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Research Article

Recent Advancement In Electricity Transmission And Distribution Technologies

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Abstract

Advanced electricity transmission and distribution technologies improve quality of power and increase the reliability of the distribution network which benefit the consumers at large. Smart Grid, Micro Grid, Energy Storage, Alternative Power Resources, Energy Efficiency, Demand and supply Response are some areas in which R&D activities are progressively making headway so as to improve the quality of distribution. The present article is elaborating the main advancement in energy sector related to electricity transmission and distribution technology.

KeyWords: Smart Grid, Micro Grid, Energy Storage, Transmission and Distribution Technology

1. Introduction

India is undoubtedly one of the rapidest growing country in the world with a population of over a billion people and GDP growth rate of about 8 percent. In spite of, its vigorous economic growth, the country is still snowed under basic problems such as scarcity of electricity, with very low per capita consumption. Although India has almost doubled its energy generation in the past decade by adding over more than 100 GW of capacity, its grid systems lose more than 30 GW of this generated power. This is extremely worrying to people working in the power sector in India, who are concerned about the efficiency of the distribution of electricity. The AT&C losses are highest in India (more than 25%) among the developing world. These understandings lead to believe that India should adopt new technology to ensure better monitoring and control of electricity transmission and distribution.

2. Difference between smart grid and conventional grid

The main difference between the Smart Grid and Conventional Power Grid is on the basis of the design. Smart Grid is based on Demand Follows Supply while conventional grid on Supply Follows Demand. That means, the amount of coal dumped into a thermal power plant in some way depends on the estimated electricity demand at a distant place in addition to transmission losses.

Nowadays, more renewable electricity from Wind and Solar is being pumped into the Conventional Power Grid. This is occurring at the supply-side, large-scale wind and solar farms,

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as well as the demand side, consumer rooftop solar. Since we are not having control of wind speed and sunshine, the only possibility is to forecast electricity generation from these sources and manipulate other generation and demand accordingly. Renewable source of energy are sourced in grid through integration of communication technology and inform the consumers about real-time electricity prices.

Apart from renewable electricity integration and demand Response, automated fault detection and correction, advanced safety measures, power quality improvement etc. are being implemented in the Power Grids so as to improve reliability of electricity service. All such upgradations give the conventional power grid a new smart look, calling it smart grid. A comparison of smart grid vs conventional grid is given in Table-1.

Table 1

Traditional Grid	Smart Grid
Electromechanical solid state	Digital microprocessor
One-way communication	Two-way communication
Centralized generation	Distributed generation
Limited monitoring, protection and control system	Adaptive protection
blind	Self monitoring
Manual restoration	automated
Check equipment manually	Monitor equipment remotely
Limited control system	Pervasive control system
Estimating reliability	Predictive reliability

3. Smart Grid

Smart grid is an advanced electricity grid network which enable two-way information and power exchange between suppliers and consumers, due to the persistent incorporation of intelligent communication monitoring and management systems [1]. It is a digital electrical grid that enables the congregation and distribution of information pertaining to the usage of power by suppliers and consumers. With Smart Grid electricity services are becoming more reliable, efficient, cost-effective, and environmentally conscious [2]. Traditionally grids which mainly fed by large thermal generators were supplying power in various regions of country but the large grid usually break down causing massive grid failure due imbalance in power system at generating station. But as the new sources of energy like solar, wind and other alternative fuel sources are coming up in view of large carbon foot print, green house effects and depleting coal and oil reserve, a need was felt to connect these traditional grids with theses alternative sources of energy to make them smarter which not only accommodate various type of sources of electricity but make them more reliable and consumer friendly.

The conventional grid is used for an electricity system, which integrates the electricity generation, electricity transmission, electricity distribution, and electricity control. A smart grid (SG) is an improved version of traditional power network. Traditional power grids carrying power from central generators to huge number of consumers. In contrast, the Smart grid uses two-way flows of electricity and information to generate an automated control and distributed advanced energy delivery network. Using newly introduced information technologies, the smart grid is capable of distributing power in more effective ways also dealing with wide ranging events. The smart grid could deal with conditions that happen anywhere in the power grid, such as power generation, transmission, distribution, and consumption while in harmony with the corresponding predefined strategies. The smart grid automatically changes the power flow and recover the power delivery service in case of any voltage transformer failure incident occurs in the distribution grid. One important factor of the "smart grid" is the capacity to store electrical energy which allow the demand from consumers to be met [1]. The principal systems in smart grid are:

a) Smart infrastructure system: The smart infrastructure system is the energy, information, and communication infrastructure underlying of the smart grid that supports advanced electricity generation, delivery, and utilization

c) Advanced technologies in communication and smart management system: The smart management system is the subsystem in smart grid that prepared advanced management and control tasks. Smart protection system is the subsystem in smart grid that provides advanced grid reliability and safety analysis, failure protection, and security and privacy protection services [1].

