CHAPTER-III

Theoretical background

3.1. Conventional power generation

Several fundamental methods exist to convert other forms of energy into electrical energy. In the conventional thermal power stations (or conventional thermoelectric) electricity is produced from the use of fossil fuels such as coal, fuel-oil or natural gas, using a thermodynamic cycle of water-steam. In conventional power generation system, electricity is generated at power plants and moves through a complex system, sometimes called the grid, electricity substations, transformers, and power lines that connect electricity producers and consumers. Most local grids are interconnected for reliability and commercial purposes, forming larger, more dependable networks that enhance the coordination and planning of electricity supply.

The stability of the electricity grid requires the electricity supply to constantly meet electricity demand, which in turn requires coordination of numerous entities that operate different components of the grid.

The origin of the electricity that consumers purchase varies. Some electric utilities generate all the electricity they sell using just the power plants they own. Other utilities purchase electricity directly from other utilities, power marketers, and independent power producers or a wholesale market organized by a regional transmission reliability organization.

The retail structure of the electricity industry varies from region to region. The company selling you power may be a not-for-profit municipal electric utility; an electric cooperative owned by its members; a private, for-profit electric utility owned by stockholders (often called an investor-owned utility); or in some states, you may purchase electricity through a power marketer. Local electric utilities operate the distribution system that connects consumers with the grid regardless of the source of the electricity.

The power plants generate electricity and deliver it to end users through transmission and distribution power lines (Wood and Wollenberg, 2012). High-voltage transmission lines, like those that hang between tall metal towers, carry electricity over long distances to where it is needed. Higher voltage electricity is more efficient and less expensive for long distance electricity transmission. Lower voltage electricity is safer for use in homes and businesses. Transformers at substations increase (step up) or reduce (step down) voltages to adjust to the different stages of the journey from the power plant on long-distance transmission lines to distribution lines that carry electricity to homes and businesses.

Several challenges exist for improving the infrastructure of the grid:

- Allocation of new transmission lines (getting the approval of new routes and obtaining rights to the necessary land).
- Determining an equitable approach for recovering the construction costs of a new transmission line built in one state when the line provides benefits to consumers in other states.
- Addressing the uncertainty in federal regulations regarding who is responsible for paying for new transmission lines, which affects the private sector's ability to raise money to build transmission lines.
- Expanding the network of long-distance transmission lines to renewable energy generation sites where high-quality wind and solar resources are located, which are often far from where electricity demand is concentrated.
- Protecting the grid from physical and cyber-attacks.

- Utilities are under pressure to evolve their classic topologies to accommodate distributed generation.
- As generation becomes more common from rooftop solar and wind generators, the differences between distribution and transmission grids will continue to blur.
- Demand response is a grid management technique where retail or wholesale customers are requested either electronically or manually to reduce their load. Currently, transmission grid operators use demand response to request load reduction from major energy users such as industrial plants.
- With everything interconnected, and open competition occurring in a free market economy, it starts to make sense to allow and even encourage distributed generation.
- The smaller generation facility might be a home-owner with excess power from their solar panel or wind turbine. These resources can be brought on-line either at the utility's behest or by the owner of the generation to sell electricity.
- Many small generators are allowed to sell electricity back to the grid for the same price they would pay to buy it.
- Furthermore, numerous efforts are underway to develop a "smart grid". The hope is to enable utilities to better predict their needs, and in some cases involve consumers in some form of the time-of-use based tariff.
- The ability to increase usage of intermittent energy sources by balancing them across vast geological regions and the removal of congestion that prevents electricity markets from flourishing.
- In India, a recent 6 GW, 1850 km proposal was priced at $790 million and would require a wide right of way.

3.2. Distributed generation

Generation of electricity mostly depends upon centralized power generating facilities, for example, coal, oil, and gas powered, nuclear, large solar plants or hydro power plants. Centralized power generating units are located at distant places from load demand. Transmission of power from generating units to load demand causes transmission loss, quality of power and reliability problems. Facilities utilized by the centralised power generating units, for example, coal, oil and gas adversely affect the environment. To overcome these issues power sectors are using decentralized power generation system, known as distributed generation system.

