of this exercise.

Table 2.1: Communicable Entity Classes for the Smart Grid

S. No.	Entity Class	Description
1	Enterprise System	Class of entities referring to enterprise layer applications that typically reside above the operational/data center level. Includes applications like enterprise resource planning (ERP), customer relationship management (CRM), meter data management systems (MDMS), billing systems, trouble-call systems, asset management systems, etc.
2	Central System	Class of entities referring to operational/data centers like energy management system (EMS)/distribution management system (DMS), supervisory control and data acquisition (SCADA) control centers, load despatch centers (LDCs), metering data centers, etc.
3	Substation	Electrical substations in generation, transmission, sub-transmission and distribution domains that includes SCADA and automation network.
4	Field Equipment	Field-located equipment like pole-top RTUs, distribution transformer meters and RTUs, metering data concentrators, etc.
5	Distributed Energy Resource (DER) Centers	Locations providing distributed energy resources such as captive generation in industries, solar and wind plants, fuel cells, local distributed generation resources, and plug-in hybrid electric vehicle (PHEV) networks.
6	Market Operations	Centers providing energy scheduling, trading and market operations.
7	Consumer	Consumer premises – AMR, demand response (DR)/demand side management, home area network (HAN).

The requirements of the smart grid calls for communication between various combinations of entities, as described in Table 2.1. To implement interoperability, it is required to enumerate the communication links between the different entities, as shown in Table 2.2.

Table 2.2: Enumerated Interface Links between the Communicating Entities

Link	Communicating Entities	Description
1	Intra Substation	Communication within the substation. Typically further classified into station bus communication (bay level functions of protection and control) and process bus communication (monitoring and control of Input/Output (IO) and sharing of current transformer (CT)/voltage transformer (VT) samples).
2	Inter Substation	Sending protection events and triggers, samples, phasors and process control data between substations. Applications typically cover extended protection schemes (special protection schemes) and WAMS.
3	Field Equipment	Represents communication originating from/destined to equipment like pole-top RTUs and data concentrators mounted in the field.
4	Substation – Central System	Communication between control and/or data centers like EMS/DMS/Metering centers and substations (typically to the RTU within the substation). Applications are typically SCADA (monitoring and control) for EMS/DMS/load despatch center (LDC)/remedial action scheme (RMS)/metering operation service (MOS) operations as well as metering (feeder metering and boundary metering).
5	Inter Central System	Communication between operational/data centers. Includes SCADA-to-SCADA communications between different utility control centers for scheduling, execution control and commercial settlements. Data includes market operations data, fault data for contingency analysis and emergency operations, metering data for monitoring and settlements across companies, metering data for state estimation and load analysis, etc. Communication may also be between different levels within the same utility, for example master control centers and sub control centers.
6	Central System – Market/ DER	This includes communication between utility control centers and energy service providers and energy market participants like real-time pricing negotiations, aggregated customer metering and settlements. May provide data later used for market operations. This environment includes the communications between distributed energy resources (DER) and the organizations that must monitor and operate them.

Link	Communicating Entities	Description
7	Central System – Enterprise System	Utility control centers require providing aggregated data and events to upstream enterprise applications like CRM/ Trouble call systems, asset management and billing systems. Distribution utilities require to pass on AMR data to enterprise levels for MDMS, billing systems and Load Management/ Demand Response, etc.
8	Central System – Consumer	Communications to the smart meter or the smart home gateway from the utility data center. Includes meter readings, billing data, information messages, tariff information, real time pricing/critical peak pricing program information and participation.
9	Intra Consumer Premises	Communications within the HAN between the smart meters, smart home gateway, in-home display and smart appliances/ smart plugs. PHEV charging infrastructure communications are also considered here.

2.2 INTEROPERABILITY MATRIX – APPLICATIONS AND COMMUNICATIONS

The table of communication links between collaborating entities of the smart grid provides one perspective for breaking down the "Smart Grid Interoperability" problem into a number of manageable entities. However, this does not cover the variances observable in the characteristics of the same communication link when applied to different business use cases from different application domains.

This section defines another parallel matrix of entities that seek interoperability at their interfaces; the core difference from the first being that the entities are discovered from an application domain perspective. These entities do not refer to tangible physical entities like substations, but refer instead to applications like fault passage indication and demand response. To extract the different possible candidates to include in our interoperability framework, we elect to approach this from application domains. For example, well-recognized application domains like AMR, AMI, and demand response provide a number of application use cases that will require to be standardized or made interoperable.

AMR/AMI domain has use cases like meter reading, meter connection/disconnection (related to bill payment/non-payment), prepayment, data concentration, and interval-data capture and storage. On the other hand, demand response will cover demand monitoring, concentration and aggregation, load analysis, disconnect/connect (related to peak load management, not billing), etc.

These use cases lead to requirements for interaction and communication between application entities and bring out more detail to the interoperability matrix from the previous section. For example, while both application domains call for communication between the data center and the meter, the use case is different in terms of function and performance requirements and therefore may call for different protocols and standards to be applied as appropriate.

The final aim is to list applicable standards against this detailed matrix for each use case and pair of corresponding entities.

2.2.1 Application Domains

- AMR/AMI
- Demand Response
- DER management
- DMS
- Electric Transport
- Cyber Security
- Wide Area Monitoring Systems/ Situational Awareness

2.3 INTEROPERABILITY MATRIX – MAPPING BETWEEN ENTITIES AND APPLICATION DOMAINS

This section maps the two approaches listed above to provide a comprehensive matrix that defines the communicating entities along one axis and the application domain use cases along the other. The content of the matrix will be the standards applicable and suitable for the specified combinations.

2.3.1 Considerations for India

Indian standards are created and maintained by the Bureau of Indian Standards (BIS) and Indian utilities are expected to prefer Indian Standards where available. The BIS in turn has a World Trade Organization (WTO)-based agreement with the International Electrotechnical Commission (IEC) standards body wherein they are aligned with IEC standards for use in India. BIS is the national body that hosts the National Mirror Committees of the individual technical committees (TCs) of IEC and can adopt/adapt IEC standards for use in India. This predominantly aligns India with IEC standards internationally. Lack of such arrangements with other standards organizations (IEEE, for example) prevents India from exploring other available and popular standards worldwide for copyright reasons. The Interoperability matrices developed in this chapter reflects this reality.

In 2011, IEEE Standards Association (IEEE-SA), a globally recognized standards-setting body within IEEE, launched the "IEEE P2030™ Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS) and End-Use Applications and

Loads", in India. IEEE-SA's India Standards Interest Group (SIG) has committed to working closely with the IEEE P2030 Working Group to introduce interoperability standards in India for faster implementation of smart grids.

2.3.2 Interoperability Matrix for AMR/AMI

Table 2.3 lists the matrix for the AMR/AMI Application Domain mapped across the different communicating entities interfaces. The end-to-end use cases considered for AMI include:

1. Meter Reading

Meter reading involves transferring instantaneous values and historic time-stamped values from the meter to the head-end system (HES). The historic values are normally the interval load profile (typically sampled at frequencies of 15 minutes in India), daily profiles (also called midnight readings in India), billing profiles, and event logs. Daily profiles are expected to be read and updated in 24-hour cycles and billing data is expected to be read within a few days after the end of each billing period. Interval load profiles can be read at every interval, and also on hourly, daily, weekly, or monthly basis. Instantaneous values are read more for monitoring purposes and may consist of power frequency values, voltages/currents, and meter status registers. These may be read in seconds or minutes or not read at all. The instantaneous values, however, may help identify energy-efficient devices and replace the inefficient devices.

The meter-reading process may be directly from the HES to the meter, or it may use an intermediate data concentrator network. There are a number of choices for meter reading standards depending on the mode and nature of the networking chosen.

2. Connect/Disconnect

Connect/disconnect signals require to be sent from the HES to the meter to handle peak management, ripple-load-shedding, and customer issues. These are expected to be triggered from an enterprise-level application like a load management system (peak load handling) or an MDMS (customer payments/billing related). These communications are triggered by specific events or needs. Transporting this signal to the meter is ideally handled by the same standard chosen for meter reading to avoid the need for multiple communication paths (connections) to the meter.

3. Time-of-Use (TOU) Metering

TOU metering refers to the meter's ability to record energy consumption not just for the full billing period, but individually in different time-slots which can accrue energy to different registers based on a tariff setting. TOU metering is a vital requirement for the smart grid since it is the basis for providing commercial incentives to customers to move their loads to different times lots, in line with the utility's ability to dispatch power. The meter standards chosen need to be able to support this function.

4. Real-Time Pricing Signals

The future smart grid is expected to make available power from different sources (sellers) to consumers and enable choice based on service quality, rates, etc. This requires the ability for utilities to send real-time price signals to the meter whereby a smart meter (or a smart home gateway connected to the meter) may allow programming the consumer's preferences or cost limits to automatically switch the supply in favour of the most appropriate source. The dependency of this requirement on the meter communication standard is minimal since it only involves the ability to write data to the meter. Most meter standards already allow that.

5. Event Notification

Notifying meter-localized events of interest to the utility is a value-adding requirement of the smart grid. This enables utilities to be notified of meter tamper events, power demand threshold crossings, fault detection, power quality events, meter errors and diagnostic events, and power failures. AMI standards need to be able to support this requirement to be considered part of this interoperability matrix.

