MultiCraft

International Journal of Engineering, Science and Technology
Vol. 7, No. 3, 2015, pp. 94-101

INTERNATIONAL JOURNAL OF ENGINEERING, SCIENCE AND TECHNOLOGY
www.ijest-ng.com
www.ajol.info/index.php/ijest

Smart grid implementation in India – A case study of Puducherry pilot project

Ramakrishna Kappagantu[1]*, Subir Senn[2], Mahesh.M[3], S. Arul Daniel[4]

[1]Power Grid Corporation of India Ltd., INDIA*
[2] Power Grid Corporation of India Ltd., INDIA
[3] Power Grid Corporation of India Ltd., INDIA
[4] National Institute of Technology, Tiruchirappalli,, INDIA
[*]Corresponding Author: e-mail: kramakrishna@ieee.org

Abstract

The basis of the smart grid concept is the extension of information and communication technologies to the existing energy infrastructure. The improved communication between different parts of the energy system is expected to increase the quality, reliability and efficiency of the overall system in smart grid. This paper presents the implementation and analysis of load management by using the platform of Smart Grids for residential consumer setup, a pilot project of utility in Puducherry under open collaboration. The analysis is done with the data outcome of smart meters installed in the utility, which have features of two way communication, polling interval & data measurement, storage and display of consumption data to consumers, support for variable tariff and micro generation. The practical issues of concern faced in the implementation of Smart Grid in distribution system are also highlighted.

Keywords: Advanced Metering Infrastructure (AMI), Peak Load Management (PLM), Outage Management System (OMS) and Power Quality Management (PQM)

DOI: http://dx.doi.org/10.4314/ijest.v7i3.11S

1. Introduction

A power system needs to perfectly balance at any instant, the demand of all the consumers with the available supply by the utility in order to maintain the, frequency of the system [1].One of the features of the smart grid vision is to tackle the problem of balancing the demand with supply using strategies that act on the demand side [2]. With the deployment of intelligent smart meters in distribution system, consumers are able to optimise the electricity consumption to minimise costs [3-4]. This also helps the distribution system operators to minimize the feeder loss and overloading and voltage deviations.

Indian distribution system became bulky and complex due to rapid increase in demand for the past few years and improper planning of system strengthening against the load growth. Because of this, the distribution system is facing high Aggregate Technical and Commercial (AT&C) losses [5-6].As per sources, a study report from International Energy Agency (IEA) on Transmission and Distribution (T&D) losses in various countries for the year 2010-11, the T&D losses in India are 23.65 percent which is very high against 9.8 percent average throughout the world [7]. However, as per sample studies carried out by independent agencies in India, T&D losses have been estimated to be as high as 50 percent in some utilities. The major reasons for these high AT&C losses are inadequate investment on transmission & distribution networks, particularly in sub-transmission and distribution levels. Low investment has resulted in overloading of the distribution system without commensurate strengthening and augmentation. Other reasons are improper load management, poor quality of equipment and loads, making unauthorized extensions of loads, tampering the meters & meter readings, changing the C.T ratio and faulty recording, bypassing the meter, power pilferage, errors in meter reading and recording, etc. These have made the system inefficient and uneconomical.

