Design Aspects, Operation and Control of Future Energy System

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***Abstract*— Ever increasing demand of electrical energy world over and environmental concerns are driving the existing fossil fueled based energy system to efficiency, conservation and utilization of more and more renewable sources of energy. The electricity consumers are becoming more proactive and are participating in energy consumption decisions which affect their lives. All these concerns necessitate that the century old energy grid should be modernized and made smart with the applications of smart devices, information technology, modern communication devices and fast computational techniques. A smart grid should employ smart control centres, smart transmission and distribution networks, creation of mini and micro grids, use of distributed generation etc. This work is an effort to investigate all the developments related to smart grid in reference to India. The development for creating smart grid in India are multidimensional in nature but the major focus is to electrify areas which have not been covered so far, to reduce losses, to strengthen the existing grid and to make greater use of renewable sources of energy.**

***Keywords*—Smart Grid (SG), Demand side management (DMS), Advanced metering infrastructure (AMI), Smart microgrid.**

1. INTRODUCTION

The creation of electric power grid is considered as the greatest engineering achievement of the 20th century. To prove reliable power at affordable cost is the basic need of the modern society and for the growth of economy of any nation. While the grid has benefited from many innovations and improvements over the last century, the basic design has little changed from the days of Edison and Westinghouse in the 1880s. The electricity is largely generated at centralized fossil fueled generating stations and transmitted and then distributed to consumers through one-way transmission and distribution system. The consuming devices are dumb in nature and have little or no knowledge about the price of electricity or whether the grid is under stress due to overload,

2. PRESENT STATUS OF INDIAN POWER GRID

Since independence India has progressed well in meeting the electricity demand. It is electrically demarcated into five regions namely, Northern, Western, Southern, Eastern and North-Eastern. Since December 2013 the Indian Grid is operated as a single synchronous grid operating at 50Hz. Each of the five regions has a Regional Load Dispatch Centre (RLDC). At the National level, National Load Dispatch Centre (NLDC) has been established for optimal scheduling and dispatch of electricity among the regions. The total installed generating capacity as on August 31, 2017 was 329.226 GW and transmission capacity of lines having 220kV, 400 kV, 765 kV and HVDC is 747810 MVA with a total length of 378087 ckm [1].

3. CHALLENGES FACING INDIAN POWER SECTOR

Inspite of tremendous progress in the power sector the grid is largely vertically integrated. The current system is less reliable, inefficient, polluting, less flexible, incompatible with renewable energy sources, vulnerable to cyber attacks and without any participation of customers. The real-time monitoring and control is difficult and hence limited to generation and transmission only. The existing system converts only one-third of fuel energy into electricity without recovering the waste heat. Almost one-fourth of the energy generated is lost as AT & C losses.

Recently vertically integrated grid was deregulated in order to introduce competition among different private and state owned players. Due to deregulation numerous private power companies with a variety of generating systems came into existence. These private players are selling power to customers utilizing the existing transmission and distribution network. Due to this a number of problems emerged such as congestion of transmission lines, rerouting of flow of power in the lines to reduce congestion, determination of appropriate transmission charges to be recovered from the participating companies etc. Outages are often recognized only after customers file complaints. Matching of generation to demand is challenging due to non-availability of large scale energy storing devices. As a consequence, they need to over generate and maintain sufficient reserve to meet peak demand which is not only expensive but contributes to degradation of environment and resources.

4. FUTURE ADDITION PLAN OF RESOURCES

Out of the total installed generating capacity of 329.266 GW the share of renewable energy (RE) capacity till July 31, 2017 is 58.9 GW [9] which is nearly 18%. This small penetration of renewable energy capacity does not pose much problem with the existing grid operation. The share of renewable energy in India's installed capacity is rapidly increasing. After Paris agreement on climate change India is vigorously pursuing the policy of increasing the share of renewable energy to 175 GW by 2022 which includes 100 GW from solar, 60 GW from wind, 10 GW from biomass and 5 GW from small hydropower. The 100 GW of solar power is proposed to be achieved through deployment of 40 GW roof top solar projects and 60 GW large and medium solar power projects. This large scale penetration of renewable energy sources in the grid will not only make the traditional concept of base load electricity generation obsolete but put forward several challenges in the operation and control of the power grid.