6. Home Area Network (HAN) Communications

HAN provides utilities the ideal opportunity to offer a value-added service. Integrating smart grid systems with home area networks empowers consumers to control their home energy consumption. The smart grid envisages significant participation among consumers and this requires an increased level of communication with the consumer. In addition to billing and energy consumption data, a utility may need to send pricing signals, peak pricing events (CPP schemes for example), information soliciting enrolment in peak load shaving schemes, incentive information, load patterns and regular announcements like planned down time. The AMI matrix needs to consider the technologies available for such HAN communications as shown in Table 2.3.

Table 2.3: Interoperability Matrix for AMR/AMI

Link (Interface Number)	Standards for AMR/AMI			
Intra Substation (1)	Substation Metering – to Substation gateway/HES			
	International Electrotechnical Commission (IEC) 62056 / Device Language Messaging System (DLMS) /Companion Specification for Energy Metering (COSEM)	Indian Standards (IS)15959	Modbus	
Inter Substation (2)				
Field Equipment (3)	Pole top Data Concentrator Unit (DCU), Distribution Transformer (DT) Mounted DCU - Upstream			
	IEC 62056 / DLMS/COSEM	IS15959		
	Pole top DCU, DT Mounted DCU - Downstream			
	Zigbee Smart Energy Profile (SEP) v1.0/v2.0	IEC 62056 / G3 Power Line Communication (PLC)	IEC 62056 / Prime PLC	IEEE P1901
	IEC 62056 / IEC 61334	EN 13757		
Substation – Central System (4)	Substation Gateway - upstream			
	IEC 60870-5-104	IEC 62056 / IS15959		
Inter Central System (5)	Boundary Metering data exchange			
	IEC 62056 / IS 15959			
Central System – Market/DER (6)	Energy Market Communications			
	IEC/TR 62325			
Central System – Enterprise System (7)	HES – to – MDMS/Billing/ERP etc.			
	IEC 61968 / IEC 61970	Generic Webservices	IEC 62056	
Central System – Consumer (8)	HES – Meter/Smart Home Gateway			
	IEC 62056	IS 15959		
Intra Consumer Premise (9)	HAN Communications			
	Zigbee SEP v1.0/v2.0	IEC 62056 / G3 PLC / Prime PLC	IEC 62056 / RS232 / Home LAN	IEEE P1901
Link-Independent Standards	Security			
	IEC 62351			
	Electricity Meter Specific Standards			
	SG-AMI 1-2009	IS 13779	IS 14697	

2.3.3 Interoperability Matrix for Demand Response

Demand response (DR) systems are becoming a critical need of the modern smart grid and this need is exacerbated in power-deficit countries like India where there is simply not enough generation to meet the peak demand. DR is considered significant for economical operation so that generation capacity can be more aligned towards the base load and capacity is not unnecessarily idle during non-peak conditions. In today's eco-aware environment, carbon footprints provide a quantifiable measure of the degradation to the ecology caused by energy demand and the need to minimize generation plants to reduce carbon emissions is of growing importance.

Demand response systems are fairly standard across the world. It involves a load management system (LMS) to keep track of actual loads (and project load requirements from historic data), a consumer sign-up mechanism to grant permission to the utility to shed non-critical loads (regulatory frameworks), and a communication network that can deliver the DR signal on event days. Increasingly, the role of DR aggregators is coming into play where the aggregator can represent the available DR capacity of a group of consumers and intermediate between the consumers and the utility (for a commercial payoff or commission). The relevant interoperability matrix for DR is shown in Table 2.4.

Table 2.4: Interoperability Matrix for Demand Response and Consumer Energy Efficiency

Link (Interface Number)	Standards for Demand Response and Consumer Energy Efficiency			
Intra Substation (1)	Substation RTU Feeder based Demand monitoring			
	IEC 60870-5-104/101	IEC 61850	Modbus	DNP3
Inter Substation (2)				
Field Equipment (3)	DT Mounted Demand Monitoring/Metering			
	IEC 60870-5-104/101	IEC 62056		
Substation – Central System (4)	Substation RTU Feeder based Demand monitoring			
	IEC 60870-5-104/101	IEC 61850-90-2	Modbus	DNP3
Inter Central System (5)				
Central System – DER (6)	DER Integration to meet Demand Peak			
	IEC-60870-5-104			

Link (Interface Number)	Standards for Demand Response and Consumer Energy Efficiency			
Central System – Enterprise System (7)	DR Aggregation and Load Management			
	IEC 61968 / IEC 61970			
Central System – Consumer (8)				
Intra Consumer Premise (9)				
Area-Independent Standards	Security			
	IEC 62351			
	DER and Microgrid			
	IEC/TS 62257	IEC 60904		

2.3.4 Interoperability Matrix for Distribution Management Systems

Distribution Management Systems have been more impacted by the evolution of the smart grid than the higher level EMS solutions. This is in keeping with the fact that a large number of features of the smart grid depend on consumer participation and the most scope for optimization is within the consumer metering space. However, if AMI-related requirements from the distribution utility are eliminated, what is left are the conventional use cases of a Distribution Management Systems:

1. Distribution Load Flow
2. Volt/Var (volt-ampere reactive) Control
3. Distribution Load Forecasting
4. Fault Location, Identification & Service Restoration (FLISR)
5. Load Shedding
6. Operations Monitoring
7. Outage Management System
8. Optimal Feeder Reconfiguration
9. Distribution Security Analysis
10. Distribution System State Estimation (DSSE)

Table 2.5 lists the interoperability matrix for Distribution Management Systems.

Table 2.5: Interoperability Matrix for Distribution Management Systems

Link (Interface Number)	Standards for Distribution Grid Management			
Intra Substation (1)	Substation Process bus			
	IEC 61850-9-2			
	Substation Station bus			
	IEC 61850	IEC 60870-5-103	Modbus	IEEE 1379-2000
	Disturbance Data – oscillography files			
	IEEE C37.111 - 1999			
Inter Substation (2)	Synchronized (Special) Protection Schemes			
	IEC-61850-90-5	IEC-61850	IEC-60870-5-104 / IEC-60870-5-103	Modbus / DNP3
Field Equipment (3)	Field Distribution Automation (DA) – Sectionalizer/Totalizer monitoring and control			
	IEC-60870-5-104	Modbus / DNP3		
	Fault Passage Indication / Fault Location / FLISR			
	IEC-60870-5-104	Modbus / DNP3		
	Renewable Generation			
	IEC 61400-25			
Substation – Central System (4)	Substation Gateway – upstream to control center			
	IEC 60870-5-104	IEC-61850-90-2	DNP3	
Inter Central System (5)	Data exchange for Scheduling, Execution and Settlements			
	IEC 60870-6 (ICCP/TASE.2)	IEC-60870-5-104	Modbus	
Central System – DER (6)	Energy Market Communications			
	IEC/TR 62325	IEC 61968 / IEC 61970		
Central System – Enterprise System (7)	EMS			
	IEC 61968 / IEC 61970			
Central System – Consumer (8)				
Intra Consumer Premise (9)				
	Area-Independent Standards	Security		
	IEC 62351			

2.3.5 Interoperability Matrix for Network Communications

This section does not represent an actual business context or use case, but is necessary to outline the different technologies available for networked communication. It was initially believed that lower-layer communication technologies are independent of the higher-layer application standards that would be derived from different use-cases. However, practice has shown that a number of popular application layer standards have narrowly defined choices for lower-layer communication technologies. A listing of the different lower-layer carrier technologies and a comparison/ranking across them is desirable for their interoperability impact. The interoperability matrix is shown in Table 2.6.

For evaluation purposes, a representative data rate comparison for the different technologies is given below:

1. Transmission control protocol(TCP)\internet protocol (IP)local area network (LAN) on Cu/FO lines – 10/100/1000 Mbps
2. RS 485/232/422 – Upto 115 kbps
3. TCP\IP-RS232 on public switched telephone network (PSTN) modems – 256kbps
4. TCP\IP-RS232 on cellular 2G,3G,4G – 2G (upto 80 – 128 kbps), 3G (200kbps to theoretically 8 Mbps), 4G (theoretically upto 100s of Mbps but in reality offering upto 40 Mbps)
5. TCP\IP wide area network (WAN) on leased lines (Cu/FO) – 2/4 Mbps
6. TCP\IP WAN on very small aperture terminal (VSAT) – 56 kbps to 2/4 Mbps
7. Prime / IEEE P1901.1 / G3 PLC – Prime (125kbps), G3 (200+ kbps), IEEE 1901.2 (200+ kbps)
8. Zigbee 2.4GHz radio frequency (RF) – Upto 250 kbps and ranges upto a few hundred meters
9. SubGHz RF – Upto 400 kbps with ranges upto a kilometer
10. IPV6/RPL/6LoWPAN (Low-rate Wireless Personal Area Network)on RF – depending on the RF carrier frequency, same as 8 or 9 above.