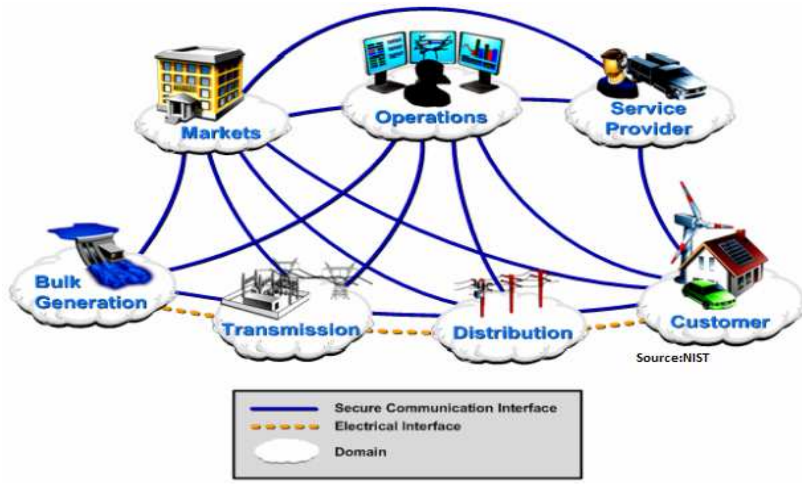

Figure 1, Conceptual model of Smart Grid

To avoid above mentioned problems and to make the grid more efficient, reliable, robust and transparent, Smart Grid technologies are introduced in Puducherry. The conceptual model of Smart Grid is shown in the figure 1. There are numerous benefits of the Smart Grid implementation such as cost reduction, enhanced reliability, improved power quality, increased national productivity and enhanced electricity service with safety / security. Smart Grid allows the direct participation of consumer to accommodate all generation, storage and load management options. It provides reliable power that is interruption free. It optimizes assets and operates efficiently, independently identifies and reacts to system disturbances and performs mitigation efforts to correct them. Smart Grid resists attacks on both the physical infrastructure and cyber-structure. Without the implementation of the Smart Grid, the full value of many individual technologies like Electric Vehicles, Battery Energy Storage, Demand Response, Distributed Energy Resources and large scale renewables integrated in the distribution system such as wind / solar cannot be fully realized.

This paper presents a detailed analysis of Puducherry (India) Pilot Project. The key issues and challenges in smart grid implementation are also highlighted.

2. Smart Grid Pilot Projects in India

To evaluate the real benefits and to identify suitable technologies/models of the Smart Grid, Ministry of Power, Govt. of India proposed 14 pilot projects across the country with different functionalities of Smart Grid. At present all these pilot projects are under initial stage of implementation. The main objectives of these pilots are indigenization of technology, development of scalable and replicable models, bringing up of suitable standards and regulations based on these pilot project experiences. Puducherry Smart Grid project is one of the proposed pilots which is being developed jointly by Power Grid Corporation of India ltd (POWERGRID) and Puducherry Electricity Department (PED).

2.1 Puducherry Electricity Distribution System: Puducherry is one of the Union Territories in India which has approximately a million of population with literacy rate of 96%. PED is not yet unbundled and distribution wise it is divided into ten divisions for the effective operation and maintenance. Smart grid pilot project covers one Division viz. Division-I which covers all the features of smart grid like Advanced Metering Infrastructure (AMI), Peak Load Management (PLM), Outage Management System (OMS), Power Quality Management (PQM), Renewable Energy Integration and energy storage. After successful implementation of the above in to the Smart Grid, the pilot is expected to be extended to a smart city that features water management, gas management, e-medical, e-education and e-transportation, e-governance etc.

2.2 Smart Grid Pilot Project (Division –I) profile: Division-I of Puducherry has 100% electrification. It has 87035 nos. of consumers, predominantly domestic (about 79%) and other consumers being commercial, HT, agriculture, street lighting, etc. The entire area is supplied by one number of 110/22/11 kV sub-station, which feeds to 7 nos. of 22kV overhead feeders, 5 nos. of 11kV underground cable feeders and 325 nos. of distribution transformers handling a total load of 127.8 MVA. The single line diagram of one 22 kV feeder is shown in figure 2.

2.3 Interim Smart Grid Pilot in operation: Amongst the 12 feeders of Division I, under open collaboration, an interim pilot covering around 1400 consumers in 22kV Town feeder with nine Distribution Transformers (DTs) is completed by POWERGRID which demonstrates all functionalities of smart grid, showcasing various communication technologies of smart meters and a state-of-art smart grid control center equipped with head ends, MDMS and Demo systems.

