Smart Grid, Standards, Policies And Regulations In India And Issues Related To Dg Integration And Solutions - A Survey

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ABSTRACT
Smart grid is envisaged to operate proactively with improved system visibility, system transparency, which consequently enables cost reduction and efficiency improvement. Smart grid technology is the key for an efficient use of distributed energy resource. The strength and capability of renewable energy lies in its ability to generate power in a decentralized and distributed mode which has advantage of production at consumption point and helps to get rid of transmission line, land and environmental related concerns. This calls for an updating of policies, standards, regulations and investments to support the renewable energy technology implementation. There are many initiatives taken in favour of this to promote smart grid in India. Many pilot projects are also launched to test the feasibility of different attributes. This paper also presents the study of integrating distributed generation (DG) to grid. The solution to which lies in optimized generator control and grid control, demand and supply side management. This would be useful for developers and practitioners of renewable energy systems, DG integration and policy makers.

INTRODUCTION

Smart grid could mean just about any grid with some intelligence and automated features (M. Vaziri et al. 2011). Smart grid is a self- healing grid, which enables active participation of consumers, operates resiliently against attack and natural disasters (Hassan Farhangi 2010), accommodates all generation and storage options, enables introduction of new products, services and markets, optimizes asset utilization and operates efficiently, and provides reliable and high quality power for digital economy (S. Massoud Amin and Bruce F. Wollenberg 2005). The main goal of smart grid is to promote active customer participation and decision making as well as to create the operation environment in which both utilities and electricity users influence each other. Utilities can improve reliability through the demand response programs, adding distributed generation or energy storage at substations and providing automated control to the grid.

In order to fight climate change and increase energy security, renewable energy and distributed generation (DG) (also called embedded power supply) (Saiyi Wang 2009; E. Prathibha and A. Manjunath 2014) is the promising option. DGs are so called because, their small size make them convenient to connect to the lower voltage or distribution part of the electric utility grid. The ever increasing price of petroleum products on account of depleting resources (finite fossil fuel resources) and the reduction in cost of renewable energy power systems, opportunities for renewable energy systems to address electricity generation seems to be increasing. Economic, technological and environmental incentives are changing the face of electricity generation and transmission (N. Phuangpornpitak and S. Tia 2012). Limited conventional energy resources, high energy consumption, environmental pollution (GHG emission) and sustainable energy requirement calls for exploiting renewable energy resources (J. A. Pecas Lopes et al. 2006; Mamatha Sandhu and Tilak Thakur 2014). World wide installed capacity of renewable sources has seen sustained growth averaging 43% per year since 2000.

In area where incremental expansion cost is high, DG may not only offer a good economic alternative, but appeals on its reliability merits alone. PV modules have the advantage of minimum maintenance and easy expansion (upsizing) to meet the growing energy needs. This modularity allows user to tailor PV system to desired situation. This scalability is applicable to wind generation also. There are many situations where there is no local...
electric utility grid in an area and DG of any type is the only possible source of electric power at lower costs.

Grid operators should recognize that this supply must be treated as any other supply source and be fully integrated into their transmission and distribution network operations systems. Implementing DG can avoid upgrade of equipment upstream and energy losses associated with T&D can be reduced. It is found that approximately 30% of end user price that consumer pay is attributed to T&D costs. Utilities can be benefited by DG for services such as voltage support or reactive power production, power factor control, harmonic filtering and peak load demand. Rather than apply existing solutions to a new problem, utilities should look for innovative and cost-effective solutions that are designed to solve or mitigate the problem. DG can effectively reduce the load demand to the grid when peak time and ease the difference between peak and valley of the regions power grid. Presence of DG provides energy security and sustainability.

The DG sources like solar PV and Wind are very intermittent and unpredictable; hence there optimum utilization is very much necessary to tackle the energy security issues (H. Ibrahim et al. 2011). These power sources distributed throughout the grid add many other challenges to the operation of the existing grid. Some of which being reliability issues, stability issues, protection issues (Edward Coster et al. 2007; Florian Romanens et al. 2011), etc. Electricity generation from renewable sources has become visible at different levels of power system creating additional challenge for management of power system, mostly due to large number of distributed generators, the variable power output and uncoordinated response to changing conditions of the power grid (Filip Andren et al. 2014). However, the increasingly large amount of power electronic devices and the nonlinear load cause a series of power quality problems such as voltage sags, voltage sag, voltage interruption, harmonics, voltage flicker, etc., (M. Ärnold et al. 2013; V. Gosbell et al. 2012; R. A. Walling et al. 2008; Ze-jun Ding et al. 2013). Optimized integration of DG into the distribution grid can be obtained by optimized grid control, generator control, as well as supply and demand side management; which can be considered as a method to mitigate such issues.

This paper discusses about the smart grid concept, relevance of smart grid in India. Standards, policies and regulations applicable for smart grid are also discussed. The subsequent section describes the issues related to the integration of DG to main grid and the solutions to the problems associated with integration of DG.

**Smart Grid Characteristics And Definition:**

Various definitions of Smart Grid published by various prominent entities are presented in this section. The 2007 Energy Independence and Security Act (ESIA07) define the major attributes of a Smart Grid as:

- Use of digital information and controls;
- Dynamic optimization of grid operations and research;
- Development and integration of distributed energy resources, especially renewable sources;
- Development and use of demand response;
- Deployment of “smart” technologies for metering, communications and automation;
- Integration of “smart” appliances and consumer devices;
- Use of peak-shaving technologies, including advanced storage technologies;
- Providing consumers with timely information on pricing for control of their energy intake;
- Development of standards for communication, and interconnection of "smart" devices (Energy Independence and Security Act of 2007).

Secondly, the attributes proposed by the Electric Power Research Institute (EPRI) IntelliGrid vision, focuses on communications and computer control. Their vision aims for an automated, reliable, intelligent, system that is integrated with the existing power grid (H. E. Brown and S. Suryanarayanan 2009).

Thirdly, the National Energy Technology Laboratory (NETL) has laid out the following characteristics for the Smart Grid: Enables active participation by consumers, accommodates all generation and storage options, green power products, reduced transmission congestion leading to more efficient electricity markets, provides power quality for the digital economy, optimizes asset utilization and operates efficiently, anticipates and responds to system disturbances (self heals), operates resiliently against attack and natural disaster (www.netl.doc.gov/smartgrid/refshelf.html).

After investigating these characteristics and visions of the Smart Grid, it is found that, there is obvious overlap and missing elements in each one of them. In order to get a complete definition these should be combined into one.

Smart Grid refers to use of intelligence and secure communications to efficiently control and deliver reliable, cost effective electric energy from a multitude of sources, including renewable, to customers giving all parties more choice to control and optimize utilization (H. E. Brown and S. Suryanarayanan 2009).

As per IEEE smart grid is defined as “A modernized electrical grid that uses analog or digital information and communications technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity”.

As per NIST smart grid is defined as “A modernized grid that enables bidirectional flow of energy and uses two-way communication and control
capabilities that will lead to an array of new functionalities and applications” (Energy Independence and Security Act of 2007).

As per IEC SMB SG 3 smart grid is defined as “An intelligent energy supply system which comprises the networking and control of intelligent generators, storage facilities, load and network operating equipment in power transmission and distribution networks with the aid of information and communication technologies. The objective is to ensure sustainable and environmentally sound power supply by means of transparent, energy and cost-efficient, safe and reliable system operation” (Mathias Uslar et al. 2013).

**Smart Grid Components:**

The grid is composed of generation, transmission, distribution and consumers. The Smart Grid vision implements changes to each key portion of the grid mentioned above along with substations and data networks as shown in figure 1. Each local part of the power system will have its own particular requirements and that each part will develop its own flavour of smartness as required (S. Massoud Amin and Bruce F. Wollenberg 2005; E. Prathibha and A. Manjunath 2014).