Table 2.6: Interoperability Matrix for Network Communications

Link (Interface Number)	Standards for Communication Networks			
Intra Substation (1)	Substation Process bus			
	Ethernet	RS-485/232/422		
	Substation Station bus			
	TCP\IP on Ethernet	RS-485/232/422		
Inter Substation (2)	Inter substation Communication Links			
	TCP\IP-RS232 on PSTN	TCP\IP – RS232 on 2G, 3G, 4G	TCP\IP – RS232 on Optic Fibre	
Field Equipment (3)	Field/Pole-top equipment Communication Links			
	TCP\IP-RS232 on PSTN	TCP\IP-RS232 on 2G, 3G, 4G	IEEE P1901.1 / G3 PLC	TCP\IP – RS232 on Optic Fibre

Link (Interface Number)	Standards for Distribution Grid Management			
Substation – Central System (4)	Substation Gateway – upstream to control center			
	TCP\IP-RS232 on PSTN	TCP\IP-RS232 on 2G, 3G, 4G	TCP\IP – RS232 on Optic Fibre	TCP\IP – VSAT
Inter Central System (5)	Inter Control Centers / Data Centers			
	TCP\IP – RS232 on Optic Fibre	TCP\IP – VSAT		
Central System – DER (6)	Market Operations / DER Integration			
	TCP\IP-RS232 on PSTN	TCP\IP-RS232 on 2G, 3G, 4G		
Central System – Enterprise System (7)	Intra Control Center / Data center			
	TCP\IP on Ethernet LAN			
Central System – Consumer (8)	WAN Communications			
	TCP\IP-RS232 on PSTN	TCP\IP-RS232 on 2G, 3G, 4G		
	NAN Communications			
	ZigbeeSubGHz	Prime PLC / G3 PLC	IEEE P1901.1	RPL/IPV6 on 6LowPAN/IEEE 802.15.4 g and e.
Intra Consumer Premise (9)	HAN Communications			
	Zigbee 2.4GHz	Prime PLC / G3 PLC	IEEE P1901.1 / IEC 61334 / IEC 12139	RS 232/485 Ethernet LAN
Area-Independent Standards	General Considerations			
	IEC/TS 61085			
	Network Management			
	SNMP v3	DMTF, CIM, WBEM, ANSI INCITS 438-2008, netconf, STD62, CMIP/CMIS		
	HAN/NAN Carrier Layers			
	IEEE 802.15.4	IEEE 802.15.4 g/e		

2.3.6 Interoperability Matrix for Wide Area Situational Awareness

Wide Area Monitoring Systems (WAMS, Situational Awareness) are currently being touted as the definitive preventive action to anticipate and prevent rolling blackouts. These blackouts are caused by grid collapses triggered by frequency instability, angle instability, and oscillations. Post mortem analysis of past blackouts has shown that phasor measurement data can predict a collapse well ahead of an event and if monitored, preventive actions could be taken in time to "island" the problem area.

WAMS technology relies on the synchronized measurements of phase angles of voltages and currents (measured by phasor measurement units (PMUs)) at different locations over a wide-geographic range (usually in a transmission network) being brought to a central location (usually over a hierarchy of concentrators called phasor data concentrator (PDCs) in near real-time, to provide rich analytics on the stability of the grid and detect issues before they occur. Table 2.7 lists out interoperability matrix for WAMS.

Table 2.7: Interoperability Matrix for WAMS

Link (Interface Number)	Standards for Wide Area Situational Awareness			
Intra Substation (1)	Substation Station bus PMU to Station PDC			
	IEEE C37.118.2	IEC 61850-90-5		
Inter Substation (2)				
Field Equipment (3)	PMU to PDC			
	IEEE C37.118.2	IEC 61850-90-5		
Substation – Central System (4)	Station PDC to Central PDC			
	IEEE C37.118.2	IEC 61850-90-5		
Inter Central System (5)	Inter Regional Center PDCs			
	IEEE C37.118.2	IEC 61850-90-5		
Central System – DER (6)				
Central System – Enterprise System (7)	Central PDC to Super PDC			
	IEEE C37.118.2	IEC 61850-90-5		
Central System – Consumer (8)				
Intra Consumer Premise (9)				
Area-Independent Standards	PMU Measurement Standards			
	IEEE C37.118.1	IEEE 1344		

2.3.7 Interoperability Matrix for Electric Transport

Electric vehicles represent a major use of electric power. An electric vehicle is estimated to use about as much energy as a typical house. In the U.S., the Smart Grid Interoperability Panel (SGIP) initially recommended three key standards for electric vehicles:

- The first standard concerns the physical connector (includes dimensions, functions, and configurations of the vehicle inlet and mating conductor) – This is already in use by the Nissan LEAF and the Chevrolet VOLT.

- The second and third standards concern the electronic information between the vehicle and the grid (examples include: identity/owner of the specific vehicle, location of the charging station, amount of electricity used, and the price of TOU electricity).

The standards-setting organizations (SSOs) and the Priority Action Plan 11 (PAP 11: Common Object Models for Electric Transportation) working group in the U.S. are also dealing with smart grid standards for electric vehicles. The Society of Automotive Engineers (SAE) International, which is a global association of more than 128,000 engineers and related technical experts in the aerospace, automotive, and commercial-vehicle industries, is playing a lead role in setting electric vehicles standards, including:

- SAE J1772 Surface Vehicle Recommended Practice
- SAE J2836 (New) - Utility programs, Off-board charger communications, Reverse Energy Flow, Diagnostics, Customer and HAN
- SAE J2847 (New) – Detail messages for advanced features
- SAE J2931 Protocol (Requirements – General requirements, control pilot, PLC over Mains, Wireless, Physical communication standards -defines how to send messages
- SAE Practice J2953/2 establishes the test procedures to ensure the interoperability of Plug-In Vehicles (PEV) and electric vehicle supply equipment (EVSE) for multiple suppliers.
- ISO/ IEC 15118-4/5 defines Vehicle to Grid Communication Interface
- J1772 Vehicle Conductive Charge Coupler - Tighten up standard to include interoperability between multiple EVSE and PEV suppliers, Add DC (level 2 – up to 80kW) connector
- J2836/2™ -DC Use Cases and general information
- J2836/3™ Use cases for communication between PEVs and the Utility Grid for Reverse Energy Flow
- J2836/4™ & J2847/4 Diagnostics
- J2836/5™ & J2847/5 Customer and HAN
- J2847/2 – DC Messages and detailed information
- J2847/3 – Messaging between PEV and Utility for Reverse Energy Flow
- J2931/1 -Digital communications for PEVs - Communication requirements and protocol (AC & DC)
- J2931/2 – In-band signalling communication for PEVs
- J2931/3 – PLC communication for PEVs
- J2953/1 PEV Interoperability with EVSE

Table 2.8 lists out the interoperability matrix for electric transportation.

Table 2.8: Interoperability Matrix for Electric Transportation

Link (Interface Number)	Standards for Electric Transportation			
Intra Substation (1)				
Inter Substation (2)				
Field Equipment (3)	Data Concentrators / Aggregators communications			
	IEC 62056	IEC 60870-5-104	Distributed Network Protocol (DNP3)	
Substation – Central System (4)				
Inter Central System (5)				
Central System – DER (6)				
Central System – Enterprise System (7)				
Central System – Consumer (8)	Charging station to Control Center			
	IEC 60870-5-104	IEC 62056		
Intra Consumer Premise (9)	Charging infrastructure			
	IEC 60309	IEC 61851	IEC 61980	Society of Automotive Engineers (SAE) J1772
Area-Independent Standards	Security			
	IEC 62351			

2.3.8 Interoperability Standards for Cyber Security

The National Rural Electric Cooperative Association (NRECA) in the U.S. came up with a "Guide to Developing a Cyber Security and Risk Mitigation Plan" in 2011, which consists of a set of security best practices and controls designed to help improve cyber security related to smart grids. There is a large amount of guidance from organizations such as the National Institute of Standards and Technology (NIST), North American Electric Reliability Corporation (NERC), Federal Energy Regulatory Commission (FERC), and others in this document. This document primarily provides a condensed set of best practices and does not delve into specific implementation details. It does, however, discuss the following security risks and provides recommendations for mitigating these risks and for security controls:

- People and policy security risks
- Operational security risks
- Insecure software development life cycle (SDLC) risks
- Physical security risks
- Third-party relationship risks
- Network security risks
- Platform security risks
- Application security risks

In addition to this document, there are several other standards that may be applicable to India and should be reviewed. These include:

- ISO (International Organization for Standardization) 27001, Information Security Management Systems: Guidance on establishing governance and control over security activities.
- IEEE (Institute of Electrical and Electronics Engineers) 1686-2007, Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities (this document must be purchased).
- NIST IR 7628:2 Smart grid cyber security strategy and requirements.
- NIST SP800-39, DRAFT Integrated Enterprise-Wide Risk Management: Organization, mission, and information system view.

Cyber Security related developments in India: The Department of Information Technology, housed within the Government of India's Ministry of Communication and Information Technology, has prepared a Crisis Management Plan (CMP) for countering cyber-attacks and cyber-terrorism and for preventing the large scale disruption in the functioning of critical information systems of government, public and private sector resources and services. The Indian Computer Emergency Response Team (CERT-In) is the nodal agency for countering cyber-attack in India.

The Ministry of Power letter No F.1/10/2010-IT(Vol-I), dated December 13, 2010, has also empowered CERT-Thermal (Nodal agency (NTPC), CERT-Hydro (Nodal agency NHPC),and CERT-Transmission (Nodal agency PGCIL) to take necessary action to prevent cyber-attacks on utilities under their jurisdiction. The state utilities were requested to prepare their own CMP and be in touch with the nodal agencies (i.e. NTPC, NHPC, PGCIL and CERT-In) regarding the necessary actions.

Nodal agencies of hydro and thermal (NHPC and NTPC, respectively) have prepared CMPs for hydro/thermal power stations and the nodal agency of CERT-Transmission (PGCIL) is preparing a CMP for the transmission sector. They are participating in mock drills carried out by CERT-In and have also carried out an audit of cyber-security in their organization. They are also providing guidance to various power utilities to enhance cyber-security.

