Development of Self-Sustainable Technologies for Smart Grid in India

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***Abstract*— The major objective of 'Smart grid mission for India' is to empower the Indian power sector in deploying smart grid technologies in an efficient, cost effective, innovative and scalable manner by bringing together all enabling technologies and all key stakeholders together under one roof. For implementing smart grid technologies on a larger scale Ministry of Power, Government of India is developing a self-sustainable technological base by building fourteen (14Nos.) Smart Grid Pilot Projects that are planned to be executed in power distribution sector in India. In this paper we are trying to analyze how these pilot projects are building a strong foundation for smart grid technologies like Advanced Metering Infrastructure, Demand Response, Distributed Generation, Home Area Network, Communication, Cyber Security, and Electric Vehicles, Electric Energy Storage (EES). Also this paper layouts various factors that will drive the adoption of smart grid in India like supply shortfalls, Loss reduction, Labor saving, Peak load management, Renewable Energy Integration, Technological leapfrogging.**

Keywords — Advanced Metering Infrastructure; Demand Response;, Distributed Generation; Electric Energy Storage; Electric Vehicles; Cyber security

I. INTRODUCTION

India's economy is growing at a GDP rate of 8%, this growth would lead to an expected energy demand rise by 3 times in the next 10 years, out of which 2/3rd would be carried by the grid [1]. The demand for energy in India is estimated to increase upto 900 GW by 2032[2-3], which could be met by exploiting renewable energy potential upto 183 GW till 2032[4-5] in addition to conventional sources. Government of India is planning to increase the share of renewable energy by 8 percent that is upto 36 GW in its 12th five-year plan [6]. As per National Mission for Electric Mobility six million electric vehicles will be running on Indian roads by 2020[7-8]. Ministry of new and renewable energy source has specified that India's renewable technologies (small hydro, wind, cogeneration, biomass and solar technologies) aggregates more than 12622.18 MW installed capacity sharing more than 8 percent of the generation capacity [9,10]. Thus it is clear that in order to manage this fast growing power sector India needs a Smart Power Grid to ensure a reliable and quality electric supply to its huge number of customers. Also, India needs a serious upgradation of its old electricity infrastructure and allied technologies from the transmission to the distribution due to certain challenges like power shortage, increased grid losses, poor reliability, poor accessibility of power in rural areas, power theft, and inefficient power consumption. A smart grid is a strong solution to all these issues and it could provide a strong techno economic foundation for modern India's growing power sector. For implementing smart grid technologies in India Ministry of Power, Government of India has planned to build a self-sustainable technological base by building fourteen (14Nos.) Smart Grid Pilot Projects that are planned to be executed in power distribution sector in India. In this paper we are presenting an overview of the smart grid technologies like Advanced Metering Infrastructure, Demand Response, Distributed Generation, Home Area Network, Communication, Cyber Security, and Electric Vehicles, Electric Energy Storage (EES) that are being employed in these 14 pilot smart grid projects in India.

II. SMART GRID TECHNOLOGIESBEING EMPLOYED IN 14 PILOT PROJECTS IN INDIA

A. Advanced Metering Infrastructure (AMI)

The term Advanced Metering Infrastructure (AMI) is used to describe the complete infrastructure comprising of Smart Meter, bilateral communication network, control center instruments and the applications that empower the collection and transfer of real time energy usage data. The aims of AMI include remote meter reading of accurate data, identification of grid problem, load profiling, energy audit and partial load cutting instead of load shedding.

Various components of AMI in Indian pilot projects;

- Smart Meters – It is an electronic device that measures the electric energy consumption in predefined intervals and sends that reading back to the utility for monitoring and billing purposes [11].
- Meter Data Acquisition system- Various application softwares that empower the hardware of the DCUs (Data Concentrator Units) and the Control Centre for communicating the information between smart meters and MDMS (Meter Data Management System) through the communication network.
- Meter Data Management System (MDMS)-

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The Control Centre's hosts system that imports the metering data, authenticate and process it before final billing and analysis.

- Communication Network- The network that empowers bilateral information exchange between smart meters and utilities like Power Line carrier Communication, Fixed Radio Frequency, Fiber Optic, Broadband over Power Line (BPL).
- Home Area Network (HAN) - An expansion of AMI installed at consumer end for the facilitation of communication of home appliance with AMI thus providing a better load management by both utility and consumer.

B. *Benefits for India's Grid system due to AMI*

- Improving System Reliability- AMI empowers the power distributors in the identification and automatic load dispatch of power demand leading to the reduction in power outages and thus an improvement in System Reliability.