**Fig. 1:** The key components of smart grid

**Smart Generation and Generation Automation:**

Focusing on dispatch only, some of the functional highlights and differentiations from classical dispatch are: Extension for price-based, distributed, less predictable resources, Active, dynamic demand, Modelling parameter adaptation, Congestion management with security constrained Optimization, Continuum from forward scheduling to real-time dispatch, Extension for dynamic, multi-island operation in emergency.

The solar panels, wind turbines, electric vehicles, fuel cells and any other types of generation can be interconnected to the distribution side of the grid injecting power at any point in the system (M. Vaziri et al. 2011).

Since generation and demand should match for better operation of the grid and since it is not possible to store excess power or generate instantly more power, controllers played a key role in automation for a fail-safe mode of operation in which the following functions are controlled automatically. Stress on turbine during start-up and shutdown, grid synchronization, controlling the loading of turbine and generator, frequency stabilization to avoid penalties, managing plant load requirement apart from external load, prevention of overloading of turbine and compressor unit, protection and control against faults and possible failure modes. The heart of control systems is formed by embedded systems platform. The performance of control systems is drastically improved by advanced communication technologies in a highly integrated control environment.

By incorporating various logical control nodes (LCN) The distributed platform is realized, which computes their own algorithm without the need of any central node for functioning, offers wide variety of flexibility in plant control automation. These algorithms are realized by a set of equations governing the operation of a specific logical node.
IEC 61850 standards have been used by generation automation engineers to realize protection, control and automation functions in a power plant. IEC 61850 GOOSE messaging and necessary logic programming on protective relay, intelligent electronic devices (IEDs) has resulted in higher performance with more data to monitor and troubleshoot the issues in real time. Such applications of configurable GOOSE messages are, to reserve interlocking or reverse blocking, breaker failure protection, high voltage direct transfer trip and load shed/transfer, while traditional advantages of GOOSE such as reducing the amount of copper wire and relays necessary for protection is well acknowledged. Also, custom defined object oriented models of IEC 61850 helped in realizing various logical node operations (Filip Andren et al. 2014).

**Smart Transmission and Transmission Automation:**

The transmission system delivers large amounts of power from large generation sources typically over long distances to substations where the power is distributed. In the legacy grid the transmission part of power system was inactive one. Where as in smart grid, more accurate sensors and measuring devices like Phasor measurement units (PMU) is added for better power flow monitoring and control of the systems for optimal utilization. This also helps to meet the ever-increasing demand for power while protecting the transmission system against overloads. Self-awareness and self-healing can also be implemented into the new smart transmission system, rerouting power flows or decreasing the loads at predetermined locations to prevent stress, safety hazards or potential failure due to unexpected conditions (M. Vaziri et al. 2011).

As the power systems becoming large and exhibiting increasingly complex nature, there is a need for advanced measurement technology, tools, data analytics and operational infrastructure that facilitates the better automation, control and management of complex power system. Such system is called as wide area measurement system (WAMS) which uses advanced satellite based time synchronization technology for complete monitoring, protection and control of the power system. Though Energy Management System (IEC 61970) and SCADA (IEC 62357) were available predominantly from quite long time performing operations like state estimation, optimal power flow security analysis, contingency analysis, stability analysis etc. The present trend in automation in this area are automatically scheduling inter- area power exchange, computing online power transactions, handling deregulated and restructured power system operations, allocating costs to various generating participants, monitoring system security against possible physical and cyber- attacks, wide area stability analysis, state estimation based on WAMS, optimal bus load shedding based on critical bus synchronism lost etc. FACTS has now become much more robust in control due to the accurate and timely measurement of reference parameters. Communication has been added to these FACTS devices which made it interoperable with remote control operations based on WAMS. The present trend in automation is to automatically control transient stability of the line, damping of the system, voltage stability, sub-synchronous resonance, short-circuit current levels, integration of wind power generation to the grid & terminal performance of HVDC converter using the FACTS based device.

Multivendor protection, control and monitoring intelligent electronic devices (IEDs) integrated with various control centres or gateways at substation carry information to a central control centre. Hence methods for information security to assure privacy of data and information, integrity of data and commands from control centres and authentication of the source of receiving data and commands play a critical role (IEC 62351). In the present trend, automated security system that complement the existing SCADA system, performs the intruder detection for possible physical and cyber-attacks based on a set of protocol and executes data integrity based algorithms using the knowledge of power system components, control actions to differentiate authentic and false trip command due to malware. Cyber Security indeed is required for all automation blocks (Balakrishna P and Swarup K S 2015).

**Smart Substation and Substation Automation:**

Electric power is transported through the transmission lines to the substations. In a typical substation, there usually reside, protective equipment and power conditioning equipments. There are switchyards between large generation facilities to isolate and protect the generation facility as well as the transmission lines from disturbances on either side. Switchyards also route power to different parts of the system. There are substations where the voltage is stepped down for distribution through smaller networks at lower voltage levels. The substation is full of sensors that monitor the various grid conditions and send data back to an operations centre. Therefore, much of the data being collected on the grid today comes from substations. With the implementation of smart grid more data is to be collected and analysed for which communication channels must be added. In addition more IEDs must be installed into current substations to replace the existing electro-mechanical relays, meters and control devices, to increase monitoring accuracy and to increase the physical security of the equipment. Instead of reactors or capacitors power electronics devices are added at substations to compensate for power quality issues. During planned upgrades, integration of real time adaptive protection schemes and control equipment has to be done. For
implementing self healing, multiple connections and pathways throughout the distribution network is to be established. If this takes place, when power is rerouted, the protection equipment will have to adapt to the new grid configuration (M. Vaziri et al. 2011).

With the advent of advanced micro-controllers today the diversification and complexity of functions required by automation becomes a strong trend of evolution. IEC 61850 standard for substation automation has totally revolutionized the power delivery industry since its introduction in 2005 time frame. The major breakthrough happened with the realization of interoperability between multi-vendor IEDs. IEC 61850 also offer easier configuration, standardized logical nodes and functions for equipment, high-speed Ethernet communication on station bus and peer-peer communications called GOOSE, enhanced security controls, predefined XML file-format etc (Filip Andreń et al. 2014). Feeder automation can be realized in a centralized or decentralized approach based on number of feeders covered.

Due to the intrinsic distributed nature of power system, multi-agents based technology can provide greater autonomy for each component in power system. In present trend, agents play key and distinct roles in monitoring and control communication by means of messages, information retrieval through mobile based agents travelling over the network and interaction between agents for specific task.

The substation secondary equipments such as sensors, transducers etc, measures various analog parameters like voltage, current, temperature and transformers to main relay using hard-wired cable. When it comes to replacement and maintenance of substation secondary equipment’s, it may impact the overall substation availability because of complex wiring and relay obsolescence. To overcome this problem IEC 61850 has introduced process bus which is similar to field bus in generator plant, where in a standardized Ethernet bus is used to provide interfaces to primary equipment. A merging unit (MU) collects all the data from field sensors in a synchronized manner digitized the signals and transfers the sample value automatically on high speed Ethernet or process bus (1Gbps) to the subordinated primary equipment’s. This help in reducing maintenance cost and time for reconfigurations. IEEE 1588 precision time protocol (PTP) made even 20ms time period wave analysis possible and multiple IEDs to look at same zone using these accurate time measurements increasing reliability to protection (Balakrishna P and Swarup KS 2015).

