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Opportunities and Challenges of ICT in AMI

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Abstract: History has proved that there has not been a reasonable up gradation in the power grid of 20th century and the current electric power network is ill-suited for 21st century. An efficient, reliable and secure delivery of energy to the consumer is required in a modern power grid infrastructure. Especially for the countries like Pakistan, where energy crisis is severe, modern power infrastructure can contribute in presenting a solution of the crisis. According to a report generated by Asian Development Bank, Pakistan is facing the transmission and distribution losses of up to 24.3%. A major flaw of the present power grid infrastructure is the lack of information and communication technologies (ICT) and load management system. The challenges being faced by existing power grid can be addressed with the introduction of new emerging smart grid technologies. Smart grid technologies facilitates the power grid with efficient sensing, faults detection, automatic meter reading, modern information and communication technology, proper energy management systems based on customer's demand and supply optimization, resilience, self-healing and sustainability. This paper overviews the issues in implementation of the information and communication technologies. It also highlights the challenges like different time spans in meter data collection and management, safe and secure communications at the deployment level, etc.

Key words: Smart Grid · Advanced Metering Infrastructure · Information and Communication Technologies

INTRODUCTION

Future electricity power network must restructure to improve their efficiency, to provide all the consumers with flexible, cost effective, reliable and accessible power delivery. With the passage of time, trend of distributed generation is extensively spreading, which adds to the complexity of the electric power network. Efficiency of electric power network can be improved by the deployment of sophisticated control system, monitoring system for energy usage, advanced or automatic meter reading system for better management of loads and a proper demand response (DR) system [1]. These issues can be sorted out by collecting and analyzing the real time data and information, energy devices used for energy reduction can be controlled [2].

The new emerging concept in Smart Grids is the implementation of ICT infrastructure that can play a vital role within Smart Grids. Through an advanced control system losses in transmission lines can be reduced and performance of transmission lines operation can be improved. The present distribution system is lacking in information and data sharing by using real time ICT. Therefore, the Distributed System Operators (DSO) are unable to estimate the exact system states that is; voltage, current and power flows, the system estates are approximated using the estate estimators. The information sharing of such kind of networks is not reliable and secure.

It is expected that ICT based distribution system will be enhanced by the large scale applications of smart meters. Various countries are looking forward for the deployment of smart meters such as UK is committed to the full deployment of Smart Meters by 2020 [3, 4]. Standards based on various communication technologies have emerged in recent past. IEEE P1901.1, P1901.2, G3, PRIME and IEC 61334 are some of the standards based on which upcoming smart grid communication products and technologies are emerging. Communication technologies with reference to smart grid implementation

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are continuously evolving and are in active research area. This paper focuses on a generalized overview for available options of ICT in smart grid and their pros and cons. Section II of paper contains the advanced metering infrastructure and its driving forces, section III highlights the legal and regulatory status of AMI and in the remaining part of the paper available communication technologies for AMI are discussed.

Advanced Metering Infrastructure and its Driving Forces: Advanced Metering Infrastructure (AMI) is an architecture which combines the power system and several technologies through a two way communication between a utility company and smart meters [5]. The restructuring of earlier power generation and distribution system is conducted to improve the efficiency and performance of a so called electric power network. With the passage of time integration of renewable energy resources in the electric power network made it complex, unsecure and eventually gave rise to the power quality and load management issues [6]. In the context of global problem of aging transmission grid over local transmission grid built 40 years ago in Pakistan, stress on the current power infrastructure is increasing which makes the power distribution system more unsecure and vulnerable to the electric utilities [7].

In order to overcome these problems and to transmit reliable and secure energy to the consumers, AMI can perform a vital role by sharing the data and information between consumers and control center of the utility company. Smart meters can provide the details of consumer power consumption profile that is per phase current, per phase voltage, maximum kW, cumulative kW, kWh, power factor etc and communicate this information back to the utility company for better load management and billings [8]. By doing this consumer will be able to understand their daily, monthly and annual load curves so that they can manage and control their power consumptions. The utility company will provide the low tariff rate according to the consumer's demand. In peak hours the utility can turn off few loads itself. The deployment of AMI in smart grid may be a strong factor with an intent to reduce the CO_x and NO_x footprints and consumer's electricity bills. Field tests are already being performed and world's largest AMI network is deployed by Enel SPA in Italy [4] [9]. Some of advantages offered by AMI are specified in figure 1 which also gives a future vision of AMI.

