Research Journal of Engineering Sciences ______________________________________ ISSN 2278 – 9472
Vol. **2(11),** 6-11, November **(2013)** *Res. J. Engineering Sci.*

Review Paper

An Overview to Smart Grid Technology

Jain Rakhi[1] and Soni Nisheet[2]
[1]Power System, S.R.I.T., Jabalpur, R.G.P.V., University, Bhopal, MP, INDIA
[2]Electrical and Electronics Department, S.R.I.T., Jabalpur, MP, INDIA

Available online at: www.isca.in, www.isca.me
Received 21st October 2013, revised 31st October 2013, accepted 24th November 2013

Abstract

Smart grid has recently been introduced to provide a smarter power grid via aiding sensors and intelligent devices. These devices will collect data from the power grid. In case of any problems, e.g., blackout, sometimes smart grid is able to heal itself automatically and oftentimes, the collected information from the power grid needs to be transmitted to the utilities (control centres), then according to the received information, the utilities will send commands to the power grid. Smart grid technology provide more efficient transmission of electricity, improved power quality, improved reliability, improved security, better integration between consumer and utility, reduction in peak load demand, reduction in operation and maintenance cost which in turn lower the electricity rates. Smart grid provides a batter option for consumer to switchover from an old electric grid to a new smart grid. This paper presents an overview on how the smart grid drives changes in consumer behaviour and the communication with smart Devices.

Keywords: Smart grid, Smart home, smart meter, Plug-in-Electric vehicle, consumer engagemen.

Introduction

“The Grid”, refers to the electric grid, a network of transmission lines, substation, transformers and more that deliver electricity from the power plant to your home or business. The electric grid is considered an engineering marvel which grew over time and were eventually interconnected for economic and reliability reasons.

Figure-1
Smart Grid Conceptual Framework[1]

The use and production of electricity are changing. Consumers are more aware of environmental impacts of electricity system. New disseminated energy sources such as solar, wind and storage lowers not only the green house gases.
But also allows consumer to produce their own electricity and sell the excess. These changes will require a new theory in the electricity system. Today, the grid is a primary vehicle for moving electricity from generators to consumer. And we require a grid which can enable two-way flow of electricity and information between energy provider and consumer.

That means we need a new kind of electric grid, which is built from the bottom up to handle the groundswell of digital and computerized equipment and technology depends on it- and one that can automate and manage the increasing complexity and needs of electricity in the 21st century. So, Smart Grid is a developing network which includes the Digital Technology, Smart Home, Smart Meter, Renewable Energy Sources (wind and solar), Consumer Engagement, Distribution Intelligence, PEVs (Plug-in-Electric Vehicles) as shown in figure-1.

Smart grid offer the potential to change the way we live, work, and play by facilitating active consumer participation in energy usage, delivering quality power and accommodating the generation of power by alternative sources.

Smart Grid Characteristics: The Smart grid is an upgrade to the current electrical power system, so it has all of the functionality of our current power system plus several new functionalities, such as: i. Self healing, ii. Motivates and includes the consumer, iii. Resists attack, iv. Increase power quality, v. Accommodates all generation and storage options,

vi. Enable electrical markets, vii. Optimizes assets and operates efficiently.

The smart grid will be self-healing. This means that it can redirect and adjust the flow of electricity in the event that an electrical transmission path is interrupted. This is done by a continuous self-assessment of the state of the power system. As a result, this can reduce the frequency and duration of major blackouts. It is estimated that the August 14, 2003 blackout in the U.S. and Canada had a societal cost of $10 billion[2]. Reducing the number of major blackouts and their severity will reduce the economic losses our society incurs during these blackouts.

The Smart Grid will motivate and include the customers. There is currently minimal interaction between customers and suppliers in the electrical power system. The Smart Grid provides customers with more information and options about their electrical power. In theory this will allow customers to make better decisions about their power usage that will not only save them money, but will also promote competition between power suppliers. This is done by enabling two-way communication between energy consumers and suppliers. The Smart Grid can also interact with electrical appliances in a customer's home. This interaction allows appliances to schedule their run time when electricity is at the cheapest price.