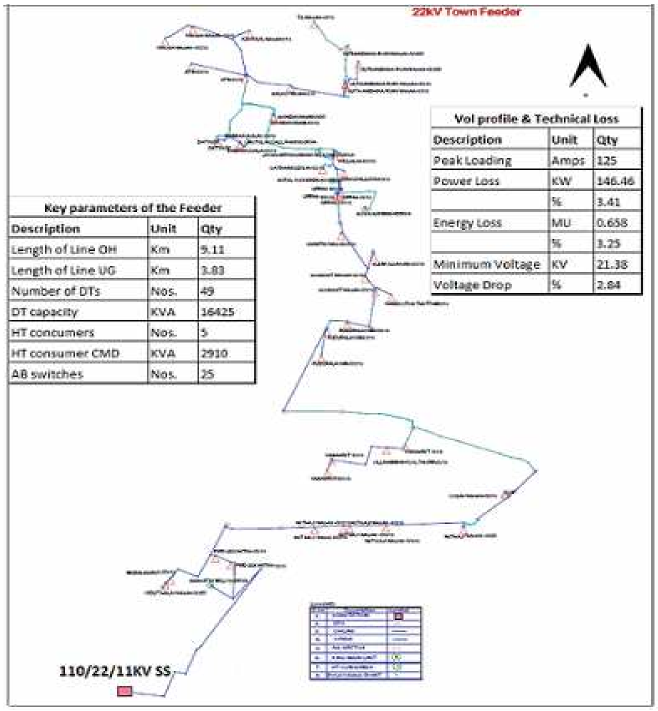

Figure 2, 22 kV Feeder Mapping

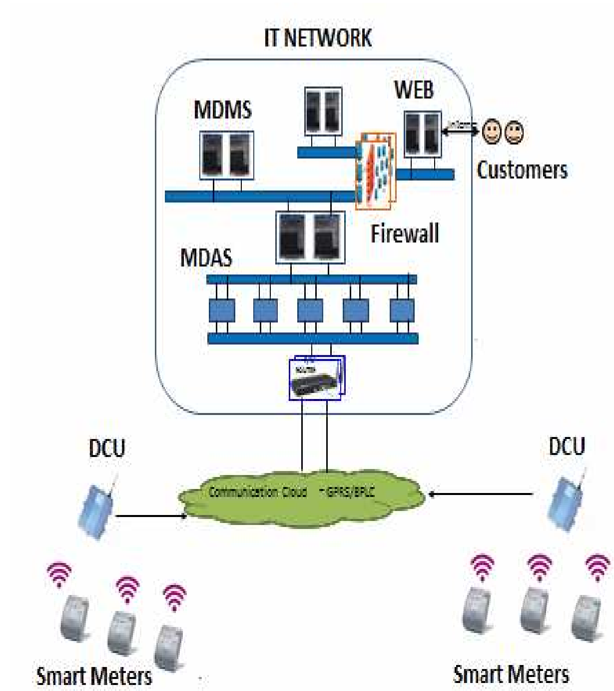

Figure 3, Basic Architecture of proposed Smart Grid

2.4 System overview and Functionality: The proposed system is initially developed for facilitating smart metering, billing operation among customers, power market, generation companies, retailers and small independent family power producers in future smart grids. The basic architecture of proposed system shown in figure 3 which consists of smart meters, communication networks, database and management system, display and control units. General operation of the proposed system includes several steps. The energy consumption data is measured by smart meters. The Data Concentrator Unit (DCU) collects and transfers data from the smart meters to the control center. Radio Frequency (RF), Power Line Carrier Communication (PLCC) and General Packet Radio Service (GPRS) networks are used to transfer data from meters to local servers. Central and local databases store all the consumption data and customer information. This data base will allow consumers to make more informed decisions about their energy consumption, adjusting both the timing and quantity of their electricity use.

3. Final Objectives of the Proposed Pilot System

The main objective of the project is to implement various components of SG as follow.

A. System Advanced Metering Infrastructure: AMI facilitates full measurement and capture of data from smart meters at consumer premises by the utility through communication mode such as wireless and wired. Net metering feature helps in integrating local distributed micro generation.