Electric power research institute defines distributed generation system as a small-scale based modular energy conversion unit located near to load demand ranged between 1 kW to 50MW (Electric Power Research Institute webpage, January 1998). In this, generation units are located near to load demand with small-scale generating capacities and directly connected to the distribution network to meet uncontrollable demand with more flexibility. It is interconnected to the same transmission grid as of central stations for the reason of reliability. Reliable power sources minimize interruption of power supply or power outages. Distributed generation also helps to enhance the quality of power, i.e., voltage levels, fluctuations and disturbances.

There are several technical and economic issues in the integration of these resources into a grid. It greatly reduces transmission loss and is a reliable power source. Technical problems arise in the areas of power quality, voltage stability, reliability, protection, and control (Tomoiagă et al., 2013). The behavior of protective devices on the grid must be examined for all combinations of distribution and central station generation (Mazidi and Sreenivas, 2011). A large deployment of distributed generation may affect grid-wide functions such as frequency control and allocation of reserves (Bollen and Hassan, 2011). For this, there will be a need for good coordination control and better as well as bigger interconnections among them. Distributed generations are expensive per watt electricity generation to central generators due to its high initial setup cost. Literature shows, the current initial costs of distributed generation systems are decreasing gradually, as many countries are increasing focus on research and development of this (Allan et al., 2015).

In the last decade, many countries have started the process of liberalization of their electrical market, opening access to grids transmission and distribution. India is also liberalizing its power sector and reforming electricity sector by increasing competition with the flexibility of participation of private sector. Still, with the liberalization and participation of private sectors, India uses far less electricity per capita than developed countries, i.e., only about 900 kWh per capita in India compared with 7,000 kWh per capita in Europe and 14,000 kWh in the US. As per sources, the electricity generation capacity will grow in India from about 225 GW in 2013 to 700 GW by 2032 to meet rising demand.

Distributed generation is mostly based on diesel engines that are used for back-up power (in the event of grid failure) and operate at very low load factors. Also, the share of the energy generation from distributed generation is marginal (about 2–3% of the total generation). Other than the diesel engines, the distributed generation options that are being promoted in India are modern renewable energy based system (Banerjee, 2006). Penetration of renewable energy sources plays a major role to enhance distributed generation systems because of its small scale capacity and environment friendly nature.

3.2.1. Importance of distributed generation over conventional one

Different terms and definitions are used related to distributed generation in the different literature (Ackermann et al., 2001). For example, Anglo-American countries often use the term ‘embedded generation', North-American countries use the term ‘dispersed generation', and Europe and parts of Asia use the term ‘decentralised generation'. Analysis of the relevant literature has shown the relevant definitions of the distributed generation which are derived regarding capacities:

1. The electric power research Institute defined distributed generation as generation from a few kilowatts up to 50 MW (Electric Power Research Institute, January 1998),
2. According to the Gas Research Institute, distributed generation is in between 25 kW and 25 MW (Gas Research Institute, 1998),
3. Preston and Rastler defined as ‘ranging the size from a few kilowatts to over 100 MW’ (Sharma and Bartels, 1997),
4. Cardell defined distributed generation as generation between 500 kW and 1 MW (Cardell and Tabors, 1997),
5. The international conference on Large High Voltage Electric Systems (CIGRE) defined distributed generation as ‘smaller than 50-100 MW’ (CIGRE, 1998),

"Distributed generation can be defined as effective and efficient fulfillment of load demand with small generating units ranging between 50 kW to 50 MW near to load demand”. As per government regulations of different countries, the rating of each distributed power station varies. For example; In English and Welsh market, distributed generation with a capacity of less than 100 MW is not centrally dispatched, and if the capacity is less than 50 MW, the power output can’t be traded via the wholesale market

(Watson, January 1999). Therefore, in English and Welsh market, distributed generation predominantly used for power units with less than 100 MW capacities. As per Swedish legislation distributed generation is used for generation of electricity up to 1500 kW. On the other hand, some of the proposed offshore wind farms in Sweden have a maximum capacity of up to 1000 MWand this would still be considered distributed generation as they plan to use 1500 kW wind turbines (Wizelius, October 1998).

Earlier, generation of electricity was mostly based upon centralized power generation system and power transmitted through a long transmission line to meet far away from load demand via the distribution networks. Transfer of power through a long transmission line or network was resulting in transmission losses and reliability problems. For overcoming these issues power generation system is being decentralized and naming distributed generation system. In this method, the electricity is generated near to load demand with small generating units. Literature defines distributed generation and compares it with conventional power generation approach (Kumar et al., 2015). It elaborates the concept behind the development of distributed generation; technologies used; its advantages and limitations. It also focuses on why it should be preferred and how it helps to minimize energy losses. This work is an analysis of distributed generation over central power generation and discusses the impact of technology in the future. Here we will see the comparison of distributed generation with central power generation. Comparison of distributed generation with central power generation by power flow from generating unit to load demand is given below in Figure-3.1:

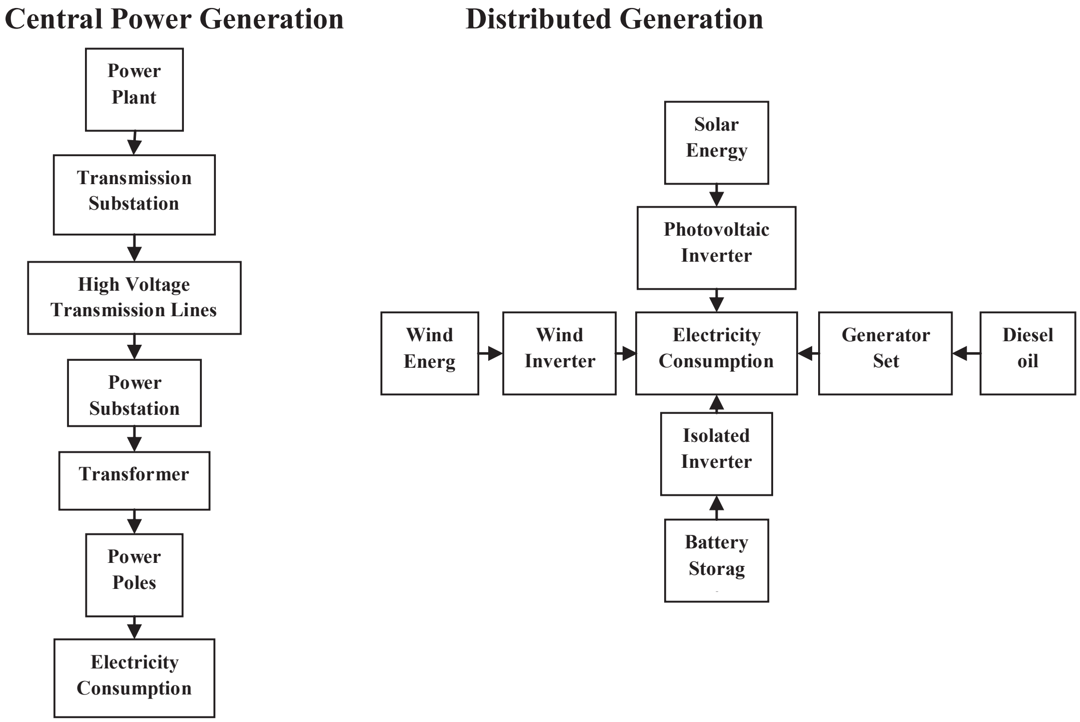

Figure 3.1: Distributed generation vs. central power generation

Multiple problems associated with central power generation, for example, are power losses through transmission, power theft, reliability and quality of power. Long distance power transmission also creates theft of power which is a big issue. Developing countries like India are mainly facing problems like lack of conventional energy resources, old technology, and power losses through the transmission. In 2010, average electricity losses in India from the transmission and distribution were about 24% of total loss, while losses because of consumer theft or billing deficiencies added another 10–15% (Alagh, 2011). If current average transmission and distribution losses remain same (32%), India will need to add about 135 GW of power generation capacity, before 2017, to satisfy the expected demand. Local production has no electric transportation losses compared to long-distance power lines or energy losses from the Joule effect in transformers where in general 8-15% of the energy gets lost. The developed countries like USA and UK have the advantage of advanced technology which is the reason for their minimum transmission power losses and theft of power.

On other side, due to lack of coal reservoir, thermal power generating units suffers for consistent coal shortage conditions and works on high risk of unit shutdown. Distributed generation resources can play a big role to meet the huge and rising electricity demand and supply gap. Thermal power generating units pollutes the environment and increases global warming. China, world‘s major polluter, plans to reduce its CO_2 emissions by 40% to 45% per unit GDP (gross domestic product) by 2020 from a 2005 baseline by implementing a carbon trading market that will penalise major polluters. On-going 20 years of discussions and consultation about sustainable development, the world‘s climate and its biodiversity are still deteriorating. With the help of distributed generation system and renewable energy sources we can overcome all such issues. Distributed generation uses generating units sized between 1 kW to 50 MW near to load demand as compared to central power generating units sized between 100 MW to 1 GW at a distance from the load demand. Applications of different types of technology in distributed generation have changed the way of operating electric power systems and utilization of renewable energy sources makes distributed generation clean and environment friendly power generating system.

3.2.2. Use of distributed generation

In the past years, there has been the good development of small-scale generation technologies, but still, they failed to push the "economy of scale" out of the system, because of its high initial setup cost. But other than this, other benefits make it desirable, and thus its utilization is increasing with days passing. Now we will see the use of distributed generation due to market liberalization and environmental concern (Pepermans et al., 2005):

3.2.2.1 Market liberalization

Now electricity suppliers are more concerned with their interest in distributed generation because they see it as a tool that can help them to fill in niches in a liberalized market. In which, customers will look for the electricity service that will suit best for them. Features of electricity supply and distributed generation technologies from the different customers are important and can help electricity suppliers to supply the type of electricity service that they want. In changing market conditions, distributed generation allows electricity suppliers in the electricity sector to respond flexibly. As compared to larger central power plants in many cases, distributed generation provides this flexibility because of its small sizes and the short construction lead times. According to the International Energy Agency (2002), the flexibility of this new technology can be understood when economic assessments of distributed generation are made. We can get further knowledge from different areas which are discussed below:

3.2.2.1.1 Peak load shaving

Many distributed generation technologies are indeed flexible in several respects: operation, size, and expandability. Making use of distributed generation gives flexibility of electricity price evolutions. Distributed generation then serves as a hedge against these price fluctuations. Europe increased their distributed generation efficiency for heat applications with the help of renewable energy sources (Pepermans et al., 2005). In 2012 North India faced black out conditions, which indicates the lack of flexibility and reliability in electricity supply. For reliable and flexible power sources demand of distributed generation in India has increased.

3.2.2.1.2 Power quality

We can have smaller voltage deviations, apart from large voltage drops to near zero. Voltage deviation shows the level of power quality. The degree of power quality refers to the power characteristics align with the ideal sinusoidal voltage and current waveform, current and voltage in balance (Eto et al., 2001). Inadequate power quality may be caused by:

(a) Interruptions, voltage dips, and transients which occur due to switching operations and failures in the network, and
(b) Phase imbalance, flicker (fast voltage variations), and harmonics.

The nature of these disturbances is related to the 'short-circuit capacity'. It is important for network operators to guarantee a specified minimum short-circuit capacity, to protect the system from degradation in power quality (Renner and Fickert, 1999). Ambiguity occurs when we go for finding a relation between distributed generation and power quality. There are many authors who stress over the healing effects of distributed generation for power quality problems. Distributed generation can contribute voltage support in areas where it is difficult, as connecting distributed generation leads to the rise in voltage in the network (International Energy Agency, 2002). Dondi et al., (2002) also mentioned the potential positive effects of distributed generation for voltage support and power factor corrections.

3.2.2.1.3 Reliability

Unreliable power source gives problem-related to repetitive power interruptions, which are voltage drops to near zero in electricity supply. Due to the liberalisation of energy markets, customers are more aware of the value of reliable electricity supply. In many

European countries, the reliability level is very high, mainly because of high engineering standards.

In general, compared to voltage fluctuation, customers do not care about supply interruptions because they do not feel it as a risk. Voltage instability can damage costly electrical and electronic equipment. Dependence of human life over technology demands continuous power supply. In these days, customer demand has increased for reliable power sources. Continuous demand implies high investment and maintenance costs for the generation and network infrastructure. In industries like chemicals, petroleum, refining, paper, metal, and telecommunications having a reliable power supply is very important. Investors of these firms facing poor reliability level of power supply to invest in these industries. Distributed generation technology helps to increase reliability level of power supply to fulfill customer demand up to the desired level (Pepermans et al., 2005).

3.2.2.1.4. Alternative to expansion

Distributed generation could serve as a substitute for investments in transmission and distribution capacity. But, this is possible only to the extent that alternative primary energy sources are also locally available in sufficient quantities so that it can give a better alternative power generation option.

According to the IEA (International Energy Agency, 2002), on-site production of electricity could result in 30% of cost savings during transmission and distribution. It directly impacts the increasing demand for distributed generation from the customer. It is seen, if the density of customer is less, the share of transmission and distribution costs in the overall price becomes large (above 40% for households) (International Energy Agency, 2002). As per system operator's point of view, distributed generation units can be a substitute for investments in transmission and distribution capacity. Distributed generation unit can be used as an alternative to connecting a customer to the grid in a 'stand-alone' application. Well-chosen distributed generation locations as close to the load can also contribute to reduced grid losses. The IEA (International Energy Agency, 2002) reports average grid losses of 6.8% in the Organisation for Economic Co-operation and Development (OECD) countries. According to Dondi et al., (2002) cost savings of 10–15% can be achieved using distributed generation technology in this way.

3.2.2.2. Environmental concerns

In the present scenario, environmental policies or concerns are probably the major driving forces for the demand of distributed generation, because of increased utilization of renewable energy sources. Government environmental regulation is forcing energy players into electricity market looking for cleaner energy and cost-effective solutions. By the use of distributed generation, we can optimize the energy consumption of firms that have a large demand for both heat and electricity (Pepermans et al., 2005). Also, most government policies which have aimed to promote the use of renewable will also result in an increased impact of distributed generation technologies, as renewable, except for large hydro, have a decentralized nature. More explanations related to environmental concern are given below:

3.2.2.2.1. Combined generation of heat and electricity

It makes sense to consider the combined generation of heat and electricity on sites where there is a considerable and relatively constant demand for heat, instead of generating the heat in a separate boiler and buying electricity from the grid. This technology is called cogeneration technology, and cogeneration units create a large segment of the distributed generation market. Compared to the separate fossil-fired generation of heat and electricity, combined generation of heat (CHP) generation may result in a primary energy conservation, varying from 10% to 30%, depending on the size (and efficiency) of the cogeneration units (Pepermans et al., 2005; Voorspools and D'haeseleer, 2002; and Voorspools and D'haeseleer, 2003). The avoided emissions are in a first approximation similar to the amount of energy saving, although the interaction with the global electricity generation system also plays a role.

3.2.2.2.2. Efficient use of cheap fuel opportunities

Installation of distributed generation gives the opportunity to use cheap fuel sources. For example, in the proximity of landfills distributed generation units used to burn landfill gases to generate electricity. But at local level biomass resources may also be envisaged. Currently, the liberalization of the electricity market and increased environmental concerns in developing countries both induce an increased interest in distributed generation applications and thus also in innovations in the appropriate technologies. However, the technical, economic and environmental challenges will be to optimally integrate this increasing number of small generation units in an electricity system that up to now has been very centralized, integrated and planned (Pepermans et al., 2005).

3.2.2.2.3 Use of renewable energy sources

Due to environmental benefits, developed and developing countries are moving towards the use of renewable energy sources to generate electricity. It reduces green house gases and controls acidification. Small-scale generation capacities of renewable energy sources are making this favourable for distributed generation. Solar and wind energy are playing the major role in distributed generation, because of its availability. Various developed and developing countries are increasing use of renewable energy for generation of electricity (Krewitt and Nitsch, 2003).

3.2.3. Types of distributed generation technologies and its applications

Distributed generation shows a range of technologies, for example, fuel cells, reciprocating engines, small gas combustion turbines, micro-turbines, load reduction and other energy management technologies. In the given below, we are discussing different types of distributed generation technologies and their fuel choices along with their benefits and drawbacks(Andersen, 2001; and Capehart, 2010):

Micro turbines

Micro turbines are small combustion turbines that produce power ranged between 25 kW and 500 kW. Micro turbines were derived from turbocharger technologies found in large trucks or the turbines in aircraft auxiliary power units (APUs). Efficiency of this technology is 28% to 33%

Fuel Choice: Natural gas, propane, diesel, multi-fuel

Benefits: Thermal recovery improves efficiency, thermal output for residential or small commercial applications, operable as base, peaking, or back-up, commercially available in limited quantities

Drawbacks: Insufficient thermal output for industrial applications

Small Gas Combustion Turbines

For distributed generation small gas combustion turbine generators typically range in size from about 500 kW up to 25 MW. Efficiency of this technology is 25% to 40%

Fuel Choice: Natural gas, distillate, methane, dual fuel

Benefits: Highly efficient when used with thermal recovery, technology commercially available today—most likely candidate for on-site needs >3 MW in distributed generation application, can operate base load, back-up, or peak load, several manufacturers, relatively low installed costs

Drawbacks: Potentially onerous siting and permitting requirements, environmental issues—emissions and noise, possible on-site fuel storage needs

Internal Combustion Engines

Internal combustion engines convert the energy contained in a fuel into mechanical power. This mechanical power is used to rotate a shaft in the engine. A generator is attached to the internal combustion (IC) engine to convert the rotational motion into power. They are available from small sizes 5 kW to large generators, e.g., 7 MW. Efficiency of this technology is 28% to 37%

Fuel Choice: Diesel, natural gas, propane, bio-gas, other petroleum distillates

Benefits: Bulk power delivered when utility is unavailable, fast start-up allows less sensitive processes to be served without need for UPSs (for the use of emergency lighting, HVAC, elevators, some manufacturing processes), very mature, stable technology, can be paralleled to grid or other generators with controls package, can be very efficient when combined with heat recovery

Drawbacks: Capital is only being used when back-up generator is running, marginal cost of production favours utility source in rare occasions, environmental issues like carbon emissions and noise, possible on-site fuel storage needs

Stirling Engines

A Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas at different temperatures. The Stirling engine is noted for high efficiency compared to steam engines, quiet operation, and its ability to use almost any heat sources. Stirling engines are cost competitive up to about 100 kW. The efficiency of this technology is ranging from 15% to 30%.

Fuel Choice: Air, hydrogen, helium

Benefits: Stirling engines can run directly on any available heat source, they require less lubricant and last longer than equivalents on other reciprocating engine types, no valves are needed, and the burner system can be relatively simple, they are extremely flexible and they can be used as CHP (combined heat and power) in the winter and as coolers in summer

Drawbacks: Stirling engine designs require heat exchangers for heat input and heat output, and material requirements for this substantially increase the cost of the engine, dissipation of waste heat is especially complicated because the coolant temperature is kept as low as possible to maximize thermal efficiency

Fuel Cells

Fuel cell power systems are quiet, clean, highly efficient on-site electrical generators that use an electrochemical process—not combustion—to convert fuel into electricity. In addition to providing power, they can supply a thermal energy source for water and space heating, or absorption cooling. In demonstration projects, fuel cells have been shown to reduce facility energy service costs by 20% to 40% over conventional energy service. High temp: Efficiency is 45% to 55%, Low temp: Efficiency is 30% to 40%

Fuel Choice: Direct by hydrogen; natural gas, propane, methanol, or other hydrogen-rich source through reformer

Benefits: Very high fuel efficiencies from hydrogen to electricity, potential to operate base load with utility back-up, possible residential application—a no-moving-parts energy appliance, very high efficiencies when combined with heat recovery, green technology—water and heat are only emissions from hydrogen fuel, low emissions from other fuels

Drawbacks: Few commercially available devices, most research efforts are for automotive applications, need for fuel reformer in almost all applications, not a zero-emission technology—the effect of that may vary by state

Photovoltaic

Photovoltaic (PV) cells, or solar cells, convert sunlight directly into electricity. PV cells are assembled into flat plate systems that can be mounted on rooftops or other sunny areas. They generate electricity with no moving parts, operate quietly with no emissions, and require little maintenance.

Fuel Choice: None

Benefits: No variable costs for fuel, in utility implementation, zero emissions may allow green power price premium, mature technology, multiple manufacturers

Drawbacks: Big foot print (600 ft^2/kW), high installed costs, not suited for base load, not suited for back-up except when accompanied by storage, variable energy output

Wind Turbines

Wind turbines use the wind to produce electrical power. A turbine with fan blades is placed at the top of a tall tower. The tower is tall to harness the wind at a greater velocity, free of turbulence caused by interference from obstacles such as trees, hills, and buildings. As the turbine rotates in the wind, a generator produces electrical power. A single wind turbine can range in size from a few kW for residential applications to more than 5 MW.

Fuel Choice: None

Benefits: No variable costs for fuel, in utility implementation, zero emissions may allow green power price premium, mature technology, multiple manufacturers

Drawbacks: Need to meet siting requirements, generation is intermittent with the wind, and energy output can vary with wind speed squared or cubed over operation range. Not appropriate as backup or off-grid applications, needs utility source for energy purchases and sales, can require footprint up to 100 ft^2/kW

Different distributed generation technologies are implemented to fulfill the requirements of a wide range of applications, and these applications and technologies differ according to the load requirements (thermal needs, stand-alone or grid-connected electrical power, requirements of power quantity and environmental issues on the site, etc.). Some of these applications are:

- Grid connection to sell the electrical energy,
- Stand-by sources to supply power for sensitive loads during grid outages,
- Peak-load shaving,
- Rural and remote applications,
- Used local fuel resources,
- CHP with injection of power into the network when the distributed generation capacity is higher than its local load, and

- Utility-owned distributed generations, to provide part of the main required power and support the grid by enhancing the system voltage profile, reducing the power losses, and improving the system power quality as well as reliability.

3.3. Renewable distributed generation

Due to lack of coal reservoir, thermal power generating units suffer from consistent coal shortage conditions and works on a high risk of unit shutdown. Renewable energy resources can play a big role to meet the huge and rising electricity demand and supply gap. Thermal power generating units are polluting the environment and increases global warming (Guttikunda and Jawahar, 2014). It was reported that green house gas emissions from power industries could be as high as 70% of the total green house gas emissions of Indian area (Daily News and Analysis, Jan 25, 2016). Ongoing 20 years of discussions and consultation about sustainable development, the world's climate and its biodiversity are still deteriorating. With the help of renewable energy used distributed generation system named renewable distributed generation, we can overcome all such issues. Compared with other power generation technologies, renewable distributed generation technologies are considered as making a major impact to reduce environmental emissions. The concept of renewable distributed generation arises from the distributed power generation with renewable energy sources (Labis et al., 2011). This came to force because of its environmental benefits and onsite power generation flexibility to improve the reliability and quality of power. With their advantages, this is a top priority in the making of energy policy worldwide. Applications of different types of technology in the renewable distributed generation have changed the way of operating electric power systems. Utilization of renewable energy sources makes this clean and environment friendly power generating system.

From a general point of view, the task of the central energy management system is to manage the power and the energy between sources and loads into the microgrid. The real and reactive power production must then be shared among the distributed energy resources units (here, a single prosumer) and the gas microturbine. Therefore, the central energy management system must assign real and reactive power references and also other appropriate control signals to the renewable energy-based generator, conventional production units, and controllable loads. Microgrid management is analyzed through various functions that are classified in a timing scale (Kanchev et al., 2011).

Long-term energy management includes the following:

1) Hourly "renewable energy resource production forecast," including the time dependence of the prime source, environmental impacts, and cost of generation;
2) Management of controllable loads that may be disconnected/shed according to the supervision requirement;
3) Provision of an appropriate level of power reserve capacity according to the electricity market and the load demand forecast;
4) Maintenance intervals.

Short-term power balancing includes the following:

1) RMS (root mean square) voltage regulation and primary frequency control;
2) Real-time power dispatching among internal sources of a distributed energy resources (Photovoltaic generator, batteries, and ultra-capacitors).

3.3.1. Increasing demand of renewable distributed generation

The renewable distributed generation is showing one of the extraordinary potential advances in power sector in recent past. While the same technology was used for decades, its potential to change our recent climatic condition has made this revolutionary. Environmental issues are becoming day by day a major challenge worldwide. For controlling excessive carbon emission without any economic fallout, the world is moving at large over renewable energy sources to generate electricity. With flexibility and small-scale generation capacity, the role of renewable distributed generation is bringing a major change in the energy sector. Use of renewable distributed generation to reach out the inaccessible or very remote areas is making this highly desirable (Karki et al., 2008). Here we have used wind-based renewable distributed generation technology for our research work. Basic knowledge of this new technology in the energy sector is very important for the development of future energy scenarios and the environmental, social and economic benefits.

Global increase in consumption of electricity demands rapid growth in the generation of electricity. Conventionally electricity is generated by fossil fuels which are limited to consume. Utilizing an excess level of fossil fuels is causing the global warming and excess carbon emission. Limitation of availability of fossil fuels is making this uneconomical and generation of green house gases making this harmful for the environment. Overcoming this issue and achieving the demand level, World is switching towards renewable energy. The earlier renewable energy was utilized by integrating along central power distribution system. Only hydro power was used with larger capacity compared to other renewable sources. Currently, environmental issues are the major concern worldwide. In recent past, many incidents have happened due to increased global warming. In climate-summit, world came together for resolving this issue. The world decided to increase generating the capacity of renewable energy and reduce utilization of fossil fuels. Mostly they talked over solar and wind energy based power generation technology. With small-scale generating capacity of renewable energy based technology made this more flexible and approachable for any unreachable area without any transmission losses. We can call this as renewable distributed generation technology. This new technology has multiple advantages over its counterparts.

3.3.2. Benefits of renewable distributed generation

In countries like India, many people are living in remote areas, and they don't have access to electricity. On the other hand, power deficiencies and transmission and distribution loss of power is about 32% in India (How-big-are-powerline-losses, 2013). Utilization of renewable distributed generation will lead to overcoming of these issues. It provides more flexible and reliable power sources to consumers. It improves voltage stability connected with the power grid. There is more security provided by renewable distributed generation to the consumers due to the setup of near to demand sites. We are considering economical, operational and environmental benefits of renewable distributed generation shown in Figure-3.2:

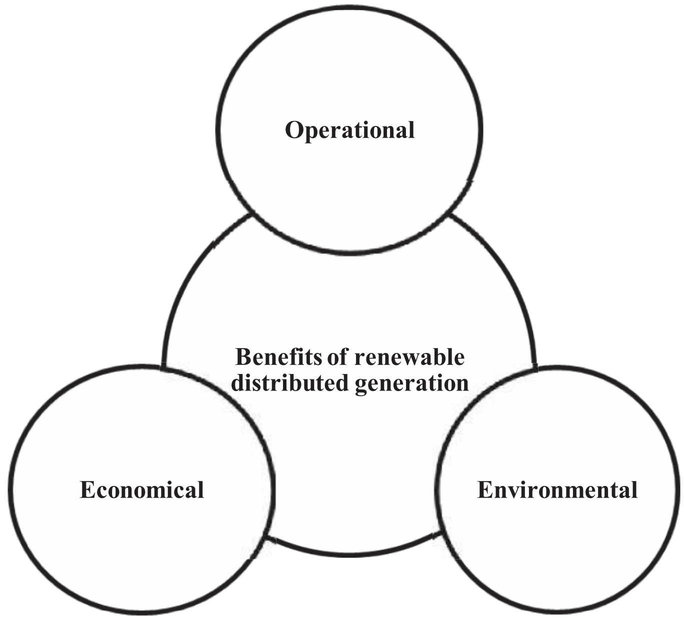

Figure 3.2: Benefits of renewable distributed generation

3.3.2.1. Operational

Decentralization of power generation with renewable distributed generation can reduce the distribution network power losses (Hadjsaid et al., 1999), distribution loads requirements by supplying some of the distribution load demand, reducing power flow inside the transmission network to fit certain constraints and improving its voltage profile (Coles and Beck, 2001). Renewable distributed generation technologies have a positive impact on the distribution system voltage profile (El-Khattam, and Salama, 2002; Hadjsaid et al., 1999) and power quality problems (Xu, and Girgis, 2001). Renewable distributed generation maintain system stability, supply the spinning reserve required and they provide transmission capacity release. Renewable distributed generation technology can help in "peak load shaving" and load management programs (Alvarado, 2001). When we are combined with renewable distributed generation, there will be new customer classifications between the high need for reliability with high service cost and others with less service cost and relatively lower reliability, especially in the case of end-user customers with low reliability. It can be used as on-site standby to supply electricity in case of emergency and system outages (Coles and Beck, 2001). It can be installed on medium and, or low voltage distribution network due to capacities varying from micro to large size which gives flexibility for sizing and site locating of renewable distributed generation units into the distribution network. As there are many generation spots not only one large centralized generation so they can help in system continuity and reliability.

From the mathematical point of view benefits of renewable distributed generation can be derived by Figure-3.3, which shows that the connection of a renewable distributed generator to the power system, where R and X are the resistance and reactance of short-circuiting, respectively, and Pg and Qg are the active and reactive power generated. According to Thevenin equivalent of the power system E is the voltage of the ideal source. At the same point of common coupling (PCC), there is a load characterized by its demand curve ($P_{load} + jQ_{load}$).