Advantages of AMI:

- Consumer's tariff will be designed for short spans of time, probably on hourly basis. It will facilitate both the consumers and utility providers for better energy planning.
- Once the smart meter's data is retrieved and available to the utility company data collection center's end, its billing and acknowledgement of received payments can be easily reported and displayed on the online web based system.
- The utility provider can easily connect/disconnect the defaulted consumer from the grid and take necessary action against them.

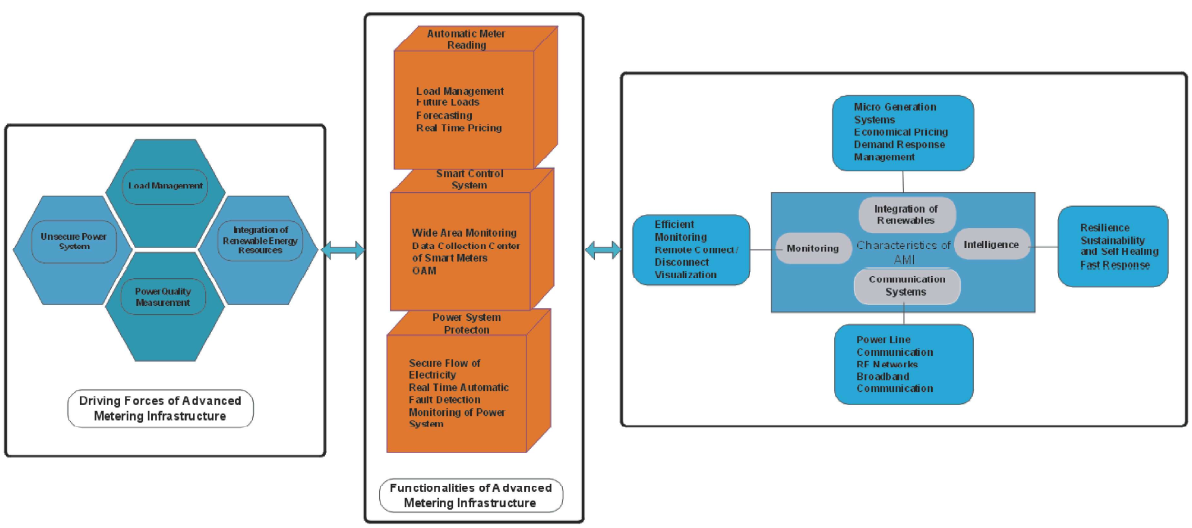

Fig. 1: Future vision of AMI

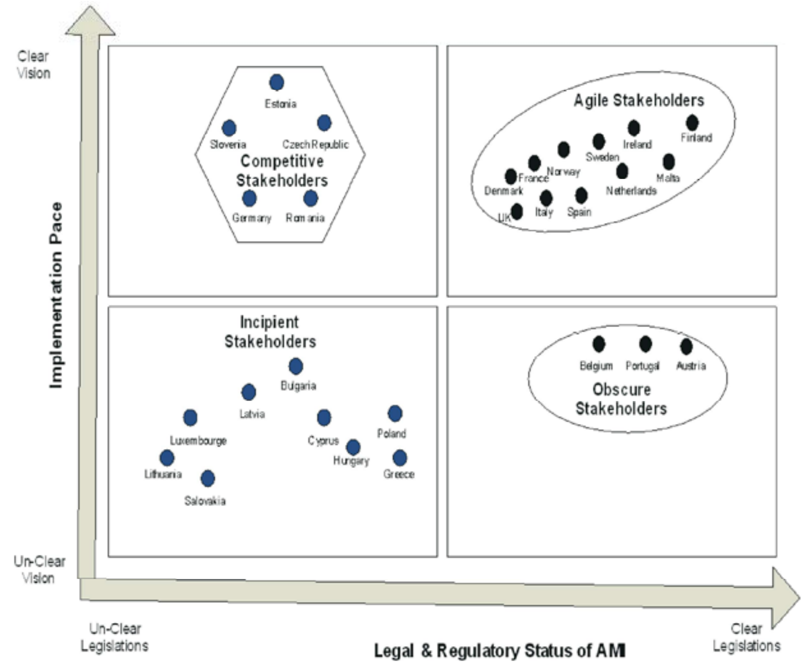

Fig. 2: Regulations and Implementation of AMI

- After the implementation of smart electricity meters, the idea can be further extended for the implementations of smart meters bundling with water and gas meters where the same communication links of AMI can be used for water and gas meters as well.
- Wide area monitoring of power system can be performed with the help of advanced metering infrastructure [10].
- Electric utility engineers cannot rely only on KWhr reading in order to plan the future network expansions and deliver secure flow of electricity [11]. Power quality involves sagging, swelling, harmonic distortion, over and under voltages. These parameters can be evaluated with the help of sensors deployed in AMI and data can be forwarded to the utility data collection center.