**Smart Distribution and Distribution Automation:**

The features of smart grid on distribution side are distribution automation and demand response. From the substation to the customer’s meters, a network of feeders is present which constitute the distribution system. The first enhancement for the distribution system is installation of the smart meters. Smart meters have either one or two way communications with the electric control, metering, and billing network. These meters can also communicate with each other passing on metering data, billing data, and information for the implementation of automatic demand response and self-healing switching as needed. The smart distribution system can be implemented in several ways. They can consist of micro grids, which are companies or communities that are connected to the main utility but are able to operate on their own with their own generation capabilities. Feeder networks could also be connected to several substations to automatically detect and isolate troubled areas and reroute power from alternate sources to minimize customer outages. This rerouting of power can also take place to maximize the efficiency of power flowing through specific paths increasing reliability. Or the feeders can use data and automatic demand response to minimize the likelihood of equipment failures. Distributed automation and DG are two other aspects of the Smart Grid implementation in the distribution network. Distributed automation consists of monitoring, control and communications. This is the system used to control switches and other devices throughout the grid rerouting power and reconfiguring the grid to restore portions of the troubled areas, avoid additional failures, and minimize losses. DG is achieved by the interconnection of generators from various resources scattered throughout the distribution system injecting power back into the system(M. Vaziri et al. 2011).

While there is an overlap between the substation and distribution automation based on IEC 61850 the main aims of the distribution automation system being supervisory control and data acquisition (SCADA) volt and var control (VVC), fault location (FL), feeder reconfiguration (FR) (Self-Healing), FLISR (fault location, isolation, and service restoration), which is a hybrid of FL and FR. It is far possible realize automation without communication which offers remote monitoring and control of the distribution system. Though there are only one TCP based protocol being used for communications from generation to substation automation, however distribution automation is being realized on a wide variety of communication types like PLC (IEC 61334), Ethernet, RS 485, wireless, 3G, CDMA, WiFi, Zigbee, GPRS, GSM etc, the reason being distribution closer to end usage who use these communications often in day-to-day life. The AMI systems usually, collect data from various smart meters in the field in an automated manner using DLMS/COSEM (IEC 62056) standard specification and transfer it to a central location called Meter Data Management System (MDMS). AMI network offers low-bandwidth two-way communication links
between meters & back office (Balakrishna P and Swarup K S 2015).

Smart Home:
The home network is also a key part of the smart grid vision. Not only are homes connected to smart meters, they will also be comprised of smart devices able to receive signals from their meters. These smart meters are the main driving force behind the concept of demand response. The meters can eventually bill customers at different rates depending on specific time of use giving customers incentive to reduce their load during higher prices. The main objective of demand response is to reduce the load during peak usage times. During peak usage time the price of electricity is very high since expensive and inefficient generation facilities must be used to meet the peak demand. Transmission lines and transformers can be overloaded putting higher stress on the equipment and reducing the life of components. These factors increase the production and delivery cost of electricity and must be passed on to the customers. Demand response reduces the load by charging customers more during peak usage time thus forcing customer control during higher prices. Demand response can also control the load of electric vehicles, or initiate use of batteries of electric vehicles and other storage devices to inject needed power back into the system during critical times. Smart devices in the homes include heaters and AC units, washer, dryer and other large load units. Demand response will be able to increase the temperature of the AC unit several degrees. Doing this through the entire grid can have a significant effect on the number of generators that must be online and their levels of production. Equipment such as washers and dryers can be set to automatically start when electricity prices drop below a certain level relieving the demand on the grid as well as saving the consumer money.

The home network will also be able to monitor energy usage in almost real time, possibly point out areas where customers can reduce their energy usage. This will give the consumer a better feedback and control options than what they have had in the past. For example the feedback for customers who have solar panels or other DG can show their generation levels per hour, per day, per year and their associated payments (M. Vaziri et al. 2011).

Data Network:
The final portion of the smart grid is the data network and the associated computing and analyses algorithms. This puts the “smart” into the Smart Grid. Without the data network none of the previous ideas would be realizable. The data network must be able to receive information from all metering devices in the network and use that data for billing, operations and maintenance. Algorithms will use the data to control power flows, distributed automations, DG output levels, demand response, protection systems, customer feedback and more. Cyber-security is also an essential part of the data network respecting the privacy of customers, prevention of bill tampering and undesirable control function. Protection against cyber and other attacks through the network would include some redundancies in the data and control networks (M. Vaziri et al. 2011).

Policies, Regulations, And Standards For Smart Grid In India:
Deregulation and liberalization of energy market favours the grid transformation. Increased demand for safe, highly reliable supply, having lesser environmental concerns of generation methods and increasing cost effectiveness of emerging technology supports the changing paradigm (J. A. Pecas Lopes et al. 2006). Reforms in tariff, insurance, regulation and operating standards are needed. Many utilities now face renewable portfolio standards (RPS), which mandate that a certain percentage of energy that they supply be generated from renewable processes. With customers and utilities both finding incentives for using DG, the difficulties faced for realizing effective and efficient implementation are more readily overcome.

Beyond the well-recognised needs for standardisation, modularity, etc, improved Smart Grids require the following policies and efforts: think bottom-up on consumer’s needs. Utilities are trying to implement the Flagship R-APDRP (Restructured Accelerated development and Reform Programme), which is the first step towards Smart grids. Smart Grid sustainability comes when there is a need for them. One has to account for marginal costs and time of day costs, instead of average costs. Cost benefit analyses (CBA) can be used for proving the business case of Smart Grids instead of utility ROI (return on investment). Infrastructure, telecoms, data center, analytics and more, can be shared by utility. If first, utility buys the smart meter, ultimately down the road, it charges the consumers. Which is a small price to pay for improved electricity (Rahul Tongia 2015).

To help drive both funding and policy, the government is planning a National Smart Grid Mission (NSGM). Smart Grids is not a product, it’s a process. Hence, the ability to engage if not mandate participation from required stakeholders will be key to success. States, which are resource-constrained, both in skilled manpower and cash are real challenges. Along with addressing transformation challenges, a Smart Grid also have to include new trends like Electric Vehicles, Renewable Energy, energy efficiency, climate change, etc. Rather than load-shedding, which is easy and cheaper, utility should be granular. This can be based on type of consumers and tariffs. This can now be done smartly, in an equitable, transparent, and efficient manner.
The EA2003 amendments must reflect Smart Grids, renewable, and storage technologies, removing generator centric licensing norms for their use. If a consumer is capable of Demand Response, they should be treated equivalent Virtual Power Plant. While demand Response is usually for larger consumers, renewable could allow anyone to become a prosumer. Beyond penalties, the Act should also allow the use of innovative supply models to meet shortfalls.

New storage technologies are on the horizon, and these are likely to have increasing impact on grid operations. If one had a very cheap electricity storage solution, it would profoundly affect Reintegration into the grid. There is evidence that storage economics are driven not by energy arbitrage by time of day but the ability to ramp up/ down rapidly, i.e., ancillary services markets. Batteries are driven by the push for electric vehicles (EVs). Since the grid doesn’t need energy density like a car does, specialized and/or cheaper battery solutions are likely to emerge. To help the growth of energy storage technologies, policy support includes pricing incentives, including Time of Day pricing; start of ancillary service in the grid; R&D support, from basic research to pilot deployments; regulatory ability for storage technologies to enable prosumer participation (Rahul Tongia 2015).

Smart Grid regulations: A draft of the model smart grid regulations has been prepared by the Technical committee of the Ministry of Power. These regulations are expected to provide an over arching regulatory framework for the deployment of smart grid technologies in the country. The scope of these regulations encompasses various parameters, including smart grid investment approval and beneficial tariffs for consumers; an incentive structure for smart grid deployment; the adoption of relevant equipment, communication and interoperability standards and codes; the integration of renewable and distributed generation for enhancing grid efficiency; and network security and consumer privacy. The model regulations will act as a guide for the review and approval of investments in Smart grids and also ensure cost recovery and alignment with the multi-year tariff cycle. As per regulations, a Smart grid Consultation Committee (SG-CC) will be appointed by the state electricity regulatory commissions (SERCs), which will assist it in evaluating Smart grid projects and in creating an SG-CC fund through the licensee’s annual fees. The process of cost recovery under the regulations will entail determining the annual revenue requirement, specific tariff schemes and the pricing of new services. The specific tariff schemes will include time-of-use tariffs, critical peak pricing, real-time pricing tariffs, and variant and combination tariffs. The regulations will also be a guide to the safety standards for products system, and communications as set by the Central Electricity Authority (CEA) and/or the Bureau of Indian Standards. They also envisage customer engagement by spreading awareness and capacity building, and ensuring customer participation through various incentives. There will also be guidelines for consumer grievance redressal (“Regulatory Initiatives” 2015).