The above-mentioned activities are being monitored by Regional Power Committees (RPCs) on a regular basis and are being discussed in the monthly OCC/TCC meetings being held with the various regional power utilities. They are also conducting workshops on cyber security for the constituent members and STUs are advised to set up a cell for cyber-security with identified nodal officers.

There are numerous standards related to encryption/decryption of data, covering different approaches. Evaluation programs continuously monitor the effectiveness of the algorithms and their applications are nominated in the overall protection and cyber-security schemes designed by utilities. These standards may be applied at the application layer communications (as an integral part of the application layer protocol) or as is more common now, as a part of the carrier layer technologies (part of the transport, network and data link layers). A Virtual Private Network (VPN) is an example of a Transaction Layer Security (TLS) scheme which provides an encrypted secure channel for communication between authenticated nodes and does not require any encryption/decryption overhead in the application layer itself. The R-APDRP specifications in India have been established mainly for TLS, specifying a small number of TLS-based VPN mechanisms. The interoperability matrix for cyber security is shown below:

Table 2.9: Interoperability Matrix for Cyber-Security

Link (Interface Number)	Standards for Cyber Security			
Intra Substation (1)	IEEE 1686-2007			
Inter Substation (2)				
Field Equipment (3)				
Substation – Central System (4)				
Inter Central System (5)				
Central System – DER (6)	ISO 27001			
Central System – Enterprise System (7)	NIST SP800-39			
Central System – Consumer (8)				
Intra Consumer Premise (9)				
Area-Independent Standards	Security			
	IEC 62351	ISO 27000	ISA SP99	NERC CIP
	NISTIR 7628	ISO/IEC 13335		

3 CURRENT STATUS ANALYSIS

This chapter describes the current state of the distribution grid and the interoperability initiatives being conducted internationally and in India. The report recognizes that different regions have different goals and objectives (expectations from the smart grid) as well as differing resource levels and socio-political factors and these differences need to be considered when comparing these initiatives.

3.1 INTEROPERABILITY INITIATIVES ABROAD

This chapter presents interoperability initiatives from a selection of global projects. The projects have been selected to provide coverage of a broad spectrum of goals/objectives, resources and methods.

3.1.1 United States

The smart grid initiatives in the U.S. are characterized by a number of initiatives across different states and utilities. Initiatives range from the Intelligrid initiative by Electric Power Research Institute (EPRI), The Gridwise Alliance and Gridwise Architectural Council by DOE, the Energy Independence and Security Act (EISA), the Smart Grid Maturity Model (SGMM) from IBM to the recent NIST Roadmap. The chief drivers behind smart grids are emission reductions (ecological concerns), DR for peak management (economic benefits) and grid security (national security concerns). Three major initiatives (two U.S. federal initiatives and one state initiative) are worth mentioning.

The U.S. government has delineated four overarching goals for smart grid implementation: (i) better alignment of economic incentives to boost development and deployment of smart-grid technologies; (ii) a focus on standards and interoperability to enable innovation; (iii) empowerment of consumers with enhanced information to save energy, ensure privacy, and shrink bills; and (iv) improved grid security and resilience. These goals are expected to be achieved through expanded partnership among the states, industry leaders, and stakeholders.

NIST – SGIP

The National Institute of Standards and Technology (NIST) is an agency of the U.S. Department of Commerce. NIST recently finished reviewing and incorporating public comments into the NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0.

The 2.0 Framework lays out a plan for transforming the nation's aging electric power system into an interoperable smart grid—a network that will integrate information and communication technologies with the power-delivery infrastructure, enabling two-way flows of energy and communications. The final version reflects input from a wide range of stakeholder groups, including representatives from trade associations, standards organizations, utilities, and industries associated with the power grid.

The Smart Grid Interoperability Panel (SGIP) was created by NIST in November 2009 to provide an open forum for members to collaborate on standards development. Through the SGIP, NIST collaborates with the private sector in coordinating smart grid standards. Its more than 1,900 volunteer members from 740 organizations serve as technical experts who work together to create usable standards for the smart grid. Hundreds of such standards - covering matters ranging from wireless communication to home energy meters to electric cars - are needed to ensure the many elements of the smart grid will work together seamlessly.

Just as its draft version did, the final 2.0 Framework adds 22 standards, specifications and guidelines to the 75 standards NIST recommended in the 1.0 version of January 2010 as being applicable to the smart grid. Further improvements and additions to the 1.0 version include:

- A new chapter on the roles of the SGIP;
- An expanded view of the architecture of the smart grid;
- A number of developments related to ensuring cybersecurity for the smart grid, including a Risk Management Framework to provide guidance on security practices;
- A new framework for testing the conformity of devices and systems to be connected to the smart grid—the interoperability process reference manual;
- Information on efforts to coordinate the smart grid standards effort for the U.S. with similar efforts in other parts of the world; and
- An overview of future areas of work, including electromagnetic disturbance and interference, and improvements to SGIP processes.

Although the NIST framework and roadmap effort is the product of federal legislation, stakeholder involvement at the state and local levels is crucial to ensure consistent voluntary application of the smart grid standards. The interoperability and cyber-security standards developed under the NIST framework and roadmap must support the role of the states in modernizing the nation's electric grid.

NIST's effort is aimed at creating a self-sustaining, on-going standards process to support continuous innovation as grid modernization continues to evolve. Grid modernization should ensure backward compatibility to the greatest extent practical. NIST envisions that the processes being put in place by the SGIP will provide the mechanism to evolve the smart grid standards framework as new requirements and technologies emerge.

U.S. DOE GRID TECH

The DOE has been at the forefront of the attempt to bring together a national plan for the smart grid in the U.S. Their GRID TECH initiative released a roadmap in 2011 which targets 80 percent clean energy by 2035, which is a significant ramp-up from its own Smart Green Grid roadmap which previously aimed to achieve 33 percent renewable energy penetration by 2020. This new vision incorporates their own "Smart Grid" definition, listing power quality, enabling markets, reliability and security as major components.

The new vision envisages:

1. Enable a seamless, cost-effective electricity system, from generation to end use:
   - A 100 percent holistically designed system (including AC-DC hybrid configurations)
   - Optimizing asset utilization and operating efficiency
   - Regionally diverse, while meeting essential requirements of a shared national vision
   - Providing the power quality for a range of needs
   - A reliable, secure, and resilient grid
   - Enabling new products, services, and markets
   - Global competitiveness and leadership

2. Capable of meeting:
   - The clean energy demands: significant scale-up of clean energy (80 percent by 2035); and accommodating all generation and storage options
   - Capacity requirements of this century

3. While allowing consumer participation and electricity use as desired:
   - Enabling informed participation of consumers
   - Allowing 100 percent customer participation and choice
   - Including distributed resources, demand response, demand-side management, electrification of transportation, and energy efficiency

Grid Tech's role is to provide thought-leadership, convene relevant stakeholders, facilitate open dialogues, and coordinate results and actions. Its responsibility is to promote a complete, well rounded systems approach that balances technical and institutional solutions with sensitivities to regulatory, policy, and market challenges. Grid Tech's vision of the grid modernization recognizes the diversity and uncertainty in future energy demands and generation options, and recognizes inherent regional differences in needs, goals, and available resources.

New York State Smart Grid Consortium

The New York State Smart Grid Consortium (NYSSGC) released a roadmap in 2010 that leverages the unique resources and requirements of New York state to define an overall strategic smart grid vision that can serve as a model to the nation.

The plan analysed three distinct environments (rural, sub-urban/urban, high-rise urban) and developed a specific investment plan of USD 7.2 billion in:

- Distribution automation/substation automation
- Metering
- Transmission automation
- Grid connected storage and
- Smart charging

This is expected to yield a total savings of USD 18.9 billion during the period 2011-2025 from:

- Reduced electricity bills
- Reduced outages
- Enabled renewables
- T&D "rate" benefits

In a white paper released in January, 2013, the NYSSG outlines its innovative effort that includes smart grid projects to analyse conditions in real-time and self-heal in the event of a system disturbance. Three key goals for New York grid modernization have been considered in the white paper. These include:

- Enhance the situational awareness and control of the grid;
- Improve the grid's 'self-healing' capability; and
- Provide more information and tools that help the consumer better manage their electricity usage.

3.1.2 United Kingdom

The U.K.'s smart grid initiatives are led by a national 40-year roadmap from 2010 to 2050. The roadmap was formulated by the Electricity Network Strategy Group (ENSG) and aims to help the U.K to transition to a low carbon economy.

The roadmap sets out how smart grids may, directly or indirectly:

- Maintain or enhance quality and security of electricity supply;
- Facilitate the connection of new low-and zero-carbon generating plants, from industrial to domestic scale;
- Enable innovative demand-side technologies and strategies;
- Facilitate a new range of energy products and tariffs to empower consumers to reduce their energy consumption and carbon output;

- Feature a holistic communications system that will allow the complete power system to operate in a coherent way, balancing carbon intensity and cost, and providing a greater visibility of the grid state; and
- Allow the cost and carbon impact of using the networks themselves to be optimised.

The chief drivers behind the roadmap are carbon reduction, energy security, and economic competitiveness and affordability. The roadmap plans for an investment of GBP 10 billion (USD 16.2 billion) in the next 10 years (2010 to 2020).

A study conducted by the Energy Generation and Supply KTN/TWI (EG&S KTN/TWI) and the U.K. Energy Research Centre (UKERC) in June, 2011 highlights the following priority areas that need to be worked on:

- Consumer behaviour studies – need more pilot projects.
- Cost benefit analysis of grid operators' involvement – taking into account cost savings in infrastructure renewal, quantifying eventual international business opportunities emerging from re-applying smart grid capabilities in other markets around the world, and regulatory incentives.