The benefits outlined by an efficient AMI can proof to be a major contribution towards practical and fast implementation of smart grid. However there are certain legal and regulatory issues related to AMI which are discussed in the following section.

Legal and Regulatory Status of AMI: Highly dynamic regulations and legislations are under development due to a strong push by the European Union and energy market actors. By knowing the legal and regulatory issues, utility companies can be provided with the clear guideline and framework for installation of smart meters according to landscape's technological geography. Progress in AMI implementation will not only refer to a number of pilot projects but also the current techniques and progress towards a futuristic, realistic and clear roadmap for AMI, the ultimate goal is to achieve the efficient peak load shaved management system. Different European countries can be classified in four groups i.e; Agile Stakeholders, Competitive stakeholders and Obscure stakeholders regarding regulation and implementation [3]. Legal and regulatory status of Advanced Metering Infrastructure for European countries is illustrated in Figure 2.

Agile Stakeholders: Agile stakeholders have clear vision towards the full rollout of AMI. They have adopted all necessary measures to implement their concerned policy. This group includes; Finland, Ireland, Denmark, France, Italy, Malta, Netherlands, Norway, Spain, Sweden and UK. In Finland and France energy market has planned to install 80 to 95% smart meters by the end of 2016.

Competitive Stakeholders: This group comprises of countries that have proper rules and legal frameworks to introduce new legislations so that maximum incentives can be provided to the consumers. Czech Republic, Germany, Estonia, Slovenia and Romania are included in this group.

Obscure Stakeholders: The countries belongs to this group has established their regulatory and legal frameworks to some extent and the policies are still unclear. Due to the lack of clarity, only a few Distribution System Operators (DSO) have shown their concern of interest to install Advanced Metering Infrastructure. Belgium, Austria and Portugal are included in Obscure stakeholders.

Incipient Stakeholders: Incipient stakeholders are beginners in the Smart Energy Market. Regulators, ministries and utilities have shown their interest in AMI. However they have just take the initiative or their project feasibilities are still under review for the implementation of Smart Metering/AMI. This group consists of Greece, Cyprus, Hungary, Bulgaria, Poland, Latvia, Lithuania, Slovak Republic and Luxembourg.

As the legal and regulatory framework moves towards a flexible implementation of AMI, researchers are focusing on the previously available communication technologies for an efficient implementation for information and communication infrastructure within smart grid.

Available Communication Technologies for AMI: For data transmission, different technologies are based upon two main communication media i.e wireless and wired. The transmission of data from smart meter to electric utility involves both the wired and wireless medium [12]. In some cases wireless communication has some advantages over wired communication like cost effective infrastructure and easy availability of connection to distant and difficult areas [13]. On the other side of the picture it is seen that wired communication is useful in the sense that it does not have signal attenuation as the path for the signal flow is dedicated to that particular signal. Secondly and most importantly they do not rely on batteries like wireless solution does. The data flow in smart grids can be categorized into two streams. The first stream is from sensors of electrical appliances to the smart meters where as the second stream of data flow is from the smart meters to the Utility data centre.

For the first flow we can have technologies like Power line communication and wireless communication which includes ZigBee, z-Waves and others. For second flow we have cellular technologies and internet. The selection of technologies may vary with place as well as with environment.

Power Line Communication: Power line communication systems operate by impressing a modulated carrier signal on the 50 or 60 Hz, 3-phase 4-wiring or 3-phase 3-wiring distribution system of electric power network. In Smart Grids and Smart Homes an explosive attention of utility companies has already been achieved by PLC technology because of its several attractive advantages. The advantage of its already existing nation-wide power line infrastructure makes it unique [14]. Because of its robustness PLC can be implemented anywhere by using already existing electricity network. It offers low installation cost since it uses existing power lines as a communication path. It reduces at least 50% costs of investment in developing a new Network Infrastructure. France being an agile stakeholder has already launched a project named as “Linky Meter Project” in which 35 million traditional meters have upgraded to Smart Linky Meters.

