Emerging Technologies in Operation & Control of Future Power Systems

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Abstract: **Power industry has undergone significant change in the last two decades due to the introduction of new technological advancements, environmental drivers and changing weather patterns, changing customer needs, regulatory requirements, natural disasters and the possibility of cyber and physical attacks by terrorists. The planning, operation and control of electrical power and energy industry of future will be significantly different than it is today. There is also a major motivation for conserving natural resources, utilization of renewable energy sources, reduction in AT & C losses, reduction in carbon footprint, slashing peak demand by converting the existing grid into a smart grid. The deployment of microgrids could be an important aspect in preventing wide-area blackouts. In this paper efforts have been made to include the recent technological developments about power and energy system particularly with reference to Indian National Grid.**

Today for the growth of any nation energy is the most important commodity in the world. Out of all forms of energy electric energy is the most convenient form of energy as it can be converted into any other form very conveniently and efficiently. There are challenging problems associated with the power industry in the design of future power systems and in the modernization of existing ones to deliver quality power in a safe, clean and economical manner with a high degree of reliability.

1. GROWTH OF POWER SYSTEM

In 1978, Thomas A. Edison first conceived the idea of central power station. On September 4, 1882 he commissioned the historic Pearl Street Power Station in New York City. It was a 30 kW, 110 V, D.C. power station. The distributor was only a one-quarter mile long and served 59 customers. With the development in the technology of transformers, induction motors and synchronous motors the growth of a.c. systems got a tremendous boost. Several different frequencies such as 25, 40, 50, 60, 125, 133, Hz etc. were tried and finally some countries including India adopted 50 Hz where as remaining countries adopted 60 Hz as the operating frequency. Transmission voltages grew from 110 V to 1200 kV and the generator size also grew from a few kW to more than 1000 MW. The world energy consumption also grew many folds.

2. INDIAN POWER GRID

Since independence, Indian Power System has witnessed a remarkable growth. We have grown from small isolated power stations to, 'one nation, one grid, one frequency' concept. The Indian electricity grid is now among one of the largest power grids in the world with an installed generating capacity of 288.665 GW as of February 29, 2016. The Indian power system is managed by the five regional load dispatch centres (RLDCs) one for each regional power grid and one national load dispatch centre (NLDC) apart from state load dispatch centres (SLDCs). All five regional grids were synchronized to form one national grid on December 31, 2013. Currently all the five RLDCs and NLDC are managed and coordinated by Power System Operation Corporation (POSOCO). The National grid has also been interconnected with neighbouring countries like Nepal, Bhutan and Bangladesh. India has recently signed trities to increase power supply to Nepal from 230 MW to 600 MW and will supply 1000 MW power to Bangladesh. Work is in progress to interconnect the National Grid with Shri Lankan Grid.

3. POWER GRID OPERATIONAL CONSTRAINTS

Present day power system is a large integrated system connecting thousands of generating stations and load centres through a network of transmission lines. The generating stations may be of different types using either conventional or renewable sources of energy. The operational objectives of a power grid are to provide continuous quality power at an acceptable voltage and frequency with adequate security and reliability at an affordable cost. Secure means that upon occurrence of a contingency, the power grid should be able to recover to its original state and able to supply the same quality of power as before. To ensure security and reliability, power plant facilities and resources must be planned and operated effectively and in a coordinated manner.

The load demand of a power grid is cyclic in nature and has a daily peak demand over a week, a weekly peak demand over a month and a monthly peak demand over a year. Since electrical energy can't be stored in bulk it is essential to schedule generating units in such a manner that at every instant an effective balance is maintained among generation, load demand and system losses.

4. POWER SYSTEM OPERATIONAL PLANNING

Power System Operational Planning can be divided into Short-term, medium-term and long-term operation planning

(a) Short term operation planning involves
    i. Short-term load forecasting (STLF)
    ii. Security analysis simulation (SAS)
    iii. Unit Commitment (UC)
(b) Medium-term operation planning involves
    i. Weekly load forecasting (WLF)
    ii. Hydro-thermal coordination (HTC)
(c) Long-term operation planning involves
    i. Monthly load forecasting (MLF)
    ii. Maintenance scheduling (MS)

Power system operations control deals with controlling the system as it is operated minute to minute. Operation accounting system records the events occurring on the grid system and by analyzing recorded data account for various events that affected the system. It is also used for planning future expansion of the system.