The CEA initiatives include finalising the minimum functional specifications of low-cost single-phase smart meters as per Indian requirements, and notifying regulations on technical standards for connecting distributed generation sources to the grid at voltage levels below 33 kV. Regulations pertaining to the operational standards of renewable energy grid connectivity are also expected to be formulated by the CEA within a year.

Some of the key area that smart grid activities are centred on relate to distributed generation sources and net metering. With the concept of grid connected solar rooftop power generation gaining consumer popularity because of its competitive costs, an effective regulatory mechanism has been gradually developed to accommodate this growing interest. Net metering primarily allows self-consumption of generated power while enabling the sale or banking of additional generation with the local discom. Tamil Nadu and Andra Pradesh were the first states to initiate the process of drafting net metering regulations, in 2012 and early 2013 respectively. In August 2013, the concept of net metering for small-scale and solar rooftop projects was discussed by the forum of regulators (FoR), following which the draft model regulations were issued in November 2013. These are aimed at facilitating and expediting the formulation of such regulations at the state level.

Regulations for enabling effective DSM by discom have thus become critical to ensure grid stability. DSM relates to the actions of a discom that are beyond the customer’s meter, and is aimed at altering the end-use of electricity. The objective of such manipulation is to increase electricity demand, decrease and shift it between high and low peak periods, or manage it when there are intermittent load demands, in the overall interests of reducing the discom’s costs. DSM has the potential to mitigate various electrical system emergencies and exigencies, reduce the quantum of load shedding, and increase system reliability. While states like Gujarat and Maharashtra have issued DSM regulations, Delhi and Haryana are among the more recent ones to do so. Haryana’s DSM regulations, which were released in December 2014, prescribe targets for reduction in peak load in different seasons, overall load, energy consumption, as well as targets for improving the power factor for a particular control period. As per Delhi’s DSM regulations, which were released in the same month, the formulation of an annual plan with identified DSM programmes and implementation schedules, along with cost benefit analysis and an approval process has been proposed. The development of these programs will be based on load.
research, consumer service and compilations of baseline data.

The critical need for these regulations can be understood in light of the larger investments and lead time that smart grid technologies entail and the nascent nature of the resources, players, standards and incentive structures associated with them. It is encouraging to see the steps taken by the CEA and the FoR, such as the formulation of model documents and the finalisation of technical standards like those for enabling the integration of renewable energy. However these plans need to be actively pursued at the state level if the desired results are to be achieved ("Regulatory Initiatives" 2015).

To accommodate the effect of varying load pattern, time of use (TOU) tariff can be introduced (N. Phuangpornpitak, and S. Tia 2012). Under TOU tariff, electricity would be expensive during the peak period and would be cheaper during the off-peak. Uniform tariffs should be applied nationwide for each individual customer category; subsidization for residential consumer should remain, particularly for small residential consumers whose consumption is low. Intelligent communication device with digital real time power measurement offers the opportunity for operation and meter reading as well as potential for real time pricing, new tariff option and demand side management.

To lower energy prices and improve service quality, competition is to be introduced in generation and customer should be given the choice to select. For this to happen, many players should be present in market. To trade in ancillary services, appropriate market conditions should exist.

There is extreme lack of standards regarding the implementation of DG – specifically with regard to interconnection methods and schemes, tariff payment schemes, power quality characteristics and insurance policies. In success of renewable energy promotion pricing is an important factor (N. Phuangpornpitak, and S. Tia 2012). The application of smart grid technology promises to provide benefit to electricity consumers by better utilizing electric system assets to securely satisfy consumer energy demands at a lower monetary and environmental cost.

Existing standards must be followed, although some must be updated to meet the needs of the new Smart Grid objective without creating protection and stability problems. Table 1 (Mathias Uslar et al. 2013) lists the standards relevant to smart grid.

**Table 1: Relevant standards for Smart Grids**

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<thead>
<tr>
<th>Sl. No.</th>
<th>Standards</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>AMI-SEC System Security Requirements</td>
<td>Advanced Metering Infrastructure (AMI) and SG end-to-end security</td>
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<td>2</td>
<td>ANSI C12 Surt (C12 1, C12-18, C12-19/MC 1219, C12-20, C12-21/IEEE P170/MC1221, C12 23, C12 24)</td>
<td>Revenue Meter Information Model</td>
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<tr>
<td>3</td>
<td>BACnet ANSI ASH-RAE 135-2008/ISO 16484-5</td>
<td>Building Automation</td>
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<td>4</td>
<td>Digital Meter/ Home gateway</td>
<td>EU Mandate M/441</td>
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<td>5</td>
<td>DNP3</td>
<td>Substation and feeder device automation</td>
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<td>6</td>
<td>EDIXML</td>
<td>Market Communication with slow transition from EDIFACT to new CIM- based technologies</td>
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<tr>
<td>7</td>
<td>IEC 60870</td>
<td>Established communication protocol</td>
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<td>8</td>
<td>IEC 60870-5</td>
<td>Telecontrol, EMS, DMS, DA, SA</td>
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<td>9</td>
<td>IEC 60870-6/ TASE 2</td>
<td>Inter-control center communications TASE 2 Inter Control Center Communication EMS, DMS</td>
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<td>10</td>
<td>IEC 61158</td>
<td>Foundation field bus automation</td>
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<td>11</td>
<td>IEC 61334</td>
<td>DLMS</td>
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<td>12</td>
<td>IEC 61400-25</td>
<td>Wind Power Communication EMS, DMS, DER</td>
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<td>13</td>
<td>IEC 61499</td>
<td>PLC and automation profile for IEC 61850</td>
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<td>14</td>
<td>IEC 61850 Suite</td>
<td>Substation automation and protection, DER, wind farm, hydropower plants, e-mobility</td>
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<td>17</td>
<td>IEC 61851</td>
<td>EV- Communication Smart Home, e-Mobility</td>
</tr>
<tr>
<td>18</td>
<td>IEC 61968</td>
<td>Distribution Management System Interfaces for Distribution Management Systems, DCIM (CIM for Distribution)</td>
</tr>
<tr>
<td>19</td>
<td>IEC 61968/61970</td>
<td>Application level energy management system interfaces, CIM (Common Information Model),</td>
</tr>
<tr>
<td>No.</td>
<td>Standard Code</td>
<td>Description</td>
</tr>
<tr>
<td>-----</td>
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</tr>
<tr>
<td>20</td>
<td>IEC 61970</td>
<td>Domain Ontology, Interfaces, Data Exchange formats, Profiles, Process blueprints, CIM, EMS, DMS, DA, SA, DER, AMI, DR, E-storage</td>
</tr>
<tr>
<td>21</td>
<td>IEC 62051-54/ 58-59</td>
<td>Energy Management, Application level energy management system interfaces, Core CIM</td>
</tr>
<tr>
<td>22</td>
<td>IEC 62056</td>
<td>Metering Standards DMS, DER, AMI, DR, Smart Home, E-Storage, E-Mobility</td>
</tr>
<tr>
<td>23</td>
<td>IEC 62270</td>
<td>COSEM DSM, DER, AMI, DR, Smart Home, E-Storage, E-Mobility</td>
</tr>
<tr>
<td>24</td>
<td>IEC 62325</td>
<td>Power plant Automation</td>
</tr>
<tr>
<td>25</td>
<td>IEC 62351</td>
<td>Market Communication using CIM</td>
</tr>
<tr>
<td>26</td>
<td>IEC 62357</td>
<td>Security, Information security for power system control operations, security profiles</td>
</tr>
<tr>
<td>28</td>
<td>IEC 62541</td>
<td>Method to achieve IT- Security regarding industry automation and control systems</td>
</tr>
<tr>
<td>29</td>
<td>IEC PAS 62559</td>
<td>Requirements Development method covers all applications</td>
</tr>
<tr>
<td>30</td>
<td>IEEE 1547</td>
<td>Physical and Electrical interconnections between and Distributed Generation (DG)</td>
</tr>
<tr>
<td>31</td>
<td>IEEE 1686-2007</td>
<td>Security for Intelligent electronic Devices (IEDs)</td>
</tr>
<tr>
<td>32</td>
<td>IEEE C37 118-2005</td>
<td>This standard defines Phasor measurement unit (PMU) performance specifications and communication for synchrophasor data</td>
</tr>
<tr>
<td>33</td>
<td>ISO/ IEC 14543</td>
<td>KNX BUS</td>
</tr>
<tr>
<td>34</td>
<td>MultiSpeak</td>
<td>A specification for application software integration within the utility operations domain, a candidate for use in an Enterprise Service Bus</td>
</tr>
<tr>
<td>35</td>
<td>NERC CIP 002-009</td>
<td>Cyber security Standards for the bulk power System</td>
</tr>
<tr>
<td>36</td>
<td>NIST Special Publications (SP) 800-53, NIST SP 800-82</td>
<td>Cyber security standards for the bulk power system</td>
</tr>
<tr>
<td>37</td>
<td>Open Automated Demand Response</td>
<td>Price responsive and direct load control</td>
</tr>
<tr>
<td>38</td>
<td>Open HAN</td>
<td>Home Area Network device communication measurement and control</td>
</tr>
<tr>
<td>39</td>
<td>The Open Group Architecture Framework (TOGAF)</td>
<td>TOGAF is a framework containing a detailed method and a set of supporting tools for developing an enterprise architecture</td>
</tr>
<tr>
<td>40</td>
<td>ZigBee/ HomePlug Smart Energy Profile</td>
<td>HAN Device Communication and Information Model</td>
</tr>
<tr>
<td>41</td>
<td>Z-wave</td>
<td>A wireless mesh networking protocol for home area networks</td>
</tr>
</tbody>
</table>