The study also identified the following five technology categories, which are critical to the successful deployment of smart grids in the U.K.:

- Demand side management
- Interaction between AMI and optimization system
- Energy storage
- Virtual power plant (VPP)
- Volt and VAR optimization

Among the above five categories, energy storage, demand side management, and AMI were pointed out as the areas where research and development over next five years would be most critical.

The U.K. has taken a two-phase approach to smart meter (AMI) rollout which includes customer involvement. In the first or foundation stage, it will enable industry to test all the systems and ensure positive consumer engagement before a mass rollout begins.

The U.K. has also taken initiative in an electric vehicle trial program (known as the Switch EV trial) with support from Technology Strategy Board. As of June 2011, the 44 electric vehicles in the program have completed 50,000 miles across the Northeast of England.

3.1.3 Ireland

The Sustainable Energy Authority of Ireland (SEAI) released a comprehensive smart grid roadmap, an EV roadmap, and a wind energy roadmap for the period 2010-2050. Their chief drivers are carbon reductions, reductions in fossil fuel imports, and energy security. The roadmap aims to:

- Achieve 88 percent renewable energy penetration by 2050
- Reduce energy-related CO_2 emissions by 250 metric tons
- Electrify transport networks to reduce fossil fuel imports by 45 percent (approximately USD 10 billion annual savings)
- 60 percent EV contribution to passenger car segment

Ireland and Northern Ireland's networks have some of the highest wind penetration levels in the world, which brings a unique opportunity to the country in developing smart grid technology.

3.1.4 JAPAN

The Japanese national vision (pre-Fukushima) was documented in a roadmap issued in 2010 and aimed at developing smart communities in select cities, emission reductions, renewables, and exporting smart grid equipment and know-how. However post-Fukushima, the roadmap prioritizes public safety, restoration of public trust in the energy system, and customer empowerment and protection.

The current roadmap is expected to increase the previous target of 10 percent renewables by 2020 to as much as 65 percent by 2030.

Unlike most other countries around the world, reliability is not considered a key issue in Japan's smart grid initiative since significant generation and transmission infrastructure improvements are already under way, with over USD 100 billion of investments having been made since the 1990s. Japan's primary focus is the introduction of advanced integrated controls for demand side management and connectivity to the end-use customer (known as "last mile"), connecting the end user to the grid. Japan's agenda for its smart grid initiative also includes integration of solar and other intermittent energy sources and sustainability with the goal of becoming a low-carbon society. Japan has already started establishing standards for smart grid applications with the Association of Radio Industries and Businesses ARIB STD-T96 protocol for automatic transmission and measurement of data from remote sources by low-power radio equipment.

3.1.5 Germany

The leading government authority in Germany for smart grid standardization and development is DKE (German Commission for Electrical, Electronic and Information Technologies of DIN and VDE). Its smart grid initiative is called "E-Energy–Internet of Energy". The main drivers for smart grid development in Germany are standards development, carbon reductions, energy efficiency, load flexibility, demand response, energy security, distributed generation, storage, VPP, electro-mobility, and avoidance of grid bottlenecks. The overall investment budget in the smart grid until 2020 is estimated at Euro 40 billion (USD 55 billion).

DKE published the first version of E-Energy/Smart Grid Standardization Roadmap in October 2010 and updated it in 2012. This initiative has a time frame of three years, during which time it seeks to complete the development of standards. This smart grid standardization roadmap includes detailed recommendations in areas of general, regulatory and legislative changes, security and privacy, communications, architecture and power automation, distribution system automation, smart metering, distributed generation and virtual power plants, electro-mobility, storage, load management (DR), and building and home automation. The key highlights of the recommendations for the development of standards are as follows:

- The development of uniform standards is of great importance for smart grids.
- International standards are the basis of national implementation.
- Importance of involving the German experts in international standardization.
- Safety and security of the systems and products in the traditional sense.
- Resilience of the indispensable core functionalities of the smart grid.
- Use and marketing of existing standards.
- Checking of interoperability.
- Further development of market communication.

Since the Fukushima disaster, the German government has announced that it plans to phase out all of its nuclear power plants by 2020. The clear implications of this announcement include accelerated development of renewable and non-emitting energy as well as development of a smart grid that is able to integrate distributed generation on a massive scale. These implications are visible in the policies and initiatives of the German government in the smart grid sector.

3.1.6 China

State Grid Corporation of China (SGCC) is the leading power utility in China, which serves 88 percent of China's land territory and almost one billion customer; by size it is the largest power utility in the world. SGCC envisions three phases of smart grid development:

- 2009-2010: planning and commissioning pilot smart grid programs
- 2011-2015: integration and development of required infrastructure and equipment
- 2016-2020: improvement and further development in the smart grid projects

According to SGCC's latest report, 238 pilot projects in 21 categories of smart grid were proposed to be completed in the early phases. SGCC has pioneered the development of smart grid infrastructure across generation, transmission, distribution, transformation of existing grid structure, information and communication technology protocols, etc. In 2010, the Chinese government provided USD 7.5 billion funding for the development of smart grids.

In December 2010, the National Smart Grid Standardization Promotion Group was established under the joint leadership of the National Energy Administration (NEA) and the Standardization Administration of China (SAC) with the aim of speeding up the standardization process. The focus of the Smart Grid Standardization Promotion Group is to draft strategic plans, formulate standard frameworks, and guide development of national and industrial standards. This group was further divided into three subgroups:

- Smart grid standardization group
- Smart grid equipment standardization group
- Smart grid standardization international cooperation group

SGCC has developed a hierarchical system for strong smart grid standards which is expected to give guidance and instruction for research and development of smart grid standards. It consists of a number of layers, as described below:

- **The first layer is domain**. There are eight domains, including general and planning, generation, transmission, substation, distribution, utilization, dispatching, as well as ICT.

- **The second layer is technical fields.** There are a total of 26 technical fields, focusing on the overall direction of smart grid study and key areas of project construction. The division of different technical fields follows a series of SGCC's guidelines, including Planning of Smart State Grid, Smart Grid Key Technology Research and Study, Key Smart Grid Equipment (System) Development Planning.

Technical fields included in each domain are:

- General and planning: smart grid methodology and interfaces, planning and design.
- Generation: coordination of conventional power sources and power grid, large-scale new energy integration, large capacity energy storage integration.
- Transmission: ultra-highvoltage power transmission, flexible high voltage DC (HVDC), flexible AC transmission (FACTS), status and operation monitoring of transmission line.
- Substation: smart substation.
- Distribution: distribution automation, distributed generation integration, distributed energy storage system integration.
- Utilization: bi-directional interactive service, power utilization information collection, smart energy utilization service, charging and discharging of electric vehicles, smart utilization detection.
- Dispatching: smart grid dispatching support system, centralized monitoring and control of power system operation.
- ICT: transmission network, communication network at distribution and user side, service network, communication support network, smart grid information platform, and communication and information security.

- **The third layer is standard series.** There are a total of 92 series, covering "general", "engineering construction" (including design, refurbishment, acceptance and test), "operation and maintenance", and "equipment and material".

- **The fourth layer is specific standards**. This includes the actual specification of the standards which are to be implemented.

SGCC is being aggressive in developing corporate smart grid standards, which play a vital role in building pilot projects, China's four national standards and 22 industrial standards, and global smart grid standards. SGCC has submitted 13 smart grid international standard proposals to IEC, primarily on smart grid interface, demand response and smart grid dispatching.

3.1.7 Denmark

The Danish Energy Association and Energinet.dk, the Transmission System Operator (TSO) are the primary energy regulatory bodies in Denmark. In 2010, the Danish Ministry of Climate and Energy set up a smart grid network involving representatives from the energy sector. This network had the objective of preparing a report of recommendations for handling 50 percent wind power in the power system by 2020. The report was published in 2011, and contained 35 recommendations.

The report, "Smart Grid in Denmark version 2.0", published by Danish Energy Association, contained several recommendations for integrating smart grids into the current grid infrastructure and contained a roadmap focusing on the role of the grid companies. The roadmap's key points are as follows:

- **Business case and strategy:** The measures which support the individual grid companies in preparing a business case and deciding on a strategy for establishing a smart grid are: (i) strategy in the grid companies; (ii) calculation model for deferred grid investments; and (iii) market potential for smart grid players. These points have to be kept in mind while conducting a cost-benefit analysis.

- **New technology in the power grid:** This includes measures concerning the introduction of new technology in the electricity grid. For example, establishing technological solutions for automation and monitoring grid loads as well as setting up further measurements at strategic points in the distribution grid. The measures that need to be taken into account are requirements for distribution grid components, establishment of measurements and automation, new operations support systems in the distribution grid, and new tools for planning and dimensioning.

- **Providing flexibility to customer's electricity consumption:** This recommendation encompasses measures which support the grid companies in actively involving end-users via price signals or through entering into agreements on regulating or shifting electricity consumption to periods with spare power grid capacity. The key areas included in this are data hub supports hourly settlement by small end-users, hourly settlement of customers, voluntary agreements with selected customers on flexibility, variable grid tariffs and handling several electricity meters at each customer.

- **Other measures:** Other measures that support the grid companies in developing a smart grid are new regulation that promotes the smart grid, IT and data security, and strengthening consumer involvement.