The short-term operation planning involves scheduling of resources and facilities on a daily basis. This task is carried out using daily load forecasting programme, security analysis simulation programme, DC coupled AC load flow programme, economic load dispatch programme. Using these programmes daily peak demand is estimated and the committed units are scheduled such that minute to minute demand is matched with generation with adequate security in an optimal manner. Due to contingency and also due to uncertainty in the load forecast some additional capacity either in the form of spinning reserve or in the form of static reserve is planned.

The medium-term operation planning involves scheduling of resources and facilities on a weekly basis. This task is carried out using a weekly load forecasting programme and a hydro-thermal coordination programme. All hydro power plants are multipurpose plants and in order to regulate the discharge of water from the dams it is necessary to coordinate them with thermal power plants for the optimal use of resources.

The long-term operation planning involves monthly load forecasting and maintenance scheduling. These two programmes estimate the peak load demand of every month and based on it and on the recommendations of the manufacturers the maintenance schedules are prepared for various equipment such as generators, transformers, transmission lines, relay systems etc.

5. ENERGY MANAGEMENT SYSTEM

The conventional energy management system consists of a SCADA system which controls the entire power system through application functions. The functions of SCADA are

i. To collect information throughout the power system by direct measurements of voltage, frequency, active power, reactive power and the circuit breaker status.
ii. To transmit collected data to control center through grid communication system.
iii. To compute power angle of the buses by the state estimator or through SCADA using power angle formula and display data in the control centre for taking an appropriate decision by the system operator.

6. WIDE AREA MEASUREMENT

In recent years it has been recognized that synchronized phaser measurement units (PMUs) are exceedingly versatile tools for power system protection, monitoring and control. Future power systems are going to make greater use of these units which are capable of measuring positive sequence voltages at the buses, positive sequence currents in the lines and transformers, harmonics, local frequency and rate of change of frequency with a perfect time stamp when synchronized with GPS. These measurements can be obtained as often as once per cycle. A measurement system that incorporates PMUs installed over a large portion of power system is known as a wide-area measurement system (WAMS) with a sufficient number of installations of PMUs the system state can be measured directly and hence no estimation is required. In order to measure system states, it is not required to install PMUs on all the buses. It has been found that by installing PMUs on about one-third of system buses, it is possible to determine the complete system state vector.

7. INSTALLATION OF WAMS ON INDIAN GRID

Looking to the advantage of PMUs the first WAMS pilot project was carried out in 2010 in the northern region and was completed on May 31, 2010. Since then several WAMS pilot projects have been carried out in India. Data such as a decrease in frequency, an increase in the rate of change in frequency, a change in angular separation and decrease in voltage magnitude as received from WAMS enabled system operators to recognize in advance tripping of generators or transmission lines due to overloading. It also helped in subsystem synchronization during restoration. Several studies have been carried out and it was revealed that extreme angular separation between two points in the grid provided useful information to the system operator to initiate preventive control actions to prevent system collapse. By December 31, 2013 more than 60 PMUs have already been installed in the Indian Grid under pilot project schemes and it is planned to install about 1700 PMUs and 30 phaser Data concentrators in future.

8. HVDC TRANSMISSION SYSTEMS

HVDC transmission systems generally provided a more economical alternative to HVAC transmission for long distance bulk power delivery from remote sources such as pit head plants, hydro electric plants or large-scale wind farms. HVDC may be the only feasible way to transmit power over long distances through underground cables, to interconnect two asynchronous networks, reduce fault currents, bypass network congestion, share utility rights of way etc.

In India the following five Back-to-Back HVDC links are in operation which connects different regional grids.

1. Vindhyachal Back-To-Back link which handles 2x250 MW power at 70 kV and connects Northern and Western regions.
2. Chandrapur Back-To-Back link which handles 2x500 MW power at 140 kV and connects Southern and Western regions.
3. Sasaram Back-To-Back link which handles 500 MW power at 140 kV and connects Northern and Eastern regions.
4. Vizag I and Vizag II Back-To-Back links each handles 500 MW power at 140 kV and connect Southern and Eastern regions.