**Status Of Smart Grid In India:**

Smart Grid Vision for India: “Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders” (Smart Grid Vision and Roadmap for India 2013).

The Indian power system is the fourth largest in the world, with 230GW of installed capacity with utilities, but per-capita consumption of electricity in India is only about one-fourth of the world average. The lack of access to electricity to a significant proportion of the population accounts for this low consumption. The demand is expected to increase to 900GW by 2032. The renewable energy (RE) generation target in 12th five year plan is 36GW which is higher than the current share of RE by around 20%. To ensure the stability and reliability of
a power system of this size growing at such a rate with an increased share of RE requires smarter system to manage it effectively and efficiently. The Government has launched a National Electric Mobility Mission (NEMM) on Electric Mobility with a target of 6 million electric vehicle (4 million two-wheelers and 2 million four wheelers) by 2020. Smarter systems and distribution infrastructure upgrades are required for efficient roll out of the EV program, to control/limit simultaneous charging of more number of EVs from the same feeder. Timing the consumption of power is required and above that policy level support is needed to build infrastructure to integrate the EVs to the existing electric network so that these EVs are connected to the power system. These can be used as virtual power plants (VPPs) that can store energy during surplus generation and supply power to the grid during deficit. To achieve these objectives Vehicle to grid (V2G) technologies are evolving rapidly (Smart Grid Vision and Roadmap for India 2013).

In Indian power system and distribution network, the transmission and distribution losses are very high (aggregate technical and commercial, or AT&C). Thus, the top priority of both utility and government is loss reduction. To arrest the losses, Smart grid solutions can be used. This will help measure, monitor, and power flow control in real time, which can help identify losses. Thereby appropriate actions can be taken to reduce them.

Smart Grid priorities for India include reduce transmission and distribution losses, improve quality of supply, revenue cycle optimization, manage peak power, Demand response and integrate renewable/distributed generators to the grid efficiently. In order to hasten the deployment of the Smart Grid initiatives in the country, the Government of India (GoI) created the India Smart Grid Task Force (ISGTF) and the India Smart Grid Forum (ISGF), and the pilot projects are positive steps in this direction (Mukesh Gujar et al. 2013).

One of the key tasks undertaken by the ISGF and ISGTF was releasing a Smart Grid Vision and roadmap for India in September 2013. The policy objectives being “access, availability and affordability of power for all” (Smart Grid Vision and Roadmap for India 2013). This serves as a guiding document and recommends an overarching set of policies and programmes to build smart grids in India. Maharashtra, Orissa and Haryana are some of the states that have moved towards formulating their own roadmaps.

The Energy Research Institute (TERI) has installed three Off-Grid solar PV plants in state of Orissa. The plant is featured with intelligent load management and battery management using load shedding protection by segregating the critical and non-essential loads. TERI has implemented first of its kind Smart Mini Grid (SMG) Project, in Haryana. For supplying captive load of the campus. The plant include solar, wind, biomass, etc, as the distributed energy source. This SMG can be operated in grid connected or stand alone mode. Norway-based Company Scatec Solar decided to setup an 8.7 kW power plant in Rampur. Which is India’s first community managed solar power plant, since the day of commissioning, this village has not been without for a single day. India based independent power producer Azure Power has been awarded a grant from the US Trade and Development Agency (USTDA) to assist the development and accelerated adoption of solar power in rural India. Gujarat and Chhatisgarh have grid-connected solar power project that are over 1MW in capacity. Azure Power will, open up the potential of electrifying rural India through solar powered micro-grids. Azure aims to setup over 100 micro-grid solar systems, with each system covering an average of 2-3 acres of rural land which would electrify approximately 800-1000 villages with little or no power connectivity to existing grids (Mukesh Gujar et al. 2013).

However to effectively implement the goals conceived in the smart grid vision and roadmap, key stakeholders proposed the launch of a National Smart Grid Mission (NSGM). Therefore, the MoP is planning to launch the NSGM, which is proposed to serve as a focal point for coordinating all activities being undertaken for the development of smart grid in India across different ministries. It will provide an institutional framework with dedicated manpower and resources to implement smart grid activities in the country on a large scale and build a cost effective, responsive, reliable and self healing power infrastructure.

One of the key activities to be undertaken as a part of the NSGM is the coordinated development of smart grid activities in 30 cities since the ISGF has been advocating that smart grid can be leveraged for creating smart cities at a marginal cost. These smart grids will then be extended to other infrastructure domains within these cities. The smart cities concept under the NSGM will be limited to the development of the smart grid activities in the country on a large scale and build a cost effective, responsive, reliable and self healing power infrastructure.

The NSGM will serve as a guide for planning and investments for future power projects, and transmission and distribution activities at an all India level, utility support and cooperation from state
regulatory bodies will be critical in order to ensure the success of the mission, given that much of the effort is required to be implemented at the utility level.

There are fourteen smart grid pilot projects under execution in India during the span 2013 to 2016. The different attributes for which are: AMI for residential, commercial and industrial consumers; Peak load management; Outage management; Better power quality; Integration of renewable energy source; Establishment of micro grids and Distributed generation.

All the selected projects will deploy advanced metering infrastructure (AMI). Various functionalities including peak load management, load forecasting, asset management, outage management, renewable energy integration, power quality management (PQM), micro-grids, aggregate technical and commercial (AT&C) lose reduction, time-of-use metering, and dynamic and real-time pricing and proposed to be tested under these pilot projects. Their successive execution will provide clarity on the feasibility of the technologies deployed as well as allow policy makers to create an enabling framework on smart grid implementation.