3.1.8 Canada

In 2010, Canada's leading authorities, the Natural Resources Canada and the Standards Council of Canada's National Committee to the International Electro-technical Commission (CNC/IEC), created a task force on Smart Grid Technology and Standards to recommend priority standards for the smart grid. In October 2012, the task force published a road map to navigate the evolving standard's environment. In order to expand the Canadian and U.S. collaboration in the energy sector, the task force formulated a path for the priority standards of Canada which supports U.S. National Institute of Standards and Technology standards, to develop a broad range of standards for smart grid.

The task force was further segregated into three working groups:

- Working Group 1 (WG1) focused on standards for advanced metering systems (e.g., smart meters) and other post-distribution elements of the smart grid, such as customer networks, electric vehicles as smart grid storage devices, and the interface requirements between the utility and its customers;
- Working Group 2 (WG2) focused on transmission and distribution standards; and
- Working Group 3 (WG3) focused on smart grid privacy and security issues, particularly with respect to cyber security as it affects both consumers and utilities.

The recommendations outlined in the report identify the standardization solutions needed for a modern electricity grid that focuses on quality, reliability, optimal usage, and cost-efficiency. Key areas covered in the report are as follows:

- Smart grid policy, legislation and regulatory considerations;
- Privacy and security requirements;
- Transmission and distribution standards; and
- Metering systems standards.

3.1.9 Australia

Smart Grid Australia is a non-profit, non-partisan organization which provides critical information and assistance for smart grid initiatives to the Australian government. Moreover smart grid is a major agenda for all utilities in Australia and the Australian Energy Regulator (AER) has already approved funding of A$ 24.6 billion (USD 23.6 billion) for smart grid projects.

The development of a smart grid roadmap for Australia involved two workshops (Sydney and Perth), an expert survey, and a review of published literature. The workshop identified the following R&D topics in the integration of smart grids:

- Common information model
- Standards
- Policy and governance
- Security
- Data handling
- Demo
- Simulation model

3.2 INTEROPERABILITY INITIATIVES IN INDIA – GOALS, RESOURCES AND CURRENT STATUS

3.2.1 India Smart Grid Vision

The National Smart Grid Mission (NSGM) defines the India Smart Grid Vision as below:

"Quality Power on Demand for All by 2027" - Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem by 2027 that provides reliable and quality energy for all with active participation of stakeholders.

In order to achieve this vision, stakeholders will undertake the following activities:

Smart Customer:

1. Appropriate policies and programmes to provide access for electricity for all with life line supply (to be defined) by 2015, electrification of 100 percent house holds by 2020 and 24x7 quality supply on demand to all citizens by 2027.

2. Smart meter roll out for all customers by 2022.

3. Tariff mechanisms, new energy products, energy options and programmes to encourage participation of customers in the energy markets that make them "prosumers".

4. Formulation of effective customer outreach and communication programmes for active involvement of consumers in the smart grid implementation.

Smart Utilities:

1. Enabling programmes and projects in distribution utilities to reduce aggregated technical and commercial (AT&C) losses to below 15 percent by 2017, below 12 percent by 2022, and below 10 percent by 2027; and in transmission utilities to reduce transmission losses to below 3 percent by 2017 and below 2 percent by 2022.

2. Development of a reliable, secure and resilient grid supported by a strong communication infrastructure that enables greater visibility and control of efficient power flow between all sources of production and consumption by 2027.

3. Development of a utility-specific strategic roadmap for implementation of smart grid technologies across the utility by 2013. Required business process reengineering, change management and capacity building programmes to be initiated by 2014.

4. Integrated technology trials through a set of smart grid pilot projects by 2015; and rollout of smart grids in all urban areas (to be defined) by 2020 and nationwide by 2027.

5. Create an effective information exchange platform that can be shared by all market participants (including prosumers) in real time, which in turn will lead to the development of energy markets.

Smart Generation & Transmission:

1. Optimally balancing different sources of generation through efficient scheduling and dispatch of distributed energy resources (including captive plants in the near term) with the goal of long term energy sustainability.

2. Implement power system enhancements to facilitate integration of 30 GW renewable capacity by 2017, 70 GW by 2022, and 120 GW by 2027.

3. Development of microgrids, storage options, VPP, vehicle to grid (V2G), solar to grid (PV2G), and building to grid (B2G) technologies in order to manage peak demand, optimal use of installed capacity and reduce load shedding and black-outs.

Smart Policies:

1. Formulation of policies and programmes for mandatory demand response (DR) infrastructure for all customers with loads above 1 MW by 2013, above 500 kW by 2015, above 100 kW by 2017, and above 20 kW by 2020.

2. Policies for grid-interconnection of captive/consumer generation facilities (including renewables) where technically feasible; policies for roof-top solar; and policies for peaking power stations.

3. Policies for DR ready appliances and public infrastructure including EV charging facilities by 2014.

4. Investment in research and development, training and capacity building programmes for developing and implementing smart grid technologies, and export of smart grid know-how, products and services.

5. Development of appropriate standards for smart grid development in India; and active involvement of Indian experts in international bodies engaged in smart grid standards development.

3.2.2 NSGM Road Map – Targets

The National Smart Grid Mission has set the following goals for the 14th Plan period as shown in Table 3.1.

Table 3.1: National Smart Grid Mission

12th Plan (2012 – 2017)	13th Plan (2017 – 2022)	14th Plan (2022 – 2027)
1. Access to "Electricity for All" 2. Reduction of transmission losses (>66 kV) to below 3 percent 3. Reduction of AT&C losses in all distribution utilities to below 15 percent 4. Reduction in power cuts; life line supply to all by 2015; grid connection of all consumer end generation facilities where feasible 5. Renewable integration of 30 GW; and EV trials 6. Improvement in power quality and reliability	1. Reduction of transmission losses (>66 kV) to below 2 percent 2. Reduction of AT&C losses to below 12 percent in all utilities 3. Improvement in power quality 4. End of power cuts; peaking power plants; electrification of all households by 2020 5. Nationwide smart meter roll out 6. Renewable integration of 70 GW; 5 percent EV penetration	1. Reduction of AT&C losses to below 10 percent in all utilities 2. Financially viable utilities 3. Stable 24x7 power supply to all categories of consumers all across the country 4. Renewable integration of 120 GW; 10 percent EV penetration 5. Smart cities and smarter Infrastructures 6. Export of SG products, solutions and services to overseas

12th Plan (2012 – 2017)	13th Plan (2017 – 2022)	14th Plan (2022 – 2027)
7. TOU tariff 8. Energy efficiency programs 9. Standards development for smart grids including EVs 10. Strengthening of EHV system 11. Efficient power exchanges 12. Research & development, training & capacity building 13. Customer outreach & participation 14. Sustainability initiatives 15. SG Pilots, SG roll out in major cities	7. Standards development for smart infrastructure (SEZ, buildings, roads/ bridges, parking lots, malls) and smart cities 8. UHV and EHV strengthening 9. Research & developments; training & capacity building 10. Export of SG products, solutions and services to overseas 11. Customer outreach & participation 12. Sustainability initiatives & public safety	7. Research & development; training & capacity building 8. Active Participation of "Prosumers" 9. Sustainability initiatives & public safety

3.2.3 Bureau of Indian Standards

The Bureau of Indian Standards' (BIS) Sectional Committee LITD10 recently established seven panels for smart grid standards development for India:

a. Panel 1 – Interoperability
b. Panel 2 – Security
c. Panel 3 – CIM
d. Panel 4 – PMU
e. Panel 5 – DMS
f. Panel 6 – Digital Architecture Framework
g. Panel 7 – AMI

These panels have released initial draft reports which are in an advanced stage of standardization. The final reports were submitted by the convenors of the respective panels to the Chairman of the sectional committee LITD10 from the respective Panels on December 31, 2012.

3.2.4 ISGTF

The India Smart Grid Task Force is an inter-ministerial group, serves as the government focal point for activities related to the Smart Grid. Members of ISGTF have been selected from the concerned ministries (power, home, defence, communications and IT, new and renewable energy, environment and forest, and finance) and organizations (Planning Commission, Department of Science and Technology, CEA, CPRI, BEE, NTPC, PGCIL, BIS, PFC, and REC).

Main functions:

- Awareness, coordination, and integration of diverse activities related to Smart Grid technologies
- Practices and services for research and development of Smart Grid
- Coordination, and integration of other relevant inter-governmental activities
- Collaboration on interoperability framework
- Review and validate recommendations from India Smart Grid Forum

The ISGTF comprises of five working groups

- Working Group 1: Trials/Pilot on new technologies
- Working Group 2: Loss reduction and theft, data gathering, and analysis
- Working Group 3: Power to rural areas & reliability and quality of power to urban areas
- Working Group 4: Distributed generation and renewable
- Working Group 5: Physical and cyber security, Standards and Spectrum

3.2.5 ISGF

The India Smart Grid Forum was launched in 2010 as a non-profit voluntary consortium of public and private stakeholders, research institutes, and selected utilities with the prime objective of accelerating development of Smart Grid technologies in the Indian power sector.

Main functions:

- To help the Indian power sector in deploying Smart Grid technologies in an efficient, cost effective, innovative, and scalable manner by bringing together all key stakeholders and enabling technologies.
- To bring together stakeholders specializing in regulation, policy, and business case for Smart Grid.
- To undertake research work and other efforts such as scoping the capabilities of Smart Grids in the Indian context through case studies, cost-benefit framework, technical advancements in the renewable energy sources, and other ancillary activities.