The long distance HVDC lines which have already been commissioned and in operation are

1. Rihand-Dadri, 1500 MW, ±500 kV, 814 km long bipolar link in U.P.
2. Chandrapur-Padghe, 1500 MW, ±500 kV, 753 km long bipolar link in Maharashtra
3. Biswanath Chariyali-Agra, 6000 MW, ±800 kV 1825 km long bipolar line connecting Assam and U.P.

Two more long distance HVDC lines, one from Champa to Kurukshetra (1350 km) and another from Raigarh-Pugalur-New Trichur (1600 km) are planned. In future HVDC lines could help to evacuate electricity to the tune of 50,000 MW and supply power from surplus north-eastern grid to power deficit northern grid.

9. FLEXIBLE A.C. TRANSMISSION SYSTEMS

Flexible a.c. transmission systems (FACTS) present opportunities for improving the power transfer capability of existing transmission systems and enable flexible operation of the grid under wide variety of operating conditions. It is more economical to install FACTS devices in the existing grid at suitable locations than to build new transmission lines. FACTS are power electronic technology based devices which can be connected to the existing networks either in series or as a shunt or in the form of a combination of both series and shunt. Series devices improve transient stability limit whereas shunt devices provide reactive power support.

India's first FACTS device thyristor controlled series capacitor (TCSC) with fixed series compensation (FSC) was installed on 400 kV transmission line between Kanpur (U.P.) and Ballabgarh (Haryana) in the Northern Grid. Some more existing FACTS devices projects which work successfully in India are

i. Ranchi-Sipat 376 km, 400 kV double circuit transmission line.
ii. Raipur-Rourkela, 412 km, 400 kV double circuit transmission line.
iii. Kapakam-Khammam, 364 km, 400 kV double circuit transmission line.

All the above lines are provided with FSC-TCSC controllers. Apart from the above stated completed projects several new projects in various states have been proposed and some of them are under way to install switchable reactor compensator on several 220 kV, 400 kV and 750 kV lines. Apart from this on two 400 kV lines, one each in Maharashtra and Tamilnadu, it is proposed to install static VAR compensators (SVC).

10. RENEWABLE SOURCES OF ENERGY

Fast depleting conventional energy resources and global warming has forced Governments around the world to think about the production of green energy using renewable sources of energy mainly solar and wind. Globally, since 2000 the annual growth rates for wind power have averaged 25% and the solar photovoltaic 43%. In 2013 the growth rate for generation from wind power for China was 37.8% whereas for India was 12%. Wind energy capacity has been increasing rapidly and has become cost competitive. A large number of wind turbines ranging in size from 700 to 1200 kW are grouped into a wind farm having a total capacity of 200 to 500 MW. The main problem with wind generation is voltage regulation apart from the fact that it is intermittent in nature. Wind generation is normally located in sparsely populated areas where the electrical system is weak. This results in voltage variations that are difficult to manage. Thus, it is sometimes impossible to serve load from the same feeder that serves the wind farm.

The solar energy programme of the Government of India is poised to take a giant leap in the near future with a recent announcement of the revision of target to 100 GW of installed capacity by 2022. The 100GW plan is subdivided into the following four major market segments.

i. 40 GW of rooftop solar systems
ii. 20 GW through solar parks and Ultra Mega Power Plant (UMPP) Scheme.
iii. 20 GW through local administrative bodies and Micro, Small and Medium Enterprises.
iv. 20GW through Entrepreneurs

This target of 100 GW looks impressive but looking to the slow progress it looks difficult to achieve it. Apart from the market activity, one of the important pre-requisites for large-scale solar power is the timely and efficient grid integration for power evacuation. A lot of investment is thus needed to erect new transmission lines.