- Reduction in electricity costs- With an improvement in the System Reliability and serviceability, reduction in power outages and smooth billing infrastructure there would be a reduction in the cost associated with the maintenance and operation of grid leading to a reduction in the power tariff rates.
- Reduction in power theft- Real time monitoring of power usage through AMI will make the system more transparent and thus will reduce the power theft.

C. Demand Response

It is an approach undertaken by utilities to transfer power consumption from peak hours to the moderate or lower power consumption intervals. The utility or the customers may shed the predefined non-critical load at peak hours.

Demand Response technologies being implemented in smart grid pilot projects in India:

- End-User Interfaces- Various channels like email, mobile phones, web portals, and business or in home display devices are used by the utilities to communicate with energy consumers regarding information about power usage and electricity pricing with smart grid. We may connect displays, load control devices and smart appliances to form a smart metering system using a Home area network.

- Load Control Devices- Various tools are being employed by the utilities to regulate heating and cooling on and off during demand response events. A direct remote control switching action of the AC units or heating devices may be incorporated by the Load control switches during peak loads. Temperature adjustment of these systems may be done remotely using Smart thermostats.

D. Advantages of Demand Response incorporation for Indian Power Sector

- Beforehand detection- Utilities can detect a load increment beforehand and take a control action also by initiating a demand response event via smart grid technologies.

- Efficient communication- A real-time energy usage and pricing data can be communicated to the consumers and thus the efficiency of the demand response can be increased by using smart grid technologies.

- Correct and smooth verification- Through smart grid the consumer's load shedding can be verified in real time in the duration of a demand response event.

- Automation technologies- Smart grid innovations are in process to develop certain technologies that would automatically sense the requirement for load shedding communicate with the consumers and manage all smart appliances in home or offices.

E. The prerequisites for implementing Demand Response in Indian power sector

Some of the most important prerequisites for bringing demand response into action is the regulatory framework and the identification of suited consumers in the pool of such diversified consumers to be served. Consumer enlightenment and keeping all the information transparent in consumer relation is must for building confidence in them for their participation in Demand Response Program. The functional reliability of Demand response can only be increased by strengthening the distribution network and by preparing customized Demand Response modules for different power system scenarios in India.

F. Distributed Generations

The energy generation and distribution nearer to its actual consumer employing small-scale technological infrastructure is known as distributed generation.

In the rural areas of India microgrids empowered by decentralized generation would supply economical, secure and clean electricity with greater reliability. Policies like Electricity act 2003, National Electricity policy 12th February 2005 notifications, Rajiv Gandhi Grameen Vidyutikaran Yojana and Remote Village Electrification scheme has encouraged various stakeholders in taking up the task of distributed generation in rural areas of India [21].

Various distributed generation technologies are being employed in the existing smart grid pilot projects in India that are shown in the figure below.

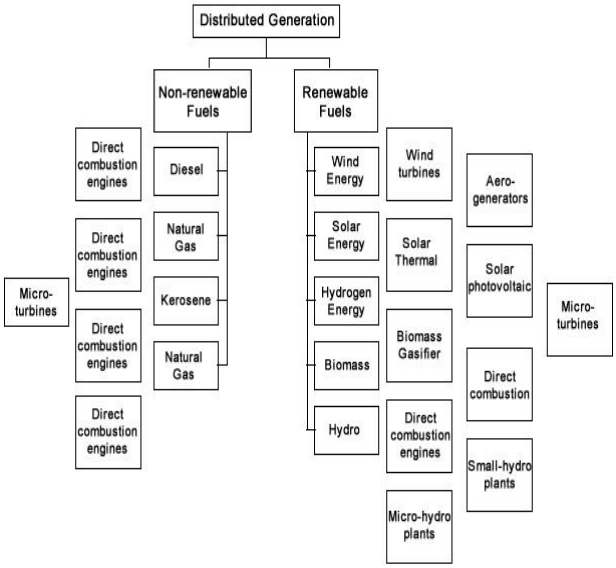

Figure1. Various distributed generation technologies in Indian smart grid pilot projects [20]

Distributed Generation Technologies in Indian smart grid pilot projects are as follows

- Microturbines: Microturbines are exceedingly becoming popular in distributed generation, combined heat and power applications and for powering hybrid electric vehicles [12]. For microgrid applications they range from 40-450 kilowatts.

- Fuel cells: Various types of fuel cells such as proton exchange membrane, phosphoric acid, molten carbonate, solid oxide, alkaline, direct methanol sizing from 15-1000+ kW range are being employed not only for standby power application mode but they may form the backbone of power generation in Indian microgrids.