b) Advanced information metering, monitoring, and management: Smart grid started with the aim of advanced metering infrastructure (AMI) so as to improve demand-side management and energy efficiency, and constructing self-healing reliable grid protection against malicious sabotage and natural disasters [3] but new requirements and demands drove the electricity industries, research organizations, and governments to revise and expand the initially perceived scope of smart grid.

3.1 Advantages of smart grid

(1) Enhancing power quality and reliability

(2) Exploiting facility usage and preventing construction of back-up (peak load) power plants

(3) Improvement of capacity and efficiency of present electrical power networks

(4) Improving resistance to disturbance

(5) Allowing predictive maintenance and self-healing retorts to system disturbances

(6) Enabling prolonged deployment of renewable energy resources

(7) Accommodating distributed power sources

(8) Systematizing maintenance and operation

(9) Reducing greenhouse gas emissions by using electrical vehicles and new power resources

(10) Reducing oil consumption by reducing the need for inefficient generation during peak usage periods

(11) Giving opportunities to make better grid security

(12) Enabling transition to plug-in electrical vehicles and new energy storage options

4. Distributed Generation

The definition of distributed generation (DG) varies somewhat between sources and capacities; however, it is generally defined as any source of electric power of limited capacity, directly connected to the power system distribution network where it is consumed by the end users. Distributed generation should not be confused with renewable generation. Distributed generation technologies may be renewable or non-renewable. Some distributed generation technologies could, if fully deployed, significantly contribute to present air pollution problems. The increased market penetration of distributed generation has also been the advent of an electric power production industry. These resources have lower energy density than fossil fuels and so the generation plants are smaller and geographically widely spread. The distributed generation may be based on fuel cells, photovoltaic system, wind turbines, mini/micro hydro turbines, gas turbines and micro turbines. Distributed generation capabilities and system interfaces are given in table 2 [5].

Table 2

Technology	**Capability Ranges**	**Utility Interface**
Fuel cells	A few tens of kW to a few tens of MW	DC to AC converter
Micro turbines	A few tens of kW to a few MW	AC to AC converter
Industrial Combustion turbine	A few MW to hundreds of MW	Synchronous generator
Reciprocating Engine	A few hundred kW to tens of MW	Synchronous. generator or ac to ac converter
Hydro Turbine	A few hundred kW to a few MW	Four quadrants. synchronous machine
Wind	A few hundred W to a few MW	Asynchronous generator
Solar, photovoltaic	Solar, photovoltaic	DC to AC converter

a) Fuel Cells

Fuel cell is defined as an electromechanical engine without any moving parts that gathers energy discharged from hydrogen and oxygen combination. This reaction produces electricity, heat and water without generating pollutants. Fuel cell working is similar to battery but it does not require recharging as it generates energy so long as fuel is supplied. The hydrogen required for fuel cell reaction is generated from hydrogen enriching fuels like propane, natural gas, and methane from biogas recovery. The fuel cell has advantage of no moving parts which intensify its reliability, no noise generation, run with a wide range of fossil fuels with more efficiency than other generation devices and generates heat and water in consort with electricity. The major disadvantage of it is high running cost.

b) Micro Turbine

Microturbine use the flow of gas to transform thermal energy into mechanical energy. The air pumped by the compressor is mixed with combustible gas in the combustion chamber forms a product which rotate the turbine also drives the generator and compressor. Normally, the compressor and turbine are straddling on the same shaft as the electric generator. The output voltage cannot be directly linked to the power grid or utility. It has to be firstly transformed to DC and then back to AC to get nominal voltage and frequency of the utility. The advantage of microturbines is low emissions, clean operation and high efficiency. Its disadvantages are more maintenance cost and less experience in this area (few micro-turbines have been operated for enough time periods to create a reliable field database.

c) Industrial Combustion Turbines

The internal combustion engines produce mechanical energy from the chemical energy in the fuel. The expansion of hot gases formed during combustion origins movement through working on mechanical parts like pistons or rotors generates mechanical energy which can further be transferred to a generator and converted into electrical energy. The piston-type is considered as most popular internal combustion engine. The advantages of internal combustion engine are low capital cost; large size range varying from few kW to some MW, more efficiency, thermal or electrical heat generation jointly in buildings and decent operating reliability. The high maintenance and fuel cost, high NOX emissions, and eminent noise level are major limitations of internal combustion engine