B. Peak Load Management: Peak load management solution helps to make the electric grid much more efficient and balanced by assisting the consumers to reduce their overall electric demand, and/or shifts the time period when they use their electricity avoiding high peaks and associated high tariffs.

C. Power Quality Management: PQM solutions are needed to address events like voltage flicker (Sags/Swells), unbalanced phase voltages and harmonic distorted/contaminated supply etc.

D. Outage Management System: OMS consists of FPI, FRTU, Sectionalizers, and DTMS etc. and empowers utility to manage scheduled and unscheduled outages of distribution system viz. DTs and, HT/LT feeders.

E. Supervisory Control and Data Acquisition / Distribution Management System: The Supervisory Control and Data Acquisition system (SCADA) shall provide real time monitoring and control functions of distribution network from a central location.

Figure 4, GPS location of Smart meters, DCU and Distribution Transformer

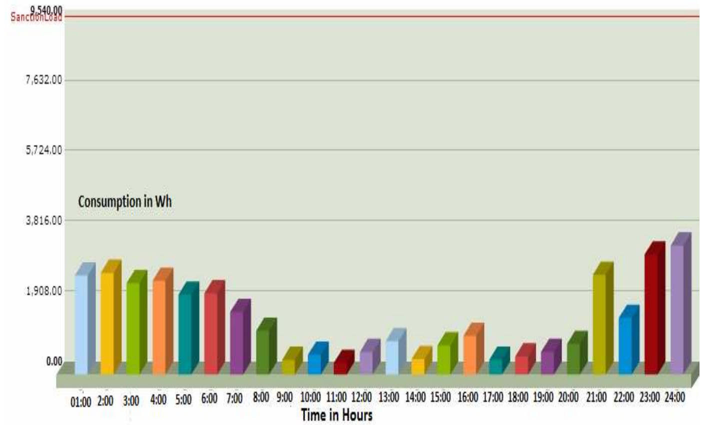

Figure 5, Day wise Load profile of consumer

F. Renewable Energy Integration: Integration of Distributed Power Generation and Renewable energy resources into the existing Grid.

G. Energy storage systems: Large scale energy storage devices shall act as energy reservoir injecting electricity in maintaining grid parameters during contingencies such as sudden loss of power, including renewables, etc. Since the renewable energy like solar and wind integration to the grid increasing day to day, large scale energy storage system at distribution substation level plays a vital role in view of maintaining stability of the grid.

H. Street Lighting: High Power savings are observed through Automation of street lighting systems with phase balancing, PF correction, voltage control and pre-set ON/OFF based on ambience &traffic movement density.

I. Electric Vehicle: Deployment of green and clean energy based battery operated Electric Vehicle (EV) driven by solar charging station. Plug in and vehicle to grid are found to be most advantageous in smart grid.

Various Smart Grid Components are discussed below:

3.1 Smart Meters: Smart meter with AMI is the basic component in smart grid with two-way communication gateway for consumer /utility interaction. Smart metering has the potential to reduce both consumer and utility costs. A major benefit of the AMI is that it supports consumer by bringing awareness about their instantaneous kWh electricity usage and pricing that aids the utilities also in load reduction needs. In general, studies have shown that if the consumers are made aware of extent of their energy usage, then they reduce their consumption by about 7 percent. Today, the increasing penetration of smart meters allow homes to connect to ubiquitous data networks and intelligent grid that gives to consumer as well as utilities, visibility of real time supply and demand balancing [8-9]. Display of consumption data and energy conservation [10] programs encourage consumers to give back some of their energy usage in return for saving money besides save the costs towards building additional generation capacity required to meet future critical peak demand rise [11-12]. Figure 4 shows some of the GPS location of installed smart meters, DCU and Distribution Transformer at interim pilot project. Load restriction [13] is one of the salient features of the smart meter demonstrated in the interim pilot as shown in figure 5.