Limitations of PLC: PLC has various limitations other than its advantages, a number of uninvited noises take place in a power line channel, due to which issues like interference and signal attenuation arise [15]. Noises in power line are classified in three types. Figure 3 illustrates the model of power line noise.

Permanent Noise: It is generated by the normal functions of power line auxiliary equipments i.e; permanent partial discharges of insulators and apparatus.

Switching Operation Noise: This type of noise is produced due to the switching operations performed by control room, switching of circuit breakers, isolators and various faults in transmission line. Switching operation noises are critical and can create the malfunctioning of equipments or interrupt the communication services.

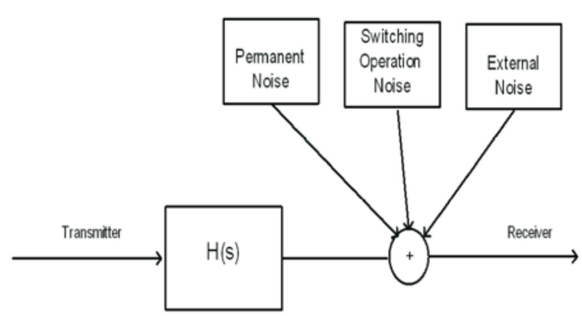

Fig. 3: Noise in Power Line

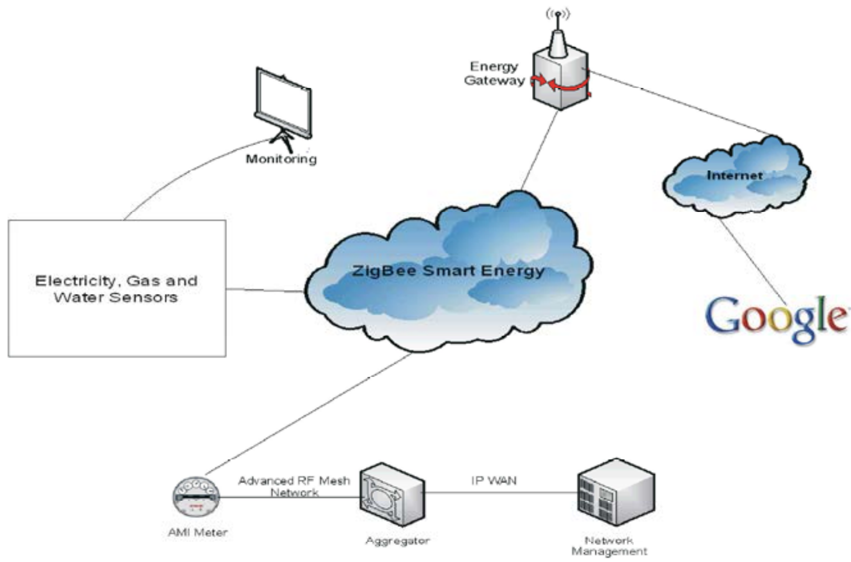

Fig. 4: Data Communication of AMI using ZigBee

External Noise: The consumer sites are becoming full of equipment that employee parallel capacitors as a filter which are commonly placed at various consumer sites. This capacitor acts as a sink or short-circuit to all high frequency signals. Increasing penetration of new devices both disturbs and filter worsens the case for PLC. Noises generated from such kind of problems are known as external noises.

In case of Smart Distribution System, utilizing the PLC technique as shown in figure 8 where PLC is implemented at the low voltage (LV) side of distribution transformer for automated meter reading of four loads/meters. In the given scenario impedance mismatch can cause the multipath propagation of the signal in power line.

ZigBee: It is a wireless communication technology; ZigBee is very well remembered by its unique features of having low power consumption, effective energy monitoring, lower complexity and lower cost of deployment etc. All the above mentioned properties make this technology an ideal for smart Grid's data carrier and ZigBee smart energy profile (SEP) have been applauded as the most suitable communication standard for the residential network of smart grid by the US National institute for standards and technology (NIST) [16].