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d) Reciprocating Engines

Diesel generator come in reciprocating engines category. It is considered as pretty appropriate for independent application and a feasible option for back up purposes, being started and shut down spontaneously because of low inertia.

e) Small Hydro Power

Small hydropower is described as hydropower which has generating power less than 10 MW by independent power producers. Small hydropower are also called mini hydropower having capacity between 100 kW and 1 MW and micro hydropower with size below 100 kW.

f) Wind Energy

After the oil crunch in 70's, application of Wind turbines started increasing to transform the wind energy into power. As wind cannot be stored being extremely variable source so should be handled carefully according to this attribute of wind. Wind turbines are either constant speed or variable speed. Constant speed wind turbines are directly connected to the grid and work synchronously according to the grid frequency. These kinds of turbines work at a predefined wind speed by rotor design and attain maximum efficiency at this speed. Till the wind regimen at a specific site is maximum exactly at the required speed, wind turbine would not be able to operate at its optimum performance. Usually, the constant wind turbine generator system provides an AC output voltage dependent upon the wind speed. Variable wind turbines either connected to straight drive synchronous generator or to gear box and an induction generator is used to covert the wind energy into electric power. In case of variable wind speed, the voltage generated is converted into DC and back again converted to grid synchronous AC with the help of inverters. The disadvantage of variable speed wind turbine is more expensive than constant speed wind and the advantage of variable speed is complete controllability by producing or consuming reactive power, facilitating stabilized node voltages. The wind turbine working is described by two steps conversion process. The rotor firstly drags kinetic energy of wind and transform into the mechanical torque in shaft and secondly the generation system transforms this torque into electric power. Two concepts named "stall and pitch control" are used to stop the wind turbines from excess speed and damaging its mechanical parts. In stall control system, blades are designed in such a way that wind produces turbulences on one side of blade when excess wind speed and decreasing the performance and hence speed of the rotor. In pitch control system, each blade is hinged on motor allowing to turn tips of blade, reducing its working surface and hence speed of rotor. Pitch control is useful for variable speed wind turbines allowing them to run on "optimum rotor tip speed vs. wind speed" ratio.

g) Photovoltaic Systems (PVs)

The first photovoltaic unit was originally developed for aerospace research programme and became commercially available in 70's. In today's time mainly three types of solar cell are available out of which silicon-based PV cells are widely spread Photovoltaic system transforms the sunlight into electricity. Semi conductive materials which are used in formation of solar cells, when exposed to sun light, convert the self-reliant energy of photons into electricity, The solar cells are positioned in an array to keep tracking the sun in order to create higher output voltage. Since PV systems produce DC voltage, the inverters transfer it to AC output. Largely, two PV designs, with and without battery storages are used. The advantage of these systems are simple designs, maintenance free, environmentally friendly without any kind of emission, quiet, easy to use. The efficiency of PV systems is independent of installations size so these are suited for small installations like private houses and large installations like industries. The limitations of photovoltaic system are high initial cost and large space requirement. Prices of PV systems should be reduced to increase its suitability for consumers.

3.1 Challenges of Distributed generation

Distributed generation technologies are overwhelmingly connected to existing electric power delivery systems at the distribution level. One of their significant benefits is that they are modular enough to be conveniently integrated within electric distribution systems, thereby relieving some of the necessitate investment in transmission system expansion. However, significant penetration within existing electric distribution systems is not without a new set of problems. The following are among the key issues that need to be addressed.

a) Power Quality

Several of the distributed generation technologies rely on some form of power electronic device in conjunction with the distribution network interface, be it ac to ac or dc to ac converters. All of these devices inject currents that are not perfectly sinusoidal. The resulting harmonic distortion, if not properly contained and filtered, can bring serious operational difficulties to the loads connected on the same distribution system. Existing standards have been enacted to limit the harmonic content acceptable in conjunction with various power electronic loads; similar standards are required for distributed generation systems and are under various stages of preparedness.

b) Reactive Power Coordination

Distributed generation, implemented at the distribution level, i.e., close to the load, can bring significant relief to the reactive coordination by providing close proximity to the reactive power support subject to the proper network interface technology. However, wind generation actually contributes to worsen the reactive coordination problem.