The smart meter store the interval data i.e. load profile of the consumer and if the consumer exceeds more than the sanction load, it disconnects the load automatically. Voluntary load reduction events may be scheduled by implementing Time of Use tariffs. However, for the utility to receive the desired demand response, consumers must be provided timely with adequate information viz. pricing, event and consumption data. Tamper alerts like meter bypass, terminal cover open and other faults are also identified with AMI. Many invisible faults inside the consumer wiring system that lead to abnormal energy readings like load through earth fault (caused mainly due to damaged wiring system that cannot be identified manually) are identified and indicated in the smart meter as tamper. Thus the consumer is restricted through the tamper alert from over drawl against sanctioned load.

3.2 Data Collector Units (DCU): DCUs collect real time consumption data from the smart meters and transmit to central data base server system. Energy consumptions are stored in the DCU in time slot of 30 minutes to implement time-of-use feature and incorporate the real time prices from the power market. One of the major concerns for the smart grid system is the illegal tapping of electricity. To avoid such pilferage, threshold detection is added in the DCU. The average electricity usage for the last several months, which can be obtained from the consumption history, is used to detect electricity theft through comparison between the usage and the threshold. Normally, the average usage is stable. If the usage for the previous month is much lower than the threshold, the proposed system will remind the utility to arrange staff to check wrong doing. The system has flexibility for adding more functions according to various demands/requirements. Though, the study says that one DCU can cater to the need of around 100 meters in general, in the interim pilot, it was found that one DCU can cater to not more than 50 meters in many cases especially when the communication is of RF.

3.3 Communication Network: Communication networks used for the metering system include RF communication, power line carrier communication (PLC) and GPRS networks. Low Power Radio (LPR) uses the non-licensed ISM (industrial, scientific and medical) band for RF communication often around 865-867 MHz and ZigBee based 2.5 GHz. In LPR case, each meter is equipped with a RF transmitter that allows communication to the data concentrator directly, or to other meters with RF transmitters which act as repeaters or forward the data e.g. in a meshed network configuration. The ZigBee is mainly used for the applications which require a low data rate. The PLC is a technology to transfer data signals through the existing power transmission and distribution network. Compared with other communication technologies, the PLC requires no extra charge for building network. Mesh network formation for data transfer from one meter to other meter till it reaches the DCU is shown in figure 6.

Both the LPRF and PLC communications are used to transfer data from meters to the coordinator (DCU). The main advantages of LPRF/ZigBee and PLC are easy access and low cost of installation. In addition, dual communication networks can reduce the data error rate and increase the reliability of data transmission. Data is transferred from meters to the DCUs which are also the nodes of communication network. Depending on the line of sight and quality of communication, routers and repeaters are also deployed as coordinators to collect the data from hundreds of meters and send the data to the local database through the DCUs using GPRS communication. Those meters with GPRS modems directly communicate with the central data base control centre. The main advantage with the GPRS communication meters is that they can be filled in the gaps where the PLC or LPR meters cannot be deployed as seen in the interim pilot.

3.4 Database and Management System: Customer information is stored in central database. The data from the DCUs is collected through Meter Data Acquisition System (MDAS) and based on which the Meter Data Management System (MDMS) provides the necessary data in the prescribed formats to both Utility and consumer. A typical MDMS is shown in figure 7, which also provides the billing details to consumers as per scheduled billing cycles for different categories and to the utility details of tampers, if any besides the occurrences of any power faults/failures in the system for corrective actions.

Validation Estimation and Editing (VEE) is an essential function of MDMS. As consumer details along with sanctioned load and meter data being loaded into the database, data syntactic and semantic checks are performed. VEE is then conducted to translate the raw data into a set of consistent and usable data for billing. Current VEE function often considers historical data statistics as well as weather, holidays, account similarity, etc. Rules are defined to detect "vacancy" and possible "tamper" or "theft." The VEE solution provides estimates that are representative of historical consumption. It is performed based on pre-defined reference values and/or rules related to individual customer without real time feeder and transformer loading reflections.