The pilot project at Pondicherry division 1 is being executed by Power Grid cooperation of India Limited (Power-grid) in partnership with the Puducherry Electricity Department and over 60 collaborators. A smart grid control center (SGGCC) has been commissioned while the integration of different smart grid systems and technologies has been completed. Under AMI, over 1650 smart meters and 33 digital control units have been installed in nine distribution transformers (DTs). Meters of different communication technologies (RF 2.4 GHz, RF 865 MHz, PLC, BPLC and GPRS) have been successfully integrated at the control centre. For the outage management system, eight DT monitoring systems were installed to monitor the health of the DTs on parameters such as oil temperature and oil level. In addition, about 21 fault passage indicators were installed, which send alerts to the SGGCC as well as to mobile phone to the maintenance crew. For PQM, automatic power factor correction panel and active filters were installed. Steps are also being taken to integrate renewable energy to the grid. As of November 2014, smart meters with net metering were installed for three consumers with solar rooftop projects, in a first-of-its-kind initiative in Pondicherry. A solar-powered charging station for electric vehicles is also in place. In addition a smart street lighting system covering 126 lamps has been implemented. The system allows automatic on-off and intensity control of street lights depending on luminous and traffic conditions. The deployment of smart meters has led to several benefits for the electricity department including about 57% saving in energy consumption and 14% increase in metering efficiency. Billing efficiency has also increased proportionally (“Smart Grid Pilots”, 2015).

Table 2 shows the location of the pilot project and the new technology used in the particular location (http://indiasmartgrid.org/en/Pages/Projects.aspx).

### Table 2: Smart Grid Pilot Projects Under Execution in India

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Name and Location</th>
<th>New Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UHBVN, Haryana</td>
<td>Model for TOU tariff, Net metering, DSM for PLM</td>
</tr>
<tr>
<td>2</td>
<td>CESC, Mysore</td>
<td>Introduction of real time pricing signal by interfacing at SLDC level, Implementation of Fault Location Isolation and System Restoration (FLISR) at feeders, Distributed Energy Sources integration using already available technologies</td>
</tr>
<tr>
<td>3</td>
<td>TSECL, Tripura</td>
<td>Model for TOU and net metering</td>
</tr>
<tr>
<td>4</td>
<td>KSEB, Kerala</td>
<td>Provide better and quality service, Prevent tampering, Accurate and timely metering and billing, Real time reporting of power failure thus reducing supply restoration time, Peak load management, Remote Disconnection / Reconnection</td>
</tr>
<tr>
<td>5</td>
<td>Electricity Dept., Govt. of Puducherry (PED)</td>
<td>Common Meter Data Management System is proposed to be developed that shall take data from MDMS of Different meter manufacturer/solution provider and integrate the information for use. Developing a mature model of “time of use tariff and net metering”</td>
</tr>
<tr>
<td>6</td>
<td>UGVCL, Gujarat</td>
<td>Introduce TOU tariff, Renewable energy integration is proposed through proper and accurate load forecast by real time monitoring of substations, feeders and RES generation</td>
</tr>
<tr>
<td>7</td>
<td>APCPDCL, Andhra Pradesh</td>
<td>AMI for Residential and Industrial, Outage Management, Peak Management and Power Quality management. The design proposes a Smart Grid Control Center housing the IT systems, a two way communication system for AMI. The customer web portal based on Green Button standards would provide all customer related information and to seek their participation</td>
</tr>
<tr>
<td>8</td>
<td>APDCL, Assam</td>
<td>Integration of the 100kW solar farm into the distribution network via a bidirectional inverter and use of battery storage, possibly Vanadium redox battery, in conjunction with the solar farm, R&amp;D on Load forecasting based on the weather, social events, festivals etc., Developing controllers for the bidirectional inverter and battery integration, Development of filters for reduction of harmonics injected into the grid and integrating it into the smart meters. Development of messaging systems (for display in house and on mobile) for power consumption information and methods to reduce energy consumption</td>
</tr>
<tr>
<td>9</td>
<td>MSEDCL, Maharashtra</td>
<td>Introduction of communication technologies like GPRS/CDMA/RF in metering environment with common protocol and near real time analytics technologies for meter analytics as well as near real time event insights coming from SCADA systems. Motorization of all feeder breakers and RMU’s is also proposed</td>
</tr>
<tr>
<td>10</td>
<td>CSPDCL, Chhattisgarh</td>
<td>Model of TOU and experimenting techniques like DSM for peak load management (PLM)</td>
</tr>
<tr>
<td>11</td>
<td>HPSEB</td>
<td>High End Power Quality meters to be installed at HT consumers (Steel Mills), 1 each at 132, 33 &amp; 11 KV</td>
</tr>
<tr>
<td>No.</td>
<td>Company</td>
<td>Description</td>
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</tr>
<tr>
<td>12</td>
<td>PSPCL, Punjab</td>
<td>Outages are very frequent in PSPCL. It is proposed to implement Outage Management Systems (OMS) to increase network reliability by proactively monitoring the grid for potential problems using distribution analytics and alarming for notification.</td>
</tr>
<tr>
<td>13</td>
<td>WBSEDCL, West Bengal</td>
<td>Problem Identification, Load Profile for PLM, Energy Audit, Signaling for Load Control, Load Curtailment beyond sanctioned limit, Tamper Detection, Reduced AT&amp;C losses, Increased Billing efficiency, Customer satisfaction.</td>
</tr>
<tr>
<td>14</td>
<td>JVVNL, Rajasthan</td>
<td>AMI involving Integrated Communication and Smart meter, Outage Management System, PLM system, Integration of DER, Data acquisition and Data management. R&amp;D for evolving a model of “TOU tariff and Net metering for Renewable energy”, Receive the instruction from AMI meter&amp; take action based on instruction. IHD (In House Device): The smart energy display device for convenient, timely and relevant information about energy consumption.</td>
</tr>
</tbody>
</table>

The ISGF is divided into several working groups focused on specific areas and one of Working Groups i.e., WG: 9 on ‘Renewable sources and Micro-Grids’ are responsible to develop an architecture and methodology for Micro-grids both off-grid and grid connected so that the same can be isolated from grid and also to develop set of standards guidelines and technology recommendations for integration and efficient operation of renewable sources into the grid; and recommend suitable grid code.

**Integrating Dg To Grid:**

The term distributed generation is generally ill defined. The criteria most commonly used to classify DG are size, location, voltage level, type and use/application. The Institute of Electrical and Electronics Engineers (IEEE) define DG as “the generation of electricity by facilities that are sufficiently smaller than central generating plant as to allow interconnection at nearly any point in a power system”. Distributed Energy Resources (DER) slightly differs from DG as it includes energy storage devices and responsive load, which can be controlled as per requirement to be considered as energy resources (J. A. Pecas Lopes et al. 2006).

The plant efficiency of most central large generation units is in the range of 28 to 35%, by contrast efficiencies of 40 to 55% are attributed to small fuel cells and various hi-technology gas turbine and combined cycle unit suitable for DG application. Increased use of renewable sources reduces greenhouse gas emission considerably. Fuel sources for electricity production have expanded beyond fossil fuel, coal, natural gas, nuclear and hydro to now include wind, hydrogen, solar irradiation, algae and even waste matter. Renewable and distributed generation are here to stay. Their production is likely to double every ten years, on conservative estimates.

To cope with several utility changes and challenges, many utility companies in India are planning to implement various distributed generation based Micro/ Mini grid in Indian power sector. India has made great progress in field of new energy and micro-grid paralleling in the traditional power grid. Since most of the micro/mini-grids are based on the distributed generation source such as Solar PV, Wind etc. These source are very intermittent and unpredictable, hence their optimum utilization is very much necessary to tackle the energy security issues.