5. CHALLENGES IN GRID OPERATION & CONTROL DUE TO LARGE SCALE PENETRATION OF RESOURCES

Variable nature of RE sources particularly solar and wind result in lower output per installed kW over the year than that of fossil fueled power plants. Large scale penetration of RE sources on the grid will need changes to the way in which energy is transmitted and used. The existing grid has very little storage capacity and hence it will be very difficult to maintain balance between demand and supply of energy at all times to avoid black outs or other cascading problems. Fast fluctuations in output from solar or wind generation not only disrupt grid planning but also instant to instant balance between energy supply and demand. Today the grid operators transmit signals to power plants every four seconds to ensure balance between generation and demand. Another big challenge occurs when significant solar or wind generation is available during low load periods. This may force the grid operator to shut down, if possible, a few generating units or run them at the minimum output levels. Solar power plants connected to the grid at transmission level provide real-time generation data to grid operators where as distributed solar power plants do not. That makes it difficult for a grid operator to ascertain whether increase in demand is because of increased load or due to decreased solar generation.

With the increasing penetration of wind power generation, the dynamic performance of grid may change considerably. A large number of cascading failures involving wind farms have happened in the past because most of the wind turbines installed were not equipped with fault ride trough capability. Sub-synchronous resonance phenomenon has also been observed on long distance transmission of wind power through series compensated lines. It is therefore necessary that installation of new wind farms and the existing wind farms should be provided with voltage and reactive power control and fault through capability in order to maintain grid stability.RE sources such as solar PV, wind, fuel cells etc do not have rotating machines. These sources are connected to grid through dumb inverters which are designed to simply lock into the grid's frequency and follow it. With the large scale penetration of these RE sources, the grid will lack the inertia, it has today, to maintain stability in the event of large disturbances. For this reason, the future power grid may need advanced inverters which respond instantaneously to disturbances and help keep the grid stable.

6. THE ENERGY GRID OF THE FUTURE

The energy grid of the future known as the Smart Grid (SG) or intelligent grid is expected to address the major short comings of the present grid. Although many different definitions have been proposed for the smart grid, the vision of Indian Smart Grid is to transform the Indian power sector into secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders [2].

Smart grid will not only provide efficient demand side management by integration of conventional and RE sources but will also help making the environment pollution free by utilization of renewable energy sources, thus reducing greenhouse gas emissions. The future grid will be reliable, efficient, economical, possess operational flexibility, integrate different types of energy sources and help in efficient utilization and management of resources.

7. THE ARCHITECTURE OF FUTURE GRID

To transform the existing grid into a smart grid it is necessary to deploy smart devices capable of two-way communication. While deploying smart devices every possible constraint should be considered otherwise it may suffer from high revenue loss due to suboptimal operation, poor service delivery excessive IT cost and heavy investment cost.

The smart grid infrastructure consists of four interactive layers. The base layer is the physical layer which involves installation and control of hardware devices such as phasor measurement units (PMUs), phasor data concentrators (PDCs), intelligent electronic devices (IEDs), smart switchgear, sensors, transducers, data acquisition devices (DADs), condition monitoring equipment, SCADA/Automation, global positioning system (GPS), FACTS devices, EHV/UHV transmission lines, asset mapping, intelligent metering etc. The second important layer is the creation of strong communication system so that all the smart devices can communicate from end to end. The two-way communication network will not only provide advanced monitoring and control, but will also support efficient generation, transmission and distribution of power. The smart intelligent communication technique to obtain two-way communication is machine to machine communication. This technique facilitates load demand management according to utility constraints. The third layer is the IT and decision support layer. This layer forms the monitoring and control system of smart grid. It involves services and softwares like servers, computers, printers, ethernet switches, network management softwares, decision support system, network control centres, forecasting softwares etc. The fourth layer is the interface layer which integrates information and power supply from different sources. It involves seamless integration and information exchange with stakeholders i.e. generators, discoms, prosumers etc.

8. ENERGY STORAGE

Energy storage technologies are going to be an important part of smart grid technology. It is beneficial to both grid connected and off grid RE systems. It is an efficient mechanism to convert infirm power of RE sources to firm power within a smart period. It absorbs excess energy generated from RE sources during low demand and supplies energy during reduced output from RE sources. Energy storing devices also help in mitigating the ill effects of high ramp up or ramp down. Energy storage systems improve grid reliability, reduce outages, lower pollution from fossil fuels and improve system security which are essential objectives of smart grid. Depending upon the requirements different energy storage devices can be commissioned. Pumped hydro electric storage reservoirs and large compressed air energy storage systems can be provided for large centralized RE sources and batteries, flow batteries, hydrogen based batteries like Ni-MH and Ni-Fe batteries can be employed for backup power support for industrial facilities. For transient loads at grid level ultra capacitors and high speed flywheel can be employed for their very fast response. In grid supplies if transient loads are not met in small time limits, it can lead to frequency and voltage fluctuations and even the entire grid may collapse.