It is important to note the different characteristics of electricity generation using renewable energy sources. The variable output of solar photovoltaic and wind power results in lower output per installed kW over the year than that of fossil fueled power stations. Greater penetrations of renewable sources of energy like solar photovoltaic and wind on the grid will need changes to the way in which electricity is transmitted, used and stored. Solar thermal plants have built-in heat storage so they can provide power through the night or during the portion of the day when solar radiations are less due to clouds.

Due to large-scale penetration of renewable energy sources in the grid, the traditional concept of base load electricity generation is likely to become obsolete. Several countries now experience periods of very low or even negative electricity prices on the spot market. Electricity generators sometimes pay to produce and supply electricity because shut down and restart of units would cost them even more.

11. DEREGULATION OF POWER SYSTEM

A phenomenal change has been witnessed the world over during the last two decades in business organization and operation of power systems from vertically integrated mechanisms to open market systems. The main reasons for deregulation are to attract private investment to cope with high demand growth, to bring in the element of competition so as to provide electricity to customers at lower prices and offer them a greater choice in purchasing energy economically. New players were encouraged in the generation of electrical energy and retail marketing of electricity while maintaining a single transmission and distribution network in the area.

In a deregulated power system an independent system operator (ISO) is made incharge of power grid operation for smooth functioning. The ISO ensures that there is a balance between generation and consumption of energy. The ISO also ensures enough operating reserve that is necessary to maintain reliable interconnected power grid operation. Each control area operates its power resources to take into account uncertainty in load forecast, forced and scheduled outages of equipment, regional and system load.

The inclusion of common transmission and distribution network in the competitive framework created by deregulation has introduced several complications. The distribution of various charges such as the use of network charges, system operation charges, reactive power charges, energy loss charges etc. among various private players is more complex. In deregulated power systems, the ancillary services such as maintenance of balance between generation and load, maintenance of static and spinning reserve, supplemental reserve, reactive power and voltage control from generator sources, real power transmission losses, use of special equipment like PSS to maintain a secure transmission system etc are also unbundled and priced separately and the system operators have to purchase ancillary services from service providers and to be distributed among the customers.

12. DEVELOPMENT OF SMART GRID

The existing electricity grid is unidirectional in nature. The existing thermal power plants convert only one-third of fuel energy into electrical energy, without recovering the waste heat. Almost 25% to 40% of generated energy is lost as transmission and distribution losses along with theft. The classical operation of power systems has no control over the load except in an emergency situation when a portion of the load is shed in order to balance generation with loads. Almost 20 percent of installed capacity is used for a short time during the peak demand only and remains idle during the remaining part of the day. Hence, it is necessary to modernize the existing grid and transform it into an intelligent or smart grid. It is expected to provide the utility companies with full visibility and pervasive control over their assets and services. The smart grid is required to be self-healing and resilient to system anomalies.

For an efficient smart grid system design and operation, substantial infrastructure investment in the form of a communication system, cyber network, sensors and smart meters must be installed to curtail the system peak demand when the cost of the energy is high. The smart power grid provides information regarding the cost of energy at any moment to its customers through real-time pricing. This information with the support of smart devices will help customers to schedule their activities in order to minimize their electricity bill and also help utilities to reduce their peak demand. Furthermore, the smart power grid provides a platform for the use of renewable green energy user to become an energy producer by giving the user the choice of PV or wind energy, fuel cells etc and to participate in the energy market by buying or selling energy through smart meter connection.

13. DISTRIBUTED GENERATION

Most of the electrical energy produced today is generated in large central generating stations and is utilized at load centres located far away through transmission and distribution networks. By contrast, distributed generation (DG) includes the application of small generations in the range of 15 kW to 10 MW located closer to the customer's site or at a local distribution network. The generation technologies on fuel resources can be conventional such as diesel, combustion turbine, combined cycle turbine, small hydro etc. or renewable such as solar, wind or low-head hydro. Distributed generation units such as high-tech gas turbine, combined cycle are not only more efficient but avoid high initial investment in T&D system and operational losses occurring there-in.

Distributed midsize generators having capacity 1 MW and above, operated in combined cycle mode with high efficiency can save a great deal of cost during peak load period when the spot price of energy is high. Also, large captive plants having surplus capacity may be integrated with the grid through a net metering system.