The Smart Grid will be resilient to attacks and natural disasters. The Smart Grid will not only be resilient to physical attacks, but also cyber attacks. The electrical power grid is a complicated system that is at the root of most U.S. economic growth. This makes the electrical power grid a critical asset, and damage to it can have devastating affects to our society's welfare. Parallels are drawn between the electrical power grid and the Roman aqueduct system in M.J. Assante[3]. Over time the Roman aqueducts underwent design changes. As the Roman Empire grew, the level of perceived threat lowered. This lead to design changes that were less concerned with security and more with form and functionality. Then towards the end of the Roman Empire these aqueducts became easy military targets for invading forces because of the design changes. Attacks against Roman aqueducts had major social impacts because they had become a critical system that the Romans depended on. The electrical power system is a critical asset that we rely on, and it needs to be resilient to all forms of attack.

The Smart Grid will provide an increase in electrical power quality. Electricity is not only required to be available at all times from the power grid, but it must also maintain a constant voltage. Some manufacturing processes are very sensitive to voltage variations. Power loss for several minutes or more on some industrial process has same effect as voltage drop for less than 100 milliseconds. These voltage fluctuations are estimated to cause productivity losses in commercial facilities ranging from thousands to millions of dollars per event. It is estimated that by 2011, 16% of the electrical load will require digital quality power[4].

The Smart Grid will accommodate all generation and storage options available. The integration of renewable energy sources into the electric power grid has several complications. The current electric power grid is a broadcast model that is designed to only allow the one-way owe of electricity from a one-generation source to many consumers. Renewable energy sources are often geographically separated from traditional power sources, and when they are integrated into the power grid, it is as distributed power sources. Since the electrical power grid was designed for only a single power source and not multiple distributed power sources, this causes complications. Germany has experienced issues related to problems in their electrical power grid. Customers using solar panels could overload the electrical power system when surges of power come from the solar panels[5].

Fossil fuels are not a sustainable energy source, and as a result new alternative power sources will be explored. The Smart Grid will be able to support these new energy sources along with the traditional power sources.

The Smart Grid will enable electrical markets. Electrical markets in the Smart Grid will encourage competition among power suppliers. This competition will promote power suppliers to develop cheaper and more efficient means of power generation. This will drive down the prices of electrical power for customers as suppliers compete for their business. The Smart Grid will also support distributed power sources. This opens the door for new electrical power suppliers and electrical service providers to enter the electrical market. The electrical market will broadcast current electricity prices based on a supply-demand model. Electricity will be more expensive when the load or demand is high, and it will be cheaper when there is surplus electricity. Customers can use this information to schedule tasks that use large amounts of electricity at a time when electricity is cheaper.

The Smart Grid will optimize assets and operate efficiently. The features that will make the Smart Grid self-healing can also be used for asset management. The Smart Grid will be able to automatically assess equipment condition and manage equipment configuration. This management automation can be done at substantially lower costs compared to manual management. The automation of equipment management will also reduce the chance of equipment failure since the degradation of equipment can be tracked. The Smart Grid will also incorporate new technologies that will reduce energy loss during electrical transit. This reduction in energy loss will increase the electrical power grid's efficiency by eliminating excess power waste.

Table-1
Comparision of Today's Grid and the Smart Grid

Comparison of Today's Grid and the Smart Grid2 Characteristic	Today's Grid	Smart Grid
Information flow and participation of consumer	customers have limited information and chance for participation with power system	Not only informed, but also active participation of consumer
Housing of all generation and storage options	Many obstacles exist for distributed energy resources interconnection and operation and conquered by central generation –	Distributed generation with local voltage regulation capabilities to support high dispersion on distribution systems; enabling high access of renewable; frequency-controlled loads to provide spinning reserve, many distributed energy resources with plug-and-play convenience; responsive load to enhance grid reliability.
New products, services, and markets	Limited comprehensive markets, not well incorporated – limited opportunities for consumers	Mature, well-integrated comprehensive markets; opens more opportunity for consumers; interoperability of products.
Power quality needs for 21st century	spotlight on outages and primarily manual restoration – slow response to power quality issues, addressed case-by-case	Power quality is a priority with a variety of quality/price options – fleet resolution of issues
Optimisation of assets and operation efficiency	restricted integration of operational data with asset management – business process silos limit sharing	Data attainment of grid parameters is noteworthy–minimizing impact to consumers, focus on prevention
Automated prevention, addresses disturbances, restraint and restitution	Responds to prevent further damage – focus is on protecting assets following a fault	Automatically detects and responds to problems – focus on prevention, minimizing impact to consumers, and automated restitution
Operates robustly against physical and cyber attacks and natural disasters	For unplanned mistakes at risk, equipment failures, nasty acts of terror and natural disasters	Flexible to inadvertent and intentional attacks and natural disasters with rapid coping and refurbishment