9. MICROGRIDS

Micro grids with distributed generation can provide major opportunity for implementation of smart grid concepts. Development and implementation of new and innovative technologies to integrate distributed energy resources through micro grids can significantly improve reliability, allow deep penetration of RE sources, provide self healing property and can help in reducing peak demand. It can play an important role in avoiding wide area blackouts due to natural disasters. To manage significant level of distributed energy resources with their wide ranging dynamics require sophisticated control systems. Electric vehicles (EVs) or plug in hybrid vehicles (PHEVs) can provide the possibility to enhance the benefits of the smart grid. They can act as energy storing devices and help in reducing peak demand and carbon footprint of modern society.

10. ADVANCED METERING INFRASTRUCTURE

Advanced metering infrastructure (AMI) provides utilities with a two way communication system Through AMI, utilities can get instantaneous information about individual and aggregated demand which is very helpful in carrying out load side management. The utility can control peak demand by imposing caps on consumption through the application of various revenue models. It is also possible to reduce AT & C power loss by detecting power theft.

11. NATIONAL PROGRAMMES IN THE DEVELOPMENT OF SMART GRID

The ministry of Power, Government of India established in 2015 National Smart Grid Mission (NSGM) to plan and monitor the implementation of policies related to smart grid activities in India [3]. It promotes deployment of Smart Grid technologies like Advanced Metering Infrastructure (AMI) substation renovation and modernization with deployment of Gas Insulated Substation (GIS) and Distributed generation (DG) in the form of Roof Top Solar PVs, real time monitoring and control of Distribution Transformers, development of micro grids creation of charging infrastructure for Electrical Vehicles (EV). The Ministry of power sanctioned twelve smart grid pilot projects between 2014 and 2017. In Rajasthan AVVNL, Ajmer was also sanctioned one pilot project in 2015. In 2012 Smart Grid knowledge centre was established and in 2016 three full SG projects were also sanctioned by the Ministry of Power under NSGM. Several large scale SG projects have also been assigned under public Private Partnership to various power companies.

Smart metering- under smart city mission, The Govt. of India has planned to install 35 million smart meters by 2019 in 100 cities, Accurate and well timed meter reading, remote connection and disconnection of consumer load, accurate temper alert will greatly help in loss reduction. It is envisaged that by 2022 it will be possible to bring down the AT & C losses from 24% to 12% and below 10% by 2027. Smart metering system will also help in the reduction of peak power demand by forcing Time-based pricing system [2].

Smart Grid in Transmission-Power system operation Corporation Limited (POSOCO), a Govt. of India Enterprise is also implementing various power projects on sychro phasors/WAMCPS (Wide Area Monitoring, Control and Protection System) in India. Synchro Phasors/WAMS are the most essential part of SG at transmission level. A pilot project is already in operation at NLDC with more than 60 PMUs already installed after the major grid disturbances on July 30& 31, 2012.The power Grid is planning to install about 1700 PMUs covering all 400 KV and above voltage level substations and major generating stations for dynamic security monitoring. The first phase scheme comprises installation of 1186 PMUs at 356 substations and its integration with 34 control centres is under implementation. PMU data based analytics is being developed in collaboration with IIT Bombay. Work is also progressing simultaneously to strengthen communication network by connecting 2,50,000 village panchayats in the country by Optical Fiber Cable and extending the fiber link to all the 33/11 kV and above substations.

Micro grids in 100 villages/industrial parks/commercial hubs are under progress and are expected to be complete by the end of 2017 and 10,000 villages/industrial parks/ commercial hubs by 2022 which can island from the main grid during peak hours or grid disturbances.

12. CONCLUSIONS

Cyber security is a major component of future smart grid systems [7]. Security must be designed in at the architectural level, not added on later. Innovative research is needed to help ensure security of the grid. New threats will continually surface and hence new technologies and methodologies will have to be regularly evolved on top priority to detect and mitigate threats to smart grids. Modernization of the electric grid is a significant long term undertaking which may span over decades. It is quite possible that future generations will look upon the development work of smart grid as the supreme engineering achievement of the 21st century.

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