c) Reliability and Reserve Margin

Traditionally, the vertically integrated utility was also responsible for the availability of sufficient reserve margins to ensure adequate system reliability. But in case of distributed generation technologies their production levels depend on nature (wind and solar) or are such that their availability is subject to the operational priorities of their owners. The requirement to use sophisticated power electronic network interfaces may affect the plant‘s availability. As a result, the issue of reliability comes to the forefront along with the necessity to maintain sufficient generation reserve margins. The ownership of distributed generation increases the reserve margin maintenance which leads to loss of reliability and effect the capability reserve of individual.

d) Reliability and Network Redundancy

Most electric distribution systems feature a radial network configuration as opposed to the meshed structure adopted at transmission levels. As a result, network redundancy becomes an issue when significant distributed generation is connected directly to distribution system, since single line outages could completely curtail the availability of generation facilities. This also leads to loss of reliability and complete collapse of the integrated system.

e) Safe and Secure System

Distribution system protection schemes typically are designed to rapidly isolate faults occurring either at load locations or on the line itself. The assumption is that, if the distribution line is disconnected somewhere between the fault and the feeding substation, then repair work can safely proceed. Clearly, if distributed generation is connected on the same distribution feeder, then significantly more sophisticated protective relaying schemes must be designed and implemented to properly protect not only the personnel working on the lines but also the loads connected to them. Some specifying relays and secured protection is required to ensure the system secure and safe and also reliable

4. Micro Grid

A micro grid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A micro grid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode. Such a distributed energy system running parallel or within the national smart grid system. Micro grid is in a way one of the component of smart grid but is not dependent on a large smart grid [6]. Micro grids are broadly classified into four categories.

- Remote grids, which are necessary due to geographical features, such as deep rural areas. Consider a country like India that
  has more than 70% population live in rural areas. It is simply not practical to connect all these to a single national grid.
- Military and security are grids necessary to maintain data and security during a national catastrophe. Commercial or industrial grids catering to a specific industrial community. The energy sources could be fossil fuel based or energy recovered for the process like waste heat, bio fuels, or waste products. These are mainly captive energy systems.
- Community grids that optimize and utilize the specific regional renewable resources to give cost effective power systems.

- Fossil fuel usage is only used as an emergency backup. This is the effective microgrid.

4.1 Micro Grids over Smart Grids

The centralized transmission grid system (smart grid) is definitely the backbone of the electricity distribution system, but has its drawbacks.

- The energy loss is almost 8 -10 %.
- There are high investment costs in transmission lines, step-up and step-down transformers, right of way and other legal issues.
- Grid management is a constantly juggling act where it balances the generation and the demand over a wide geographic area.
- The generating capacity has to match the peak load, which means a lot of excess capacity is built into the system, which increases the investment cost.
- All the users feel the grid disturbances, outages, frequency changes and voltage fluctuations, blackouts and brownouts. This can affect the performance and life of electrical equipment.

The Micro grid, even though not a replacement of the national grid, improves certain aspects especially for communities and regions that have adequate renewable resources.

- Have much smaller financial commitments.
- Use renewable resources hence are more environmentally friendly with lower carbon footprints.
- Require fewer technical skills to operate and rely more on automation.
- Are isolated from any grid disturbance or outage.
- Place the consumer out of the grip of large corporations that run the generation networks.

4.2 Microgrids and Renewable Energy

- Microgrids are cost effective only if you can tap into locally available renewable energy resources. Solar energy is available everywhere but with limitations. Wind, mini hydro, geothermal and bio mass are regionally available and can augment Solar energy. This combined with a storage device, battery or super capacitors and backup diesel generator makes Microgrids highly reliable and cheap.
- Storage devices in large grid systems are not economically or technical proven. The advent of latest technologies in nano batteries and nano super capacitors makes electricity storage a reality in the smaller capacity range. This is an advantage for Microgrids.
- Advances in computerized control technology make it possible to have simple and efficient controls with less human interference and is the key ingredient that makes Micro grids feasible.

  Microgrid are efficient in communities and regions that require heating or cooling apart from electricity. Heat from large thermal power plants goes to waste because it cannot be economically transferred large distances. In Microgrid communities, because of the limited geographical distances it is possible to use the waste heat from the power generation sources for effective heating or cooling using chillers.