Technologies like ZigBee are considered to be an attractive choice for the smart metering along with its mobility, austerity, robustness, low deployment cost, low bandwidth and workable nature under non licensed spectrum. There is no conundrum in implementing the ZigBee based network. With electric utility's monitoring, ZigBee is known as the best option for communication technologies for AMI along with other types of Utilities based on Gas and Water respectively as shown in figure 4.

Communication between home appliances and Smart meters is very important. ZigBee protocol is largely used by many Vendors for smart metering [17]. Many AMI based application used ZigBee protocol installed in them. ZigBee protocols not only communicate with ZigBee integrated devices but they have a control over them.

It sends messages to the home owners which enables the owners to know about their appliances' energy consumption status. It sets up a network, Manages network nodes, Stores network node information, Routes messages between paired nodes and Receives data constantly [18].

In this regard the system can achieve demand load control, real time metering support as well as real time tariff control. Along with its enormous potentials and advantages, there are some constraints which is necessary to be mentioned here such as interfering nature with other devices sharing same transmission medium, small memory size, small delay requirements and low processing [19, 20]. These issues of ZigBee having easy property of interference with the other devices using same wireless link such as WiFi, Bluetooth and Micro wave etc can have the possibility of corrupting

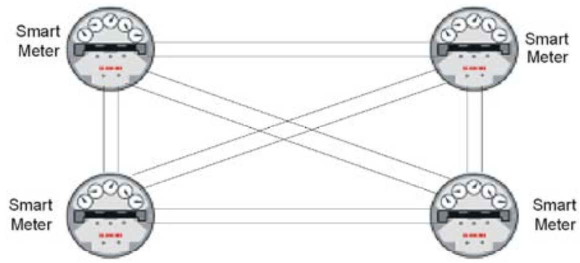

Fig. 5: Redundancy of Mesh network for AMI

the channel. In order to avoid such noxious situation from occurring there are Interference detection schemes, interference avoidance schemes and energy efficient routing protocols which should be implemented.

Mesh Network: The mesh network is known for its distinctive feature of data redundancy. The fault tolerance and recuperating characteristic of mesh network enables the signal to find another alternate route through the active nodes as shown in figure 5 [21]. The smart energy meters act as routers not only containing the data but also sharing it with other nearby meters. The wireless mesh network contains an RF module in which it performs wireless signal amplification which is helpful in remote data transmission.

Benefits: It is a self organizing, recovery and reconfigurable network with high scalability services. This leads to many benefits like balancing the network's load, enhancing network's coverage range and improving the network's performance [20]. We have advanced metering infrastructures and home energy management as one of the applications of mesh network.

Drawbacks: Due to its state of being wire free it can be subjected to common wireless communication losses like interference. In metropolitan or urban areas the network can experience coverage problems. The wireless density of the meter is not able to provide complete coverage of communication. Taking into account of this problematic issue it is considered necessary to have flexible routing. To achieve this we need to have sufficient number of smart nodes in our network. Now again this strategy starts pointing towards the cost of these smart nodes which cannot go in the favor of cost effective wireless mesh network. In addition to that Data while travelling through the nodes undergo additions of overheads which results in the reduction of available band width.

Cellular Technologies: The cellular technologies provide number of good choices for data communication between smart meters and utilities. So far the cellular technologies have been proved successful in having low operational cost of the smart infrastructure. These technologies become helpful in deploying smart metering network to remote areas [10]. Most common cellular technologies for deploying AMI is WiMAX, 2G, 2.5G, 3G and LTE. If a data transfer interval of 15 min is used between the meter and the utility, a huge data is generated and to transfer this data we need high data rate connection. To support the above mentioned statements let us take an example of the famous American cellular company named T-Mobile which is deploying the Echelon's networked Energy Services (NES) systems.

T-mobile takes its SIM along with RF module integrated into Echelons smart meter in order to establish communication between meter and utility. As T mobiles network covers all the important areas for the data communication of smart meters therefore there is no need left to develop a new dedicated communication network by utilities. Along with T-mobile other companies agreed to put GSM services for smart metering communication are Telenor, China mobile and Vodafone etc.