**Technical Issues And Challenges:**

Centralized generating facilities are giving way to smaller, more distributed generation. Penetration level must be considered when investigating the effect of DG on grid. Distributed generation if not optimally placed, sized and operated increases issues regarding network loading, stability and power quality (M. Arnold et al. 2013). The degree of impact is closely related with the location and capability of DG. If number of generator nodes increases, finding optimal network layout becomes difficult. There is a need to transform the existing distribution system, from passive to active distribution system. The rise of DG is shifting the grid paradigm away from centralized system that has long been the basis of grid operation (J. A. Pecas Lopes et al. 2006; M. Arnold et al. 2013).

**Influence on Network Loading:**

DG may reduce loading on transmission line as the load is supplied locally and hence it is not needed to bring power from distant power plant. But it will ultimately lead to the distribution lines being at its capacity limit. If the location and capacity of DG is inappropriate, it could cause network loading (load on cables and lines) to increase leading to loss of power or even lines (N. Phuangpornpitak and S. Tia 2012).

**Influence on Grid Stability:**

DG when not used carefully, however, may compromise the stability of the grid. It is important for grid stability that power plants can operate synchronised and with stability, during and after faults. DG does not have significant inertia and is therefore in danger of losing synchronism with the grid during a fault. The loss in generation would destabilise the system, and lowers the critical clearing time significantly. As synchronous induction machines pole-slip in the case of faults, they draw large amount of reactive power (M. Arnold et al. 2013).

Traditionally, distribution network was passive and hence remained stable as long as transmission network was stable. With the presence of DG, steady
state stability and transient stability is to be considered while designing active distribution system.

**Influence on Power Quality:**
Poor power quality is reflected as heat dissipation of different form in different parts of distribution system. The thermal resilience defines the maximum load that can be handled by equipment, if this limit is exceeded it will lead to reduction in lifetime, reduction in efficiency or even failure of equipment (J. A. Pecas Lopes et al. 2006; M. Arnold et al. 2013).

**Steady State Voltage:**
The specified voltage at the point of connection is called the steady state voltage. Voltages greater than this, may cause equipment insulation to degrade faster than intended, resulting in a reduced lifespan. If the voltage is less than this, equipment may fail to operate as intended. Motor driven equipment may fail to start or motor might overheat and trip or be damaged.

The point at which DG is connected to grid is called point of common coupling (PCC). The voltage at PCC is influenced locally by the grid impedance and the power flow due to load and generation. Power consumption lowers while power generation increases the steady state voltage (V. Gosbell et al. 2012).

**Voltage Swell:**
Voltage swell are short term reduction in the rms voltage. A voltage swell is formally defined as an increase in voltage of 10-90% for a time of a fraction of second to a minute. When a DG is connected to the system it starts supplying load locally which reduces the voltage drop in line and takes up the load thereby creating voltage swell. Also the DG whose primary source is unpredictable injects unpredictable power to the system, if not properly managed (Mamatha Sandhu and Tilak Thakur 2014; V. Gosbell et al. 2012).

**Voltage Sag (Voltage Dip):**
Voltage sags are short term reduction in the rms voltage. A voltage sag is formally defined as a reduction in voltage to 10-90% for a time of a fraction of second to a minute. Faults within the power system or starting of very large induction motor cause a short term reduction in voltage. The depth of sag depends on the position of fault on the feeder and duration depends on the fault current. With the presence of DG if the protection system is not adapted, it can cause frequent voltage sag due to power system faults. Voltage sag if prolonged can cause equipment failure (E. Prathibba and A. Manjunath 2014; V. Gosbell et al. 2012; Sandra Hutter 2013).

**Voltage Interruption:**
Voltage interruption is defined as the decrease in voltage to less than 10% for a period of time not more than 1 minute. The causes can be temporary faults, equipment malfunctioning, false tripping of protective relay due to presence of DG etc. (V. Gosbell et al. 2012).

**Voltage Unbalance:**
Ideally the three voltages of the three phases should be of equal magnitude and should have a phase displacement of 120 degree among each other. Due to connection of single phase loads and generators the balance between the three phases is disrupted.

The unbalanced voltage can be split into three symmetrical components namely, positive, negative and zero sequence. For analysis of unbalance only positive and negative sequence are considered, as zero sequence will be limited by transformers and network grounding. The voltage unbalance factor (VUF) is defined as the ratio of negative sequence ($V_N$) to positive sequence ($V_P$) voltage (Zhixuan Liu and Jovica V. Milanovic 2013).

It can have serious negative impact on transformers, controls, distributed three phase generators and power electronic devices. Such an unbalanced supply can cause three phase load to malfunction and overheat. Unbalance significantly increases the distribution loses and create loading on the lines (M. Arnold et al. 2013).

Electric vehicle chargers are single phase units, might impose significant unbalance on the system.

**Voltage Fluctuation:**
Some variations are cyclic in manner with a period ranging from a fraction of a second to several minutes. This gives an approximately cyclic change in the voltage magnitude over a similar time scale. The wind turbine characteristics and grid position will cause voltage fluctuations. As penetration of wind power increases, this issue will become increasingly prominent (Ze-jun Ding et al. 2013).

**Flicker:**
The term flicker refers to a visual effect caused by voltage variation below a certain frequency. DG like wind and solar PV could cause the voltage flicker (M. Arnold et al. 2013; Ze-jun Ding et al. 2013; Sandra Hutter 2013).

**Harmonics:**
Mostly electronic equipments draw a current with a wave shape which is usually a series of positive and negative pulses which are narrower than would be expected from a sinusoid. The effect is to change voltage magnitude and also wave shape, this effect is called harmonic distortion.

DG itself is a harmonic source. Harmonics is introduced due to the power electronics interface of
DG to the system. This derates the components in the system like conductors and transformers due to the presence of high frequency components (E. Prathibha and A. Manjunath 2014; V. Gosbell et al. 2012).

**Transients:**
A very high current is injected into a power line during lightening or switching causing transients. They can cause high voltages of several times the nominal value, thereby causing overvoltage protection equipment to trip. This voltage surge propagates along the lines with reduced magnitude can cause damage to sensitive electronic equipments. Switching in or out of DG with large rating can cause transient( Mamatha Sandhu and Tilak Thakur 2014; V. Gosbell et al. 2012).

**Influence on System Protection:**
Distribution system throughout the world is primarily radial in fashion. A radial system feed load from a single supply point which greatly simplifies the task of protection system( J. A. Pecas Lopes et al. 2006).

The presence of DG changes the magnitude of fault current. The change in fault current magnitude can make the fault invisible to the protection equipment, called blinding of protection. Due to presence of DG the coordination among the relays also changes. The presence of DG can cause false tripping or nuisance tripping, this disconnects customer from service unnecessarily and deteriorates system reliability. False tripping can cause delayed clearing of fault and unsynchronised reconnection (Saiyi Wang 2009; Edward Coster et al. 2007; Florian Romanens et al. 2011).

The power, or current, that is sustained during a short circuit is an important measure for the design of protection equipment. Short circuit currents cause high magnetic forces, high temperatures in equipment, thermal and mechanical impacts of arcing and dangerous touch and step voltages. The lowest possible short circuit power is important to set the right tripping parameters, the highest possible power to choose the right breaking capacity (M. Arnold et al. 2013).

DG can be classified into synchronous, asynchronous generators and power electronic interfaced generators. Out of the three synchronous generators contributes significantly to short circuit power. In weak system DG adversely affects the fault current( Mamatha Sandhu and Tilak Thakur 2014).

**Intermittent and Undipatchability:**
Renewable energy sources like wind and solar PV are highly unpredictable, due to the variability of its primary source. Their availability at the time of need and the amount in which they will be available cannot be known for sure.