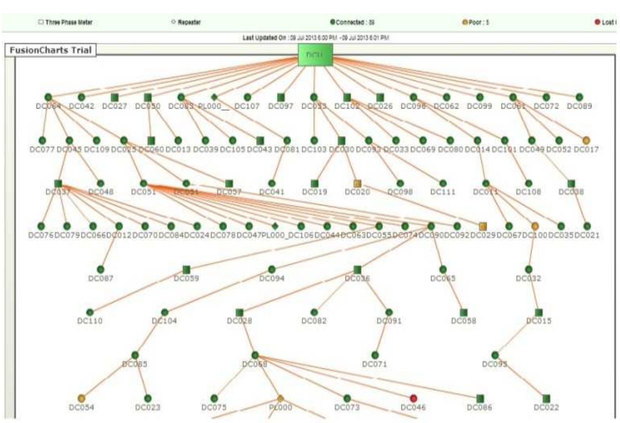

Figure 6, The mesh network formation of PLC based smart meters

Figure 7, Load monitoring from MDMS solution

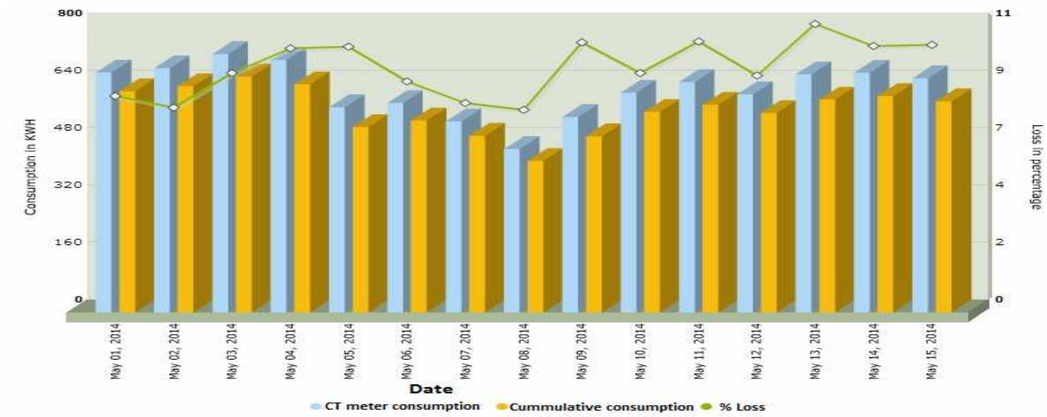

Figure 8, Distribution Transformer wise Daily Energy Audit

3.5 Energy Audit: On-line Energy audit is one of the solitary features of this project which finds the instantaneous technical and commercial losses. Monthly energy audit has been carried out for the consumers covering of one distribution transformer (as shown in figure 8),and it is found that un-accounted energy is contained within 7 to 10 percentage using smart meters in smart grid. Thus the on-line energy audit helps in checking the un-accounted energy that can be reduced further, if preventive actions are taken. Major difficulties for the energy audit are integration of different communication / manufacturing technologies and integration of which is a real challenge ahead for the smart grid operators.

4. Major Challenges in Implementation

As we migrate from the current grid with its one-way power flows from central generation to dispersed loads, toward a new grid with two-way power flows, two-way and peer-to-peer customer interactions, and distributed generation [14-15], there are many challenges in the part of integration of various technologies.

4.1 Interoperability: As smart grid is spanning the globe and many players are into manufacturing and implementation of smart grid worldwide, it is necessary for the system to adopt interoperable standards.

4.2 Cyber security: Information and communication infrastructures will play an important role in connecting and optimizing the available grid layers. Smart grid architecture should support the capability to resist unwanted physical and cyber intrusions and protect the privacy of customers.

4.3 Communication Technologies: Various technologies are being deployed for the smart grid data communication network. Issues of concern are cost, success rate of communication, technological issues viz. Electro Magnetic Interference (EMF), Signal to Noise Ratio (SNR), Baud rate, parity check, etc.

4.4 Social Barriers: No program will be successful until unless the end users participate in the program. There are many concerns of consumers about the smart grid issue. Awareness programs are necessary and clear benefits must be presented to them.