The ISGF comprises of 10 Working Groups

- Working Group 1: Advanced Transmission
- Working Group 2: Advanced Distribution System
- Working Group 3: Communications for Smart Grids
- Working Group 4: Metering
- Working Group 5: Consumption and Load Control
- Working Group 6: Policy and Regulations (including Tariffs and Finance)

- Working Group 7: Architecture and Design
- Working Group 8: Pilots and Business Model including planning and implementation, and capacity building
- Working Group 9: Renewables and Micro-grids
- Working Group 10: Cyber-Security

3.2.6 Restructured Accelerated Power Development and Reforms Programme (R-APDRP)

The on-going R-APDRP program is one of the largest utility-led IT initiatives anywhere in the world. Under the program, distribution utilities are building IT infrastructure, IT applications and automation systems. The program is organized into three parts.

Part A of the R-APDRP program covers the following scope:

- Consumer indexing using geographic information system (GIS)
- Asset mapping (entire distribution network – high tension and low tension lines, transformers, poles, meters) using GIS
- Automatic meter reading for all distribution transformers and feeders
- IT applications for meter reading, billing and collection, management information system (MIS), redressal of consumer grievances, and establishment of IT enabled consumer service centres
- Energy accounting and auditing
- SCADA/DMS system (only in the project area having a population of more than four hundred thousand and annual input energy of the order of 350 Million Units (MU). As the study shows that SCADA for smaller towns/areas is economically not feasible.)
- Feeder Segregation/Ring Fencing

Part B is aimed at strengthening and upgrading the electrical network while Part C is for capacity building activities.

3.3 GAP ANALYSIS – GOALS, RESOURCES, METHODS AND STATUS

This section provides a comparison and gap analysis between the international interoperability approaches and the Indian context, aiming to bring out best-practices for the Indian scenario.

The following characteristics stand out as glaring differences between most of the international smart grid visions and drivers as compared to the Indian situation:

1. Despite GOI's effort there are still around 400 million people without access to power. Urban areas still experience power cuts as a result of which electric storage (inverters) and local LV generation is widely used.

2. Power quality is not up to the mark and many households use voltage stabilizers and other correctional equipment.
3. The distribution sector is still struggling with losses as high as 30 percent mainly due to theft/ fraud.

These three issues are included in the NSGM, which seeks to address these major problems in its first five-year plan (the 12th five-year plan).

The penetration of EV in the passenger car segment is very low, except in some early-adopter markets like Bangalore, which has a small but notable penetration of EV. Present utility practices do not differentiate between EV charging and normal household loads and there is no regulation to separate the two. However, despite the significant economic incentive (aided further by the fact that EV charging is billed at normal household rates) the penetration of EV does not show a proportional increase. Under this situation, investment in EV charging infrastructure may seem to be uncalled for. The 12th Plan however does target an early stage study in the form of EV trials and goes on to target 5 percent penetration in the 13th Plan and 10 percent penetration in the 14th Plan.

Renewables integration appears to be the main driver for most international smart grid plans. Recent revisions to international plans include even higher targets for renewable penetration, which shows a significant confidence in overcoming the traditional obstacles to using renewables (the low reliability and dispatch-ability of wind and solar power for example). The Indian plan targets a 30 GW capacity for renewable energy in the 12th Plan and seeks to grow that target to 120 GW by the 14th Plan. The current state of renewables is at around 25 GW (out of a total installed capacity of 210 GW), making the current plans' target quite modest in ambition. However India's power demand is projected to reach 330 GW by 2017 which would require an installed capacity of around 440 GW (accounting for plant availability and a necessary spinning reserve to be maintained). To achieve the goal of "Power for All" by 2017 would, therefore, mean more than doubling the current installed capacity. As such, the 30 GW of renewables planned in the same five-year plan would only constitute 7 percent of the total power mix, which is not in keeping with the world-wide focus on renewables.

The Indian plan for peak management is comprehensive and utilizes all currently-known approaches, including demand response and distributed energy resources (including all kinds of captive/consumer generation like micro-grids, storage options, VPP, vehicle to grid (V2G), solar to grid (PV2G), and building to grid (B2G) technologies).

These three five-year plans also focus on standards development for smart grids, investment in nation-wide smart grid rollouts, capacity building, transmission and distribution strengthening in keeping with international initiatives.

4 ROADMAP AHEAD

This chapter presents a roadmap for achieving a high degree of interoperability between India's communicating entities and applications. The following roadmap is classified into the following four categories: (i) standards; (ii) regulatory frameworks; (iii) institutional capacity building and training; and (iv) need for a smart grid body.

4.1 Standards and Companion Standards

The road ahead will rely on open international standards to be applied at the interfaces of all communicating entities and applications. This section lists out additional action items that may be required in the form of adapting standards for India-specific use (creation of Companion Standards). One of the leading areas of development is in smart metering. The metering standards requirements can be classified into three distinct layers.

Enterprise Layer

The enterprise layer refers to standards for communication of meter-originated data between the head-end system (the meter data acquisition system) and all the enterprise applications like billing systems, MDMS, ERP, CRM, etc.

IEC61968/61970 CIM standards are the most likely candidates for this layer and will require customization/adaptation through a country-specific companion standard to ensure the development of all CIM classes required for all forms of meter data including India specific settlement systems like Availability Based Tariff (ABT).

Wide Area Network (WAN) Layer

The WAN layer refers to the communication between the HES and the data concentrator unit (DCU) network. There is a plethora of lower layer carrier technologies including private networks and public networks. The choice of carrier technologies is related to the technical availability and performance of different networks in the different utilities' region of working as well as on commercial feasibility. It is not recommended to impose standardization until more clarity is available.

On the application layer, IEC-62056 (DLMS/COSEM) standards are recognized and already have the benefit of an Indian companion standard adapted to Indian needs. This standard was initially designed for three classes of meters: (i) energy accounting and audit meters; (ii) boundary (ABT) meters; and (iii) consumer meters. However, efforts are on-going to include single phase, whole current meters in the companion specification. This report recommends the following additions/enhancements to the Indian companion specification for IEC-62056:

1. **Enabling advanced security profile:** The current version of the International Classification for Standards (ICS) mandates the use of a basic security profile which only provides for authentication technologies for access control and no encryption technologies for data transport. The advanced security profile which provides for authentication, encryption and encrypted authentication is marked "optional" due to the lack of clarity for the topic in the base standard (at the time). The base standards have since evolved to provide a full suite of security for all stages of meter communication including access control, data transport security and intermediate storage like DCUs. This report recommends that the BIS panel re-visit the topic and enable the advanced profile.

2. **Connect/Disconnect control:** The DLMS/COSEM capabilities for Connect/Disconnect control operations was only loosely referred to in the current version of the ICS. Considering the significance of this operation for load control, prepayment metering, and demand response, it is imperative to clarify all such use cases and provide for standard clauses to implement Connect/Disconnect on a per-consumer level in the ICS.

3. **Standard data lists:** The ICS specified the standardized meter data lists required by utilities and the individual object lists for each of the associations. Once advanced security and connect/disconnect are brought into the ICS (as discussed above), it becomes imperative that these data lists be re-defined to include the new data objects arising for the above.

4. **Newer communication profiles:** The ICS mandates the use of the 3-layer connection oriented communication profile which uses DLMS/COSEM on High-Level Data Link Control (HDLC). This is primarily for serial networks. The TCP\User Datagram Protocol (UDP)\IP profile for DLMS/COSEM though being fully defined at the time was not considered for the standard due to the lack of carrier layers for IP upto the meter level. The modern movement towards IP over low power networks provided by 6LowPAN standards with RPL would make the DLMS TCP\UDP\IP profile technically feasible over most networks. Under this condition, it is worthwhile to revisit this topic and enable support for the TCP\UDP\IP profile in the ICS.

Near-me Area Network (NAN) layer

The NAN layer refers to the localized communication networks under the DCU extending to all the meters. This is usually preferred to be a private network using RF mesh technologies or power line carrier technologies. Once again, there is a wide variety of technologies available for adaptation on both fronts. The top contenders for upcoming carrier technologies are RF mesh technologies and power line carrier technologies. This report recommends the following action items:

1. One area of concern specific to RF technologies is the low bandwidth available in India as unlicensed spectrum in the sub-Gigahertz range. Unlicensed spectrum usually refers to the ISM bands that are open for unlicensed (but possibly regulated) use. The existing unlicensed SubGHzrange 865-867 MHz in India is not conducive to supporting a self-healing and error-recovering mesh network. This is primarily due to the narrow bandwidth of 2 MHz which can provide at most 10 channels and hence less flexibility to deal with interference and collisions in the network. An extension of this unlicensed range or a provision of a centrally regulated additional range of frequencies with an easy-licensing framework would aid the growth of RF technologies in India. The globally available 2.4 GHz range is also available in India but is recognized to have low range characteristics and may be better suited to HAN networks than to NAN networks. It may be noted that Region 2 (as defined by ITU) consisting of the Americas and Greenland, have a 902-928 MHz ISM band which gives a 26 MHz band that can provide for more channels and hence better effective throughput. However this ISM band is not allowed in India. The Ministry of Communication and Information Technology may be approached to consider an extension of the available band of spectrum in the SubGHz range in line with International programs.

2. IP over low power noisy networks. A new set of standards provides for establishing IPv6 communications over low power and noisy networks. This technology uses Routing Protocol for Lossy networks (RPL) in conjunction with IPv6 in the network layer and MAC/PHY layers defined by IEEE 802.15.4 g and e. The adoption of these standards would be expected to provide for a fully functional IPv6 layer on top of both RF mesh as well as PLC technologies and can be a major stepping stone towards a high-performing and scalable communication solution in the NAN area.