14. MICROGRIDS

There are several instances world over when the grid power failed due to the impact of natural disasters like Fukushima (Japan) or due to human errors like Chernobyl (Russia) and could not be restored for several weeks. After the disaster had knocked out power system, people realized the importance of microgrid projects. Initially, the focus was primarily on energy efficiency and later on it shifted to generating where it is consumed and to having a diversity of energy sources. A microgrid is a localized limited energy system of distributed energy sources, customers and optionally storage. It may continuously operate in on-grid or islanded mode or in dual mode by changing the grid connection status.

A microgrid energy manager which is a monitoring and control software equipped with functions like SCADA, energy generation and load management, system reconfiguration and restart after a fault etc. helps operate a microgrid in a very efficient way, while local controllers of distributed generators, batteries and loads ensure stable voltage and frequency within the microgrid in a grid connected as well as in islanded mode. Microgrids can be considered the building blocks of smart grid or an alternative path to the super grid as it can be restored very quickly after a natural disaster.

Some of the key advantages of microgrids are improved reliability, better power quality and outage management for critical and remote customers, optimal dispatch of renewable energy sources, reduction in emissions, cost saving and reduced energy losses.

15. FUTURE SCENARIO OF POWER SYSTEMS

The world consumption of electrical energy is expected to rise to 39.0 Trillion kWh by 2040. Nearly half that increase in demand will come from developing countries like China and India. Thus, there is an enormous challenge before us in order to meet this huge energy requirement for our Country on a sustainable basis. On the 'Earth Day' April 22, 2016, 174 countries including India and EU put signatures on the Paris Agreement on climate change that was negotiated in December 2015. The challenge before India now is to implement its pledge to sharply cut down emissions intensity by 2020. A small reduction was achieved between 2005 and 2010 and the effort now should be to put greater emphasis on the generation of electricity using renewable sources of energy mainly wind and solar. The ambitious target as announced by GOI can be partially achieved by encouraging investments in renewable energy with an effective grid connected rooftop solar subsidy programme.

The transmission and distribution networks of our regional grids need modernization and strengthening so that power can be transferred from surplus energy area to deficit energy area. We also need to make the grid smarter using recent technologies developments. There are many aspects of smartness and each aspect meets a particular objective. In what sequence India should develop various aspects of the smart grid will depend on the various objectives, their relative importance and the cost associated with each particular smart feature. AT & C losses can be reduced considerably by installing smart meters at the consumer end which will feed real-time data to central computers on energy consumption. The meter can be tripped off by the central operator if power theft is suspected.

Microgrids with distributed generation using renewable and conventional sources of energy can play an important role in avoiding wide area black-outs due to natural disasters. Suitable islanding schemes need to be designed for quick restoration of power in the affected area.

Due to rapid development in power electronic devices, computers, servers etc. the requirement of d.c. power has increased many folds. In future the d.c. load may go as high as 30% of total load. With the existing a.c. grid frequent conversion from a.c. to d.c. and vice versa becomes necessary. HVDC transmission also requires these conversions. This results in huge power loss. A hybrid grid can reduce the unnecessary process of d.c. to a.c. and a.c. to d.c. conversions compared with an individual a.c. or d.c. grid and thus a great deal of energy can be saved. The importance of hybrid grid would further increase when renewable power sources are allowed to feed power into the grid through a low voltage distribution network. Thus the reemergence of d.c. first in transmission, next in utilization and ultimately in generation of electric power may prove the dream of Edison true.

In future demand side management may introduce new concepts about providing a differentiated value of service quality to end users. With this business model users pay for the reliability, power quality and overall service they want. In new business model customers may be given a rebate on their energy bills if they voluntarily participate in the curtailment of their loads during peak demand.

Exciting yet challenging times lie ahead. The electrical power industry is undergoing rapid change. The rising cost of energy, the mass electrification of everyday life, climate change, natural disasters, physical and cyber attacks are going to be major drivers that will determine the direction and speed at which transformations of existing power systems will occur. Many research centres across the globe are developing next generation technologies required to give a new look to the existing power industry which will provide more secure and reliable power with better quality at an affordable price in a sustainable manner without degrading the environment.

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