5. Energy storage

Energy storage (also called large-scale energy storage) is a collection of methods used to store electrical energy on a large scale within an electrical power grid. Electrical energy is stored during times when production (especially from intermittent power plants such as renewable electricity sources such as wind power, tidal power, solar power) exceeds consumption, and returned to the grid when production falls below consumption [7]. The largest form of grid energy storage is dammed hydroelectricity, with both conventional hydroelectric generation as well as pumped storage. Developments in battery storage have enabled commercially viable projects to store energy during peak production and release during peak demand. Two alternatives to grid storage are the use of peaking power plants to fill in supply gaps and demand response to shift load to other times.

5.1 Benefits of Energy Storage

The stores are used feeding power to the grids when consumption that cannot be deferred or delayed exceeds production. In this way, electricity production need not be drastically scaled up and down to meet momentary consumption – instead, transmission from the combination of generators plus storage facilities is maintained at a more constant level. electricity generated by intermittent sources can be stored and used later, whereas it would otherwise have to be transmitted for sale elsewhere, or shut down peak generating or transmission capacity can be reduced by the total potential of all storage plus deferrable loads (see demand side management), saving the expense of this capacity more stable pricing the cost of the storage or demand management is included in pricing so there is less variation in power rates charged to customers, or alternatively (if rates are kept stable by law) less loss to the utility from expensive on-peak wholesale power rates when peak demand must be met by imported wholesale power. Emergency preparedness vital needs can be met reliably even with no transmission or generation going on while non-essential needs are deferred.

Energy derived from solar, tidal and wind sources inherently varies the amount of electricity produced varies with time of day, moon phase, season, and random factors such as the weather. Thus renewable in the absence of storage present special challenges to electric utilities. While hooking up many separate wind sources can reduce the overall variability, solar is reliably not available at night, and tidal power shifts with the moon, so slack tides occur four times a day. can reduce the overall variability, solar is reliably not available at night, and tidal power shifts with the moon, so slack tides occur four times a day. How much this affects any given utility varies significantly. In a summer peak utility, more solar can generally be absorbed and matched to demand. In winter peak utilities, to a lesser degree, wind correlates to heating demand and can be used to meet that demand. Depending on these factors, beyond about 20–40% of total generation, grid-connected intermittent sources such as solar power and wind turbines tend to require investment in grid interconnections, grid energy storage or demand side management. In an electrical grid without energy storage, generation that relies on energy stored within fuels (coal, biomass, natural gas, nuclear) must be scaled up and down to match the rise and fall of electrical production from intermittent sources (see load following power plant). While hydroelectric and natural gas plants can be quickly scaled up or down to follow the wind, coal and nuclear plants take considerable time to respond to load. Utilities with less natural gas or hydroelectric generation are thus more reliant on demand management, grid interconnections or costly pumped storage.

5.2 Energy storages for grid application

Energy storages are a valuable asset for the electrical grid. They can provide benefits and services such as load management, power quality and uninterruptable power supply to increase the efficiency and supply security. This becomes more and more important in regard to the energy transition and the need for a more efficient and sustainable energy system. Numerous energy storages (Pumped-storage hydroelectricity, Electric battery, Flywheel energy storage, Super capacitor etc.) are available each different in technology and design. The potential they bring depend on how they are used and where they are deployed to. Not all energy storages operate equally well in all situations. Energy storage technologies can be used to support the normal operations of the grid, and as such provide grid operational support. Energy storage technologies can improve power quality and reliability. Grid operational support can be divided in four types of support operations:

1. Frequency regulation services: energy storage can be used to inject and absorb power to maintain grid frequency in the face of fluctuations in generation and load.
2. Contingency reserves: at the transmission level, contingency reserve includes spinning and supplemental reserve units that provide power for up to two hours in response to a sudden loss of generation or a transmission outage.
3. Voltage support: energy storage can support the injection or absorption of reactive power into the grid to maintain system voltage within the optimal range. Energy storage systems use power-conditioning electronics to convert the power output of the storage technology to the appropriate voltage and frequency for the grid.
4. Black start: black start units provide the ability to start up from a shutdown condition without support from the grid, and then energize the grid to allow other units to start up. A properly sized energy storage system can provide black start capabilities.

6. Conclusion

The paper emphasizes the utility of Smart grid, micro grid and energy storage and their benefit in making a very strong frame work for efficient, reliable and consumer friendly smart electricity network .In India a smart grid mission under Ministry of Power is operational with various pilot projects running all over India . The need of the hour is to integrate all and operate a very efficient smart network which not only conserve the energy but also meet the smart city mission of present government to provide 24x7 powers to all. Research and development in this area is of utmost importance.

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