- Wind Turbines: Wind turbines produces clean electricity using wind energy and does not require any new transmission infrastructure thus could be easily utilized for providing electricity to remote areas in India.

- Photovoltaic: Photovoltaic (PV) in the form of solar panels whether on roof tops or free standing consists of an array of solar cells producing DC (direct - current) power which is then converted into AC power by using Inverters.

G. Benefits of Distributed Generation integration in Indian Power Sector

- High system reliability and energy management- being islanded from utility grid distributed generation empowered microgrid operation make the management of power, correct voltage and frequency profile quite easy. Congestion management also becomes easier due to power back up energy storage devices.

- Peak demand management- Local generated electric supply during peak hours can mitigate the problem of power shortage during peak demand period.

- Electricity supply to remote areas- Rural areas in India can get electrification in an economical manner by implementing distributed generation.

- Decreased transmission and distribution losses- Due to the nearness of the power generation source and the load, the implementation of distributed generation rules out the need for transmission and large distribution networks which in turn reduces transmission and distribution losses.

H. Communication

The effectuation of intelligent electronic devices combined with telecommunication technologies in a smart grid set up provides better bidirectional information exchange between smart meters, local control units, intelligent relays and the centralized control station. Communication technologies integration in the smart grid will not only provide a more stable energy management set up but also a transparent information exchange between operators and consumers that would help them in monitoring and optimizing their own power consumption in an efficient manner.

Communication technologies being implemented in Indian smart grid pilot projects [13]:

- Low Power Radio [LPR] - Trunk mobile dispatching channels and meshed meter networks forms LPR set up.

- Wireless – Mobile phone communication set ups whether GSM/GPRS/EDGE method or the CDMA method and Wi-Fi forms Wireless communication technology.

- Power Line Carrier Communication – The superimposition of control signals by using the technology of broadband-over-power line at the distribution voltage forms this communication system.

- Land line – A combination of analog subscriber lines digital subscriber lines, coaxial cable and the fiber optics forms this communication system.

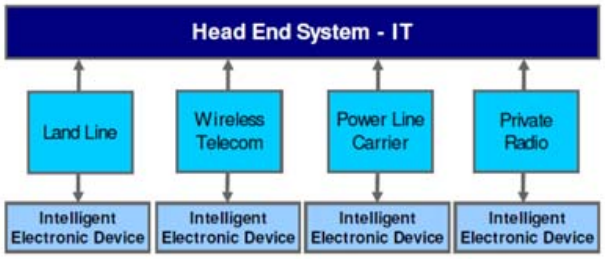

Figure 2. Communication technologies being implemented in Indian smart grid pilot projects [13]

Along with distributed intelligence the communication technologies make the real time reporting and control quite functional. Also, the intelligent electronic devices connected to the head end system through these communication systems makes it easier for the control center operator in monitoring the smart grid in an efficient and secure manner.

I. The Scenario of communication technology in Indian microgrid set up:

India stands at no. 3 after U.S. and China in smart grid investment as per a technology research and analysis firm innovation observatory [14]. The major communication network prevailing in India is mobile cellular network but it is facing the problem of congestion even in urban areas. The solution to the problem of congestion is to transmit the microgrid data during off-load periods through mobile cellular network from the data collector boxes to the control stations. The smart grid communication infrastructure in India is showing its reliability and scalability in supporting the implementation of other smart grid technologies like AMI and advanced Wide Area Network.

J. Electric Energy Storage (EES)

Indian Ministry of power has planned to integrate about 41 GW of Renewable Energy in Indian power grid sector by 2016-17 [15]. Keeping in mind the intermittency and local dependency of Renewable energy sources, Electric Energy Storage development is of utmost importance.

Various EES technologies being developed in Indian Smart Grid Pilot Projects:

- Flywheels – It's a rotating mechanical device with huge moment of inertia which can store energy in it proportional to the square of its constant rotational speed. A transmission device increases or decreases its acceleration by injecting or taking out electricity.

- Batteries – Depending upon the size and storage capacity of the battery its application in a smart grid ranges from powering electric vehicles upto transient power back up and grid integration. The different types of batteries used in Indian smart grid are as follows:

  - NaS – Mainly manufactured by NGK corporations, Japan, the NaS batteries have a high transient power rating. At Mitsui house in New Delhi, India, a microgrid set up has been made which uses NaS batteries.

  - LiB – Lithium Bromide batteries are rechargeable and can be used to power electric vehicles and grid connected applications in a microgrid.

  - Lead Acid – Although used for renewable and distributed power systems these batteries has huge space and maintenance requirements.

  - Vanadium Redox Flow Battery (VRB) – The net efficiency of this battery could be upto 85% [16]. UTC Labs is looking forward towards the commercial manufacturing of VRB batteries in India sensing the growth of smart grid set ups in this country.