The idea of using CDMA for smart metering was introduced by Verizon Company. Verizon's CDMA network will provide the backbone of smart grid communication along with SmartSynch smart grid solution. UMTS is data based/ip based service used for metering application. Telenor used UMTS for Smart Metering. Likewise a company named SP AUSNET used WiMAX for data transfer in Smart Metering. Here WiMAX chips are burnt in the Smart Meters. General Electric started making WiMAX based Smart Meter and collaborated with smart grid software provider Grid Net. Furthermore companies like Motorola, Intel, Grid net, Cisco and Verizon etc also implementing WiMAX smart grid's application. WiMAX becomes the demand of the time due to its lower deployment cost, high data speed (Up to 75 Mb/s) an appropriate amount of bandwidth and scalability. As cellular networks already exists so there is no need to put extra cost to build communication infrastructure for the smart grid's projects separately. In short intervals large data is being generated which can be sufficiently transmitted as well as received by using ample bandwidth provided by these cellular technologies. Cellular networks also provide security by strong security controls. GSM technology performs up to 14.4 kb/s, GPRS provides up to 170 kb/s, both of them supports AMI.

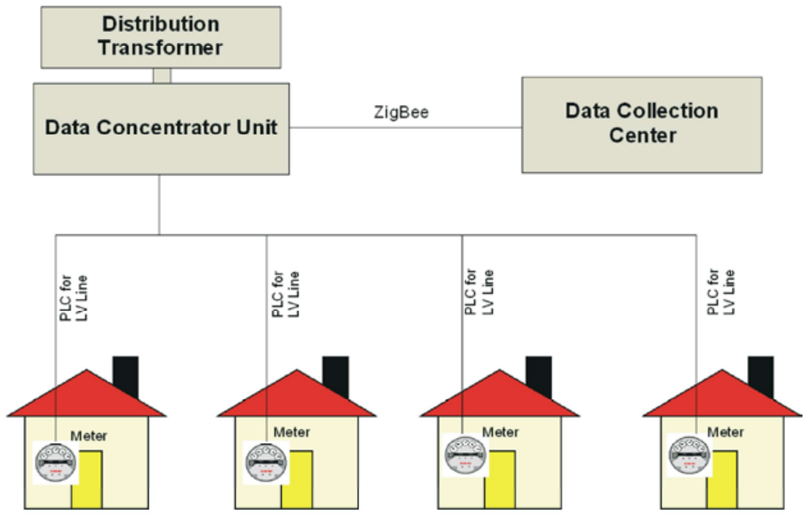

Fig. 6: Hybrid Systems for AMI

Disadvantages of Cellular Technologies: There are few applications in AMI which requires continuous availability of communications. As the cellular networks are subjected to severe congestion or reduction in network's efficiency especially at emergency occasions. Taking into account the mentioned constraints forced the utilities to establish their own private communication network. It will then be a network of networks going on making operations more complex to manage. There are environmental issues which pose great threats to the performance of cellular services e.g. due to wind storms and due to rapid climatic change cellular service is not able to with-stand and may not provide guaranteed service. On the other hand if we see private networks they have variety of solutions available to handle such situations by usage of multiple technologies and widened spectrum band.

Hybrid Ami Communication Network: This part of paper presents an infrastructure for automated metering utilizing a hybrid communication system for the purpose of data collection and its management. Figure 6 provides an overview of Hybrid AMI System, data communication in such system comprise of two steps;

- Data from Smart Meters to Low Voltage (LV) side of Distribution Transformer.
- Data from Distribution Transformer to Main Control Center or Data Collection Center.

Although a number of communication technologies are available for the purpose of ICT but the most promising techniques for data transmission in above mentioned two steps are: In first step information data will be communicated with the help of "Power Line Communication technique" [22] and in second step information data will be communicated by utilizing a ZigBee network.

CONCLUSIONS

The need and importance of Information and Communication Technologies in the present electric power network is discussed in this review paper. The paper highlights the Advanced Metering Infrastructure and its role in Smart Grids. This infrastructure received an appreciable attention and innovation in the electric power network, due to its features like increased demands of efficient monitoring, remote connection/disconnection, sustainability, self healing and demand response. The DR based economical pricing can be accomplished by having suitable infrastructure within the framework of legal and regulatory status defined for AMI. Secondly an overview of available ICT for Smart Grids is discussed which includes technologies like PLC, Mesh Network, ZigBee and cellular networks discussed as WiMAX, 2G, 2.5G, 3G and LTE, having an immense role in the implementation of AMI. The existing infrastructure deals with different Telco based and database technologies, which should be further enhanced to support the implementation of next generation monitoring, control functions and analysis. This research work will cover pilot projects, key players and research challenges of incipient smart grid system.

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