The electricity grid to accommodate higher percentage of renewable energy would need large quantities of conventional backup power and huge energy storage. These would be necessary to compensate for natural variations in the amount of power generated depending on the time of day, season and other factors such as the amount of sunlight or wind at any given time (N. Phuangpornpitak and S. Tia 2012).

**Influence on Reliability:**
Parallel operation between DG and power network, the reliability of power supply system is possible to be weakened. If there are a number of DG in the system, if DG is failed to coordinate with each other DG will decrease system reliability.

DGs have lower reliability than large power plants as they may be out of service much more frequently due to disconnection necessity than faults (Saiyi Wang 2009).

The power quality issues introduced by the DG increases the loading on the lines thus reducing the reliability of the system.

There has to be a good correlation between production and consumptions to ensure grid reliability and maximising income from production. It is difficult to achieve this if the DG is solar PV or wind.

**Low X/R Ratio:**
While X/R >>1 for transmission line, it is around one or even lower for low voltage distribution system. Reactive power control for voltage control is not possible. The system stability control become complex with the presence of DG. This factor can also have an adverse effect on short circuit power (Edward Coster et al. 2007; M. Arnold et al. 2013).

**Interference Between Devices:**
The high frequency switching in power electronic interface produces EMI, which can cause interference with communication channels and other devices nearby.

**Technical Solutions For Problems Associated With Integrating Dg To Grid:**
As penetration level of DG increases it becomes imperative to optimize the control of generation, placement and sizing of DG. There are many optimization techniques available but the feasibility of each method is yet to be validated. There are active management systems available, for optimum operation of power grid. By doing which many of the issues mentioned above can be mitigated. Many other methods are also available which provide solution for a few specific issues (M. Arnold et al. 2013).

Virtualize (e.g. micro-grid, local grid etc.), a local generator as a constant load, source, or zero load to the grid, therefore the stability and reliability of the grid can be enhanced. Take the case of one transmission line outage which leads to a cascading sequence of line outages since when one line trips, its
power flow redistributes to other lines in the grid, and may cause them to be congested and tripped. With the help of DG the maximum line loading decreases as we increase the number of local generators, when most of the load buses are local generators, the maximum line loading is close to zero. As most of the loads are served locally the amount of flow inside the grid is very low, thereby preventing cascading sequence of line outages.

In order to ensure the security of power grids, high quality operation, the DG must be able to accept the dispatch. To achieve this goal, the necessary control and regulation is to be done while integrating DG to existing distribution system.

Power quality issues can be detected by continuous and extensive monitoring of the power system quantities. Prevention and corrections of probable causes can be done. Small loads and generators have little impact on the systems balance, however generators bigger than 4.6kVA have to be connected to all three phases. There are control strategies for three phase inverters that reduce unbalance.

D-FACTs (distribution FACTs) equipment can be used to coordinate the loading in the grid. FACTs controllers can change line longitudinal and lateral impedances, series voltage and lateral currents within the network to control the power flow (Sandra Hutter 2013). Additionally, microprocessor based controllers and power electronic based FACTS devices can be added to increase the power quality, efficiency and stability of the system. On load tap changer (OLTC) or line drop compensator (LDC) can be used to keep voltage a constant (M. Arnold et al. 2013).

DGs can help in improving power quality issues of the grid by providing ancillary services like grid support (V,f,Q), active filter etc (Peter Esslinger and Rolf Witzmann 2013). It can help in improving power factor of the grid thereby reducing T&D losses in the system. During night time due to lightly loaded distribution transformers the system becomes inductive in nature (lagging power factor) the inverters can be so controlled that it supplies reactive power at night( J. A. Pecas Lopes et al. 2006). The use of virtual grid approach (recommended by IEC 61400-21) can effectively solve the problems that assess the reactive power compensation of wind farm capacity (Ze-jun Ding et al. 2013).

As DG penetration increases, its participation in providing ancillary services for secure and reliable operation of power system become economically imperative (Moncef Labed 2014). Many DG have the ability to operate at various power factors and may even be able to act as sources/sinks of reactive power when not generating. With the help of active management system balancing of generation with load and ancillary service can be achieved. Generator dispatch, control of transformer taps, voltage regulators, reactive power management and system reconfiguration in an integrated manner help in doing so. A sensible control strategy of generators as well as DSM (demand side management) and SSM (supply side management) are advised to tap the full potential of load reduction by synchronizing load and generation within the grid. Active power management like DSM, SSM, and managed storage can be used to stabilize voltage.

Finding sites for DG that demand manageable levels of alteration to protection scheme to make the project economically feasible.

Operating radial distribution system in looped fashion may have benefits when DG is connected. Since DG unit would be connected to two feeders during looped operation, the unit could remain connected to the grid when a fault on one feeder would otherwise require a complete disconnect. Distribution system with high DG penetration could benefit from operating normally in looped fashion (Saiyi Wang 2009).

In order that intermittent energy sources provide constant power sources storage devices and inverters may be used to regulate output. The unpredictable variables that govern these systems are not completely unpredictable, they are predictable to some degree. The foresee ability of variability of primary source is the key to manage its operation. For example, a solar powered unit would never experience an instantaneous transition from full sunshine condition to pitch darkness. Solar powered system also tends to follow load demand since both are high during day and minimal at night. The unpredictability can be modeled to a fair degree of accuracy by conducting a survey of climatic conditions (H. Ibrahim et al. 2011).

Rerouting of power to maximize the efficiency of power flowing through specific paths increasing reliability.

The idea of transient stability is to survive disturbances and return to balanced operation by recovering voltage and staying in synchronism with the network, fault ride through is expected to solve this issue. Fault ride through is the ability to stay in operation during the fault ( Mamatha Sandhu and Tilak Thakur 2014).

The influence of DG on system protection can be dealt with by simple setting modification to the introduction of differential relays or measurement based adaptive over current relays. Microprocessor-based reclosers are applied to restore the coordination between the fuse and reclosers. In microprocessor several trip curves can be programmed and the microprocessor keeps track of which curve is in use. In microprocessor the fast curve should be programmed in such a way that this curve is selective with the lateral fuses, especially in presence of DG (Edward Coster et al. 2007).

The inertia provided by big rotating generators (especially wind generator) stabilises the frequency
even during deep voltage depressions and enables long critical clearing times in a network. Automated disconnection due to frequency deviation for frequency below nominal frequency is to be avoided. Output power of DG is to be reduced, for frequency deviations above nominal frequency.

As DGs are connected to the distribution side, the low X/R ratio of distribution line and the type of DG used should be considered while modelling the system.

The equipment/devices used in DG interface should be electromagnetically compatible (EMC).

Conclusion:

This paper has discussed the features of smart grid, how each component of traditional grid has to be modified to make it a smart grid. The additional features required for smart grid are also mentioned. The smart grid is envisaged to provide customer with more choices based on one’s own power. The policies to be adopted to make it happen, regulations to be imposed to ensure the smooth transition, and standards relevant to smart grid is also discussed. The various initiatives taken and status of pilot projects in India are briefly discussed.

Many technical challenges and solutions are present in integrating DG to main grid. The challenges include power quality issues say 15% drop in voltage increase the loss by 44%, a fall in power factor from 0.99 to 0.85 increase loss by 30%, voltage unbalance of 2% increase loss by 12%. All such losses create reliability issues due to network loading. Also due to presence of DG there are reliability issues, stability issues, protection issues etc. The solutions to these come in the form of optimized control, placement and sizing of DG. Operations of DGs if so optimized can also be made in favor of grid, by increasing reliability, reducing transmission network loading, improving power quality, supporting grid stability (ancillary services). Some of the issues mentioned above can be solved by more than one measure. Financial, technical and regulatory arguments have to be examined to choose the best solution. Everything possible should be done in favor of DG as it addresses the most grave concern all over the world today which is even capable of wiping off the planet earth namely the climate change.

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