4.1.1 Regulatory Frameworks

Demand Response

A regulatory framework needs to be developed to allow utility regulations to setup a DR environment. Current regulations in force require the utility to provide a 15-day ahead written notice before disconnecting a consumer supply, whereas load shedding is done at will, depending on utility requirements. This is a major obstacle for implementing a dynamic and granular DR scheme to handle peak load conditions. The regulation needs to cover a mechanism (to be developed by a competent body comprising of technical and administrative experts) for a utility to release a DR Plan, solicit consumer participation (including consumer education), and perform DR load shedding at times of need. The scheme needs to consider the incentive for the consumer, the business case for the utility, and the incentive for any intermediating DR aggregation body.

4.1.2 Institutional Capacity Building and Training

Technology Demonstration Pilots

While India is moving ahead with smart grid pilots, it is apparent that the pilots are moving together in the choice of technologies with a predominant focus on radio frequency communications. This report recommends that a set of technology demonstration pilots be established to cover the range of technologies that are available/evolving and arrive at benchmark performance figures that take into account availability of vendor products, relative performance of the technology, a cost-benefit analysis of each technology, and the future roadmap of each technology. A quantified scoring mechanism to evaluate each of these parameters and an overall benchmark to compare the technologies is required. The selection of these technology demonstration pilots should provide a wide coverage for different grid environments like rural, sub-urban, urban and metropolitan and it is expected that different technologies may be found to be suitable in these different situations.

Interoperability Test Labs and Certifying Bodies

It is recommended that a detailed study of the interoperability standards be carried out and that it focus on their interoperability test definitions. The study should check for the presence of interoperability test definitions, test tools and certifying authorities and explore further the possibility of creating authorized test laboratories for each of the standards within India. The Central Power Research Institute (CPRI), for example has brought DLMS/COSEM and IEC61850 standards interoperability test and certification facilities to India. For this purpose, CPRI has licensed the appropriate test tools and is accredited by the appropriate test body (DLMS User Association and the UCA). CPRI is also entrusted with certification testing of the Indian companion specification for DLMS/COSEM as a wholly Indian procedure.

Utility Training

Utility personnel have to be trained to bring them up to speed on interoperability standards. The training should cover the salient working theory of these standards, specification of products and using these standards, the performance evaluation of vendor products and networks, the evaluation of test and certification procedures and best practices in operations, and monitoring of the grid using the new standards.

Consumer Outreach

A planned consumer outreach program is required to educate consumers on the modern needs of the smart grid and the increased role of the consumer as an active participant (and not just a passive user) in its operation. Many features of the smart grid are intensely dependent on customer participation, such as demand response, time of use metering, real time pricing, critical peak pricing, DER, PHEV as a DER and require confirmed customer buy-in to be successful.

4.1.3 Smart Grid Body or Steering Committee

India should follow international best practises and elect a suitable body of technology experts, business and domain experts, SDOs, utilities, vendors, regulators and possibly consumers to drive smart grid activities in the country. An effective example in this is the SGIP in the U.S. This body would need to be funded by the Government of India to enable it to be truly inclusive and open so that it can attract all the categories of participants described above. It should include a democratic process with appropriate by laws and include the BIS (the only SDO in India) so that the output of this body can be readily crystallized into Indian Standards. The currently available bodies, like the ISGF, do not resemble the SGIP in that they require paid memberships and do not have a clear liaison with an SDO like BIS.

ACRONYMS

ABT	availability based tariff
AMI	advanced metering infrastructure
AMR	automatic meter reading
CIM	Common Information Model
AT&C	aggregate technical and commercial
COSEM	companion specification for energy metering
CT/VT	current transformer/voltage transformer
DCU	data concentrator unit
DR	demand response
DLMS	device language messaging specification
DMS	data management system
DOE	Department of Energy
DT	distribution transformer
ERP	enterprise resource planning
EPRI	Electric Power Research Institute
FACTS	flexible ac transmission system
HES	head-end system
HAN	home area network
HVDC	high voltage direct current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ICS	International Classification for Standards
MIS	management information system
MOS	metering operation service
LDC	load despatch center
MDMS	meter data management system
NHPC	National Hydro Power Corporation

NIST	National Institute of Standards and Technology
NISTIR	National Institute of Standards and Technology Interagency Report
NLDC	National Load Despatch Centre
PDC	phasor data concentrators
PHEV	plug-in hybrid electric vehicle
RLDC	Regional Load Despatch Centre
RTU	remote terminal unit
SCADA	supervisory control and data acquisition
SGIP	smart grid interoperability panel
SGMM	smart grid maturity model
TCP/IP	Transmission Control Protocol/Internet Protocol
VSAT	very small aperture terminal
VPP	virtual power plant
WAMS	wide area monitoring system

REFERENCES AND LITERATURE

SMART GRID REFERENCES

India – BIS (Bureau of Indian Standards) - In a recent initiative, Sectional Committee LITD10 instituted seven panels for Smart Grid Standards development for India as listed below. These panels have released initial draft Reports which are in an advanced stage of standardization, submitted as finalized reports from the respective Panels as of December 31 2012.

a. Panel 1 – Interoperability
b. Panel 2 – Security
c. Panel 3 – CIM
d. Panel 4 – PMU
e. Panel 5 – DMS
f. Panel 6 – Digital Architecture Framework
g. Panel 7 – AMI

IEEE P 2030-2011

U.S. – NIST (Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.03 and 2.0 Draft).

Smart Grid Interoperability Panel (SGIP) for stakeholder categories

Customer Energy Services Interface White Paper, Smart Grid Interoperability Panel B2G/I2G/H2G Domain Expert Working Groups, Editor - Dave Hardin, EnerNOC, dhardin@enernoc.com

GridWise Interoperability Context-Setting Framework (GWAC)

LITERATURE STUDY

Yemula Pradeep, Abhiroop Medhekar, Piyush Maheshwari, S. A. Khaparde, Rushikesh. K. Joshi, "Role of Interoperability in Indian Power System", Grid Interop Conference, Albuquerque, New Mexico, Nov. 7th 9th, 2007.

Yemula Pradeep, P. Seshuraju, S. A. Khaparde, Vinoo. S. Warrier, S. Cherian, "CIM and IEC 61850 integration issues: Application to power systems", IEEE Power and Energy Society General Meeting, 2009. PES '09. 26-30 Jul. 2009, pp. 1–6.

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ISGF "ISGF -Smart Grid Roadmap for India - 24 July 2012-FINAL recommendations". ISGF Presentation

BIS-LITD10-Panel1- Interoperability Draft Report, Dec2012.

NIST "http://www.nist.gov/smartgrid/framework-022812.cfm"

GLOSSARY

Special energy meter	Special energy meter is a microprocessor-based energy meter. It is useful for metering and data logging, particularly along side a data collecting device and personal computer. It allows the user to process metered data with the use of application software.
Data concentrator	Data concentrators are used with automatic meter reading (AMR) and advanced metering infrastructure (AMI) architectures. They collect information and data, often from multiple meters, before forwarding the data to the utility. Concentrators are heavily used in densely-populated areas.
Wide area monitoring system (WAMS)	Wide area monitoring systems (WAMS) are based on the new data acquisition technology of phasor measurement and allow monitoring transmission system conditions over large areas in view of detecting and further counteracting grid instabilities.
Plug-in hybridelectric vehicle	A plug-in hybrid electric vehicle (PHEV) is a hybrid vehicle which utilizes rechargeable batteries, or other energy storage devices, that can be restored to full charge by connecting a plug to an external electric power source (usually a normal electric wall socket).
Head-end system (HES)	A head-end system is hardware and software that receives meter data brought back to the utility through the AMI. Head-end systems may perform a limited amount of data validation before either making the data available for other systems.
Home area network (HAN)	A home area network is a dedicated network connecting devices in the home - such as displays, load control devices and "smart appliances" - to the overall smart metering system. It also contains software applications to monitor and control these networks.
Device language messaging specification (DLMS)/ Companion specification for energy metering (COSEM)	DLMS/COSEM is the common language used between devices. DLMS: Generalised concept for abstract modelling of communication entities COSEM: Sets the rules, based on existing standards, for data exchange with energy meters
Wide area network (WAN)	A communications network that uses devices such as telephone lines, satellite dishes, and radio waves to span a larger geographic area than can be covered by a LAN.

Transmission Control Protocol/Internet Protocol (TCP/IP)	Transmission Control Protocol/Internet Protocol provides end-to-end connectivity specifying how data should be formatted, addressed, transmitted, routed and received at the destination.
Very small aperture terminal (VSAT)	Internet Protocol-based very small aperture terminal (VSAT) systems enable utilities to extend the smart grid anywhere it is required and expand connectivity across multiple utility operations over 100 percent of their coverage area. VSAT networks can run broadband applications such as video and voice over IP reliably and efficiently while maintaining supervisory control and data acquisition (SCADA) connectivity at these sites. VSAT also can support real-time data exchange, as well as extend high-speed networks or VPNs to enable secure file transfer, video or similar broadband services.
Electric vehicle supply equipment (EVSE)	Electric vehicle supply equipment is defined as all the equipment installed specifically for the purpose of delivering energy from the premises to the electric vehicle. This includes: conductors, including the ungrounded, grounded, and equipment grounding conductors, the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets or apparatuses.

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