4.5 Political Barriers: Since there are high costs involved during initial implementation of the system, the administrators, policy makers and implementers must be convinced with the returns on investments and end results including supply disturbances to consumers during implementation of the system.

5. Conclusions

A Smart Grid (SG) infrastructure in the existing distribution system of Puducherry has been successfully developed. Preliminary studies show improvement in efficiency and reliability of the distribution network. Distributed computing and communications which deliver real-time information and enable near-instantaneous balance of supply and demand at the device level has been incorporated. By providing awareness and training on smart grid features to consumers viz. load restriction and data consumption display, the consumer also derive benefits by monitoring / adjusting loads besides saving the energy through demand response. The utility also reap the smart grid benefits viz. demand side management suiting the Time of Use (ToU) tariffs, optimized outage management systems, integration of renewables by net metering, etc.

Nomenclature

AMI	Advance Metering Infrastructure
PLM	Peak Load Management
OMS	Outage Management System
PQM	Power Quality management
AT&C	Aggregate Technical and Commercial
IEA	International Energy Agency
T&D	Transmission and Distribution
PED	Puducherry Electricity Department
DTs	Distribution Transformer
DCU	Data Concentration Unit
PLCC	Power Line Carrier Communication
GPRS	General Packet Radio Service
SCADA	Supervisory Control and Data Acquisition
EV	Electrical Vehicle
LPR	Low Power Radio
ISM	Industrial, Scientific and Medical
MDAS	Meter Data Acquisition System
VEE	Validation Estimation and Editing
EMI	Electromagnetic Interference
SNR	Signal to Noise Ratio
ToU	Time of Use1

Acknowledgement

Authors are thankful to the management of POWERGRID for granting permission for presentation of this paper. Views expressed in the paper are of the authors only and need not necessarily be that of the organization to which they belong.

References

Green J.P., Smith S.A., and Strbac G., 1999. Evaluation of electricity distribution system design strategies. IEEE Proc.Generation, Transmission and Distribution, vol. 146, No.1, pp.53-60.

Varaiya P.P., Wu F.F., and Bialek J.W., 2011. Smart operation of smart grid: Risk-limiting dispatch. Proceedings of the IEEE, Vol. 99, No.1, pp. 40 –57.

Deconinck G., 2008. An evaluation of two-way communication means for advanced metering in Flanders (Belgium). IEEE International instrumentation and Measurement Technology Conference Victoria, pp. 900-905.

Tram H., 2007. AMI Benefits in T&D – What Is for Real? Distribu TECH Conference.

Lahiri R.N, Sinha.A, Chowdhury S., Chowdhury S.P. and Gaunt C.T., 2009. Importance of distribution automation system for Indian power utility. IEEE Power & Energy Society general meeting (PES'09), pp. 1-7.

Krishna Rao M.V., Pandurangam J.V., Peri R., and Clinard K.N., 1995. Development and evaluation of a distribution automation system for an Indian utility. IEEE Transactions on Power Delivery, Vol. 10 , No.1, pp. 452-458.

International Energy Agency (IEA): Technology Roadmap Smart Grid, OECD/IEA, Paris, France. IEA Smart Grid 2011. http://www.iea.org/papers/2011/smartgrids_roadmap.pdf

Steklac I., and Tram H., 2005. Advanced AMR Benefits – Utility Case Studies. Electric Light & Power, July/August.

Su C., and Kirschen D., 2009. Quantifying the effect of demand response on electricity markets. IEEE Transactions on Power Systems, Vol. 24, No.3, pp.1199–1207.

Chen J., Lee F.N., Breipohl A.M. and Adapa R., 1995. Scheduling Direct Load Control to Minimize System Operational Cost. IEEE Transactions on Power Systems, Vol.10, No.4, pp.1994-2001.

Tompros S. L., Mouratidis N.P., Draaijer M., Foglar A. and Hrasnica H., 2009. Enabling applicability of energy saving applications on the appliances of the home environment. IEEE Network, Vol. 23, No. 6, pp. 8–16.