- Electric Double Layer Capacitors – ELDC are ultra-capacitors that are used for large storage applications and have a long life.

- Thermal Storage – The heat is stored by using cold water or hot water for later usage in systems that involves large scale renewable energy integration mainly solar.

- Compressed air energy storage (CAES) – In this system we compress air in an underground storage cavern by using electricity and later the combustion of the mixture of compressed air and natural gas drives a modified gas turbine with the round trip efficiency of 70%.

K. Electric Vehicles (EVs)

Electric vehicles, in addition of not polluting the atmosphere by any carbon emissions are more energy efficient and are increasingly empowered by renewable energy sources. EVs in a smart grid can be connected into a Vehicle to Grid (V2G) connection when not running and thus provide electrical energy to the grid during peak hours in day time through the discharging of their batteries and charge their batteries during night when there is abundant power generation.

The Government of India in collaboration with Automobile industry has encouraged the development of EVs infrastructure in the following manner:

- Indian Government has run a road–trip of electric vehicles that covers 2500 kilometers of distance in southern India. The starting point of this road trip is Mumbai and the participating EVs halts at many colleges, schools, shopping malls and important museums etc. in prominent cities of India such as Bangalore, Hyderabad, Pune and Goa.
- Indian Government has formed a council named " The National Council for Electric Mobility " that will involve the participation of various ministries for developing a comprehensive policy for encouraging the development of EVs infrastructure in the country.
- 50 sub-stations in Delhi are equipped with the charging facility for EVs. Bangalore has made provisions for the charging of electric cars in the parking lot of commercial malls and offices.
- The Ministry of Heavy Industry in India proposed a monetary incentive of Rs 6,000 crore, along with full relaxation from customs duty and a waiver in the excise duty on imported batteries, to boost the production of electric and hybrid cars in India [17].

At the present stage EVs production in India is relatively naïve with Mahindra Reva being the most prominent product in the electric car market. Mahindra automobile company has sold nearly 5,000 cars from 2001 upto 2011 with almost 50 percent being sold to domestic customers.

L. Important steps to be taken by Indian Government for future growth of EVs in Indian smart grid set-up

The Indian Government has to work hand in hand with the industry to improve the battery technology and charging infrastructure for making EVs more affordable and efficient in commutation for the customers. The factors of low manufacturing cost, huge domestic market size and dedicated research and development council makes the future of electric vehicles development in India quite bright. The importance of including EVs in Indian smart grid could be assessed from the fact that an inclusion of about three lakh Electric Vehicles on Indian roads by 2020 could reduce the carbon dioxide, nitrous oxide and hydrocarbons emissions by 16 lakh metric tons and a saving of more than Rs 3700 Crores foreign exchange since India is dependent upon foreign countries for 70 to 80 percent of its fossil fuel needs [18].

M. Cyber Security

Smart grid involves vital communication technologies for bidirectional information exchange between utility and consumers. Now, the information being transferred may include energy usage, status of grid availability and electricity prices in real time for trading purposes. With an increase in the cyber- crime the protection of such valuable information exchange between smart devices through communication network is of utmost importance. Indian smart grid cyber security development is based upon the guidelines given by the National Institute of Standards and Technology (NIST). As per NISTIR 7628 report any smart grid should follow certain guidelines given below [19]:

- The regulatory bodies should form policy and regulatory framework that provides supporting environment for cyber security objectives.
- Risk assessment techniques should be developed for threat assessment and its impact.
- Four aspects of user privacy i.e. Personal information, personal privacy, behavioral privacy and personal communication privacy should be protected.
- Security architecture based on smart grid conceptual reference model should be developed
- Certification schemes for smart grid devices, networks, systems and processes should be developed enabling the stakeholders in benchmarking their infrastructures.
- Cultivate research and development (R&D) program targeting four R&D issues; 1) Device level security, 2) Cryptographic and key management, 3) Networking issues related security and 4) System level security.
- Security awareness and training programs that adhere to the organization's local, state and national policy and regulatory framework should be developed that backs up the overall smart grid security.

III. CONCLUSION

As seen from the above discussion it is evident that all the government and private agencies concerned with smart grid development in India must work in close association for greater research and development on the above discussed smart grid technologies in order to form a sustainable technological and infrastructural base for implementing smart grids nationwide. Also can be concluded from the above discussion that in an emerging economy like India all these smart grid technologies, which are interdependent on each other for a complete sustainable set up, must be developed in a parallel fashion without neglecting any technological aspect for a end to end success of the smart grid concept.

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