Overview of Indian Power Market

In India, electricity reforms started with the re-evaluation of Electricity Supply Act, 1948 and the Indian Electricity Act, 1910 which led to the electricity Act 2003. The Electricity Act, 2003 has been brought about to facilitate private sector participation and to help cash strapped state electricity boards to meet electricity demand. The electricity Act, 2003 envisages competition in electricity market, protection of consumer's interests and provision of power for all. The act recommends the provision for national electricity policy, rural electrification, open access in transmission, phased open access in distribution, mandatory state electricity regulatory commissions (SERCs), license free generation and distribution, power trading, mandatory metering and stringent penalties for theft of electricity. One more welcome step that the Indian electricity market has been taken is the implementation of availability based tariff (ABT) which brought about the effective day ahead scheduling and frequency sensitive charges for efficient real time balancing and grid discipline.

The fixed and variable costs of electricity production are treated separately in the ABT. Fixed cost, known as capacity charge, is associated with plant availability and its capacity to deliver MWs on day-to-day basis. Generating plant is paid the capacity charge according to its average availability over; a year. Variable charges, known as energy charge, are the charge associated with the variable cost of energy production and the total amount paid to the generators is based on their scheduled energy production rather than actual production. The third component of ABT is called unscheduled inter change (UI) which is the payment for deviation from the schedule, and the rate is decided according to the system frequency. Beneficiaries are paid for the underdraw or charged for the overdrawal according to the system frequency. Thus the UI mechanism acts as a balancing market in which real time price of the electricity is determined by the system frequency.

To promote power trading in a free power market, central electricity regulatory commission (CERC) approved the setting up of Indian Energy Exchange (IEX) which is the first power exchange in India, in June 2008. IEX has been modelled based on the experience of one of the most successful international power exchange, Nordpool. At present, two power exchanges are operating in India, namely,

Table-2
Indian power market structure

Time Scale	Market clearing	Approval of Scheduling	Settlement
Long-term contracts	Traders and Utilities	Nodal agency(RLDC/ SLDC)	Utilities
Short-term contracts	RLDC	RLDC	RLDC
Day-ahead	IEX/PXIL	RLDC	IEX/PXIL
Day-ahead scheduling of central and state generations (under ABT)	RLDC/SLDC	RLDC/SLDC	RLDC/SLDC
Real-time	Through ABT-UI price signal		RLDC/SLDC

IEX and Power Exchange India Limited (PXIL). These exchange have been developed as market based institutions for providing price discovery and price risk management to the electricity generators, distribution licenses, electricity traders, consumers and other stakeholders. The participation in the exchange operation is voluntary. At present exchange offers day-ahead operations whose time line is set in accordance with the operations of regional load dispatch centres (RLDCs). Power exchange co-ordinate with the national load dispatch centres (SLDCs) for scheduling of traded contracts to get up-to-date network conditions.

Currently, about 96% of the market transactions in India are in the form of bilateral (long and short terms) contracts. The rest is dealt by two power exchanges. The day-ahead market of power exchange offers double side auction and discovers the price incorporating the supply and demand side bidding. Network constraints are considered in deriving the price and market splitting approach is used to clear the market with congested lines. All buyers and sellers are expected to bear transmission charges and losses in their regional transmission systems till the periphery of transmission system. The are also required; to bear operating charges (a charge to cover costs of system operations) and transaction fee of the exchange which is nominal at INR 0.01paisa/kWh. The exchange as of now, offers only day-ahead contracts of an hourly time block. However the exchange has plans for future to offer the adjustment contracts and long term contracts like forward and futures to hedge the risk against uncertainty in electricity market. The Indian power market operation can be described as shown in table II.

A. Recently introduced market products and services in power exchanges in on August 31, 2009, the CERC accorded its final approval for the much awaited term-ahead market proposed by IEX. Following new contract has been approved by CERC to be traded at IEX platform[6].

Day-ahead contingency contracts: These are the contracts which will be available for trading after the day-ahead market for all the 24 hours of the next day i.e. the participants will be able to buy/sell power for any hour of next day. Trading will be organized from 15:00 Hrs to 17:00 Hrs on daily basis. These region specific hourly contracts would enable participants to manage their next day contingency requirements on a day-ahead basis.

Daily Contracts: These are the contracts which will be available for trading on rolling basis i.e. everyday seven daily contracts of the following week will be available. Each contract will be for specified block of hours of one day. The trading session for daily contracts will be organized daily from 12:00 Hrs to 15:00 Hrs. These region specific contracts are designed to enable participants to manage their requirements upto one week in advance with a delivery period of one day.

Intra-day Contracts: These are the contracts which will be available for trading on daily basis. These region specific hourly contracts would enable participants to match their same day contingency requirements for the duration 18:00 Hrs to 24:00 Hrs of the same day. The contracts will be traded from 12:00 noon and will continue till 17:00 hours of the same day. All the above contracts will be matched. Continuously on price-time priority basis i.e. buyers and sellers will submit bids on real time continuous basis. The seller with minimum price and buyer with maximum price will be considered as best seller and best buyer, respectively. The best buy bids will be matched with the best sell bids through out the trading period. Five best buy and sell orders will be displayed on the trading screen to all the participants on real time basis.

Weekly Contracts: These are the contracts which will be available for trading on all Mondays of the month and also on 15th day prior to the close of every month. These region specific contracts would enable participants to manage their requirements upto one month in advance with; a delivery period of one week and maximum delivery period upto four weeks. The contracts will be traded from 12:00 noon and will continue till 14:00 hours of the same day.

Buyers can submit buy-orders in various regional contracts and will be considered as link orders. In link order buyer will have the opportunity to put their buy bid in any of five operational regions (eastern, western, northern, southern and north-eastern regions) [7]. Maximum bid volume in any of the regions will be considered as; the maximum quantum buyer is willing to buy from all regions will be considered as the limiting quantum for that region.

The exchange will carry out trading in such contracts through closed auction session only i.e. closed auction means that the members can not see the other bids/offers submitted. Both buyers and sellers enter anonymous orders for contracts. Members can input several orders each with limit price and quantity. Orders from buyers and sellers are processed and matched. Members are allowed to enter, modify or delete bids during call period but not during auction freeze state. At the end of call period, such bid/offers are aggregated as demand and/or supply curve and intersection of two will determine uniform clearing price referred as equilibrium price. All orders in the contracts having prices, better than the equilibrium price are executed and the ones that have a price equal to the equilibrium price are executed according to a fact in first in first out (FIFO) ALGORITHM. All the above contracts will be available for all five regions i.e. Northern, Eastern, Western, Southern and North Eastern. Sellers will quote bids for selling at their respective state periphery i.e. interconnection of regional entity with CTU however buyer can buy power from any of the five regions.

Smart Grid Communication Network

As mentioned earlier to upgrade the current power grid to a smart one, the information collected by smart one, the information collected by smart devices needs to be provided to customers, operators and utilities, offering the opportunity of dynamically responding to changes in power grid conditions[8]. Therefore, a reliable two-way digital communication network is essential for smart grid implementation. However, there is currently an ongoing debate surrounding what will be the best choice for smart grid communication technology[9]. Among wireless technologies, Worldwide Interoperability for Microwave Access (WiMAX) and wireless mesh networks are the two considered technologies for smart grid realization. WiMAX[5], as a next generation network, covers a large area, 10 km, and provides a high data rate of 63 Mbps. On the other hand, it is not as secure as other; wired; communication technologies and it still has not been deployed everywhere.

Wireless mesh network is a favourable Advanced Metering Infrastructure (AMI) solution implemented by some utilities in the United States. It is a self configuring network and can be deployed easily. It experiences high latency and uses unlicensed radio frequency. Hence, it can interfere with other communication devices.

Among wired communication technologies, there is an increasing interest in using powerlines communication (PLC). Utilities may prefer to have their own communication infrastructure and PLC offers them this opportunity. Powerlines exist everywhere. Even rural areas can be covered by PLC since powerlines are already deployed there, while providing these areas can be covered by PLC since powerlines are already deployed there, while providing these areas with other kinds of communication technologies is hard. On the other; hand, PLC has some disadvantages. t suffers from noise. For example, turning electrical devices on and off makes noise and pulse. Furthermore, transformers because of their high inductances act as low pass filter's and block high frequencies. Therefore, in Broadband Power Line Communication (BPLC) couples are needed to be attached at the transformers to allow high frequencies to pass through them. There; are two general technologies for PLC: Narrow Band Power Line Communication (NBPLC) and BPLC. Different governments define different frequency ranges to be used for NBPLC. According to the European standard, NBPLC operates in the frequency range of 9 to 140 kHz with maximum 128 kbps data rate[10, 11], while the USFCC standard allows a frequency spectrum usage of up to 500 kHz providing 576 kbit/s data rate[11]. BPLC modems operate in the frequency range of 500 kHz to 30 MHz and a high data rate of at least 100 Mbps in provided[12].

Conclusion

A smart grid precisely limits electrical power down to the residential level, network small scale distributed energy generation and storage devices, communicate information on operating status and needs, collect information on prices and grid condition, and move the grid beyond central control to a joint network.

There is marvellous enthusiasm about the latent of smart grid. There may be false start and dead end. Open standard and integrated approaches are the keys to minimizing the risk of standard technologies. Demonstration and technology are the tools to test technology to see how they perform in the real world. Synchronization on several different stage is the key success of developing the smart grid. From the technical point of view, there should be some set standards at different level to allow devices to be developed by multiple suppliers. The smart grid must enable the transparent exchange of operating and price information to efficiently link customer choice with dispatch of resources and the operation of the grid.

In recent years there have been some efforts for application of smart grid in developing countries. Some countries like China, India and Brazil are pioneer on smart grid in developing world. In India, the implementation of smart grid is not going to be an easy task as the Indian power sector poses a number of issues such as minimizing transmission and distribution losses, power theft, inadequate grid infrastructure, low metering efficiency and lack of awareness and last but most important, availability of funds.

References

1. "Smart Grid" [online]. Available at: http://www. smartgrid.gov /the smartgrid/renewableenergy **(2013)**

2. DOE, Final Report on the August 14, 2003, Blackout in the United States and Canada, U. S- Canada Power System Outage Task Force, 2004, [Online]. Available: https:reports.energy.gov/BlackoutFinal-Web.pdf **(2014)**

3. M.J. Assante, Infrastructure Protection in the Ancient World", Hawaii International Conference on System Science, **0,** 1-10, 2009. [Online]. Available: http://www.inl.gov/nationalsecurity /energysecurity/d/infrastructure_protection_in_the_ancient_world.pdf **(2009)**
4. New Scientist, Solar Power could crash Germany's grid, 2010. [Online]. Available: http://www.newscientis.com/article/mg 20827842.800-solar-power-could-crash-germanys-grid-html **(2010)**
5. NETL, the NETL Modern Grid Initiatives Powering Our 21st Century Economy: Modern Grid Benefits. Department of Energy, **(2007)**
6. [Online]. Available: Indian Energy Exchange Website www.iexindia.com/, **(2009)**
7. [Online]. Available: Ministry of Power Government of India Website, http://powermin.nic.in, **(2009)**
8. NIST Framework and Roadmap for Smart Grid Interoperability Standards Release 1.0, NIST Special Publication 1108, National Institute of Standards and Technology, **(2010)**
9. L.A. Burkhart, "The DOE's "7 Traits of a Smart Grid", "Fortnightly's, 70, **(2009)**
10. H. Hrasnica, A. Haidine and R. Lehnert, Broadband Powerlines Communications Networks, Network Design. John Wiley and Sons Inc, **(2004)**
11. Prime Project, Prime PHY, MAC and Convergence Layers, Technology Whitepaper, **(2008)**
12. IEEE Draft Standards for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications, IEEE P1901/D4 .01, July 2010, 1-1-1589 **(2010)**
13. F. Aalamifar, Viability of Power line Communication for Smart Grid Realization, April, **(2012)**
14. U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, "Smart Grid Research and Development-Multi Year Program Plan (MYPP), 2010-2014 **(2014)**
15. V.S.K. Murthy, S.A. Khaparde, R.P. Gupta "Smart Grid Initiative and Power Market in India' IEEE PES General Meeting, Minneapolis, USA, **(2010)**