Pedrasa M., Spooner T., and MacGill I., 2010. Coordinated scheduling of residential distributed energy resources to optimize smart home energy services. IEEE Transactions on Smart Grid, Vol. 1, No.2, pp.134–143.

Wu Q., Wang P., and Goel L., 2009. Direct Load Control Considering Interrupted Energy Assessment Rate in Restructured Power Systems. Proceeding of IEEE Power Engineering Society(PES'09), pp. 1-8.

Ali Ipakchi, 2007. Implementing the Smart Grid: Enterprise Information Integration. Grid Interop Forum.

National Institute of Standards and Technology (NIST)- A report on Interoperability standards road map-07

Biographical notes

Ramakrishna Kappagantuis presently working as Additional General Manager inPower Grid Corporation of India Limited and is responsible for implementation of the first Pilot Project on Smart Grid in Puducherry. Earlier he was responsible for the operation of the Southern India Regional Grid of 55 GW, maintaining its safety & security and facilitating the necessary logistic support in SCADA, Market and System Operations. .He has done his graduation in Electrical Engineering in 1984 from Regional Engineering College, Jaipur followed by M.Tech. in Automation& Control from JNTU, Hyderabad. Currently he is pursuing Ph.D in Electrical Engg. from NIT,Trichy. He is a Senior Member and currently the Region10 Director in IEEE. His fields of interests include Power System Economics and Operation, Power Markets, Energy Management Systems, Smart Grids and Renewables.

Dr.Subir Sen is currently working as General Manager (STF – Smart Grid) in Power Grid Corporation of India Ltd. Dr. Sen has over 25 years of experience in the field of Power System Planning, Analysis, Design, Construction, Operation& Optimization. He obtained his B.E., M.E and Ph.D degrees from Jadavpur University, Kolkata, IISc,Bangalore& IIT, Delhi respectively. He also obtained Advance Diploma in Management from Indira Gandhi National Open University. He is an accredited Energy Manager & Energy Auditor of Bureau of Energy Efficiency. A Fellow of Institute of Engineers (India), Dr. Sen has published/presented more than 75 technical papers in various National & International Journals/Conferences. His research interests include power system planning, analysis, development of analytics, operation & control, optimization, communication and energy conservation. He has guided many researchers at the UG & PG levels. He has received the Young Engineer award in recognition of his significant contributions and achievements in the field of Electric Power System from Central Board of Irrigation and power. He has co-authored one book titled “Next General Unit Commitment”.

Mahesh.M is presently working as Engineer in Power Grid Corporation of India Limited and is involved in implementation of the Pilot Project on Smart Grid in Puducherry. He is Post graduate from NIT Warangal in the specialization of Power Electronics and Drives in 2009. His areas of interests are Smart Grid Technologies, Power Electronics applications in Power systems and Renewable Energy sources.

Dr. S. Arul Daniel, received the B.E. degree from the Government College of Technology, Coimbatore (Bharathiar University), India, in 1988, and the M.E and Ph.D. degrees from the Regional Engineering College, Tiruchirappalli(Bharathidasan University), India, in 1991 and 2003, respectively. He was a British Council study fellow at the University of Manchester during 1997. He is with the Department of Electrical and Electronics Engineering, National Institute of Technology, Tiruchirappalli, since 1994, where he is currently a Professor. His areas of interest include distribution systems, hybrid renewable energy systems, distributed generation, and micro-grids S. N. Singh received M. Tech. and Ph.D. from Indian Institute of Technology Kanpur, India in 1989 and 1995, respectively. He is a Professor in the Department of Electrical Engineering, Indian Institute of Technology Kanpur, India. Presently he is on leave from IIT Kanpur and working with Centre for Electric Technology (CET), Technical University of Denmark His research interests include power system restructuring, power system optimization & control, voltage security and stability analysis, power system planning, and ANN application to power system problems. He is a Fellow of IE (India), Fellow of IETE (India), and senior member of IEEE.

Received March 2015
Accepted July 2015
Final acceptance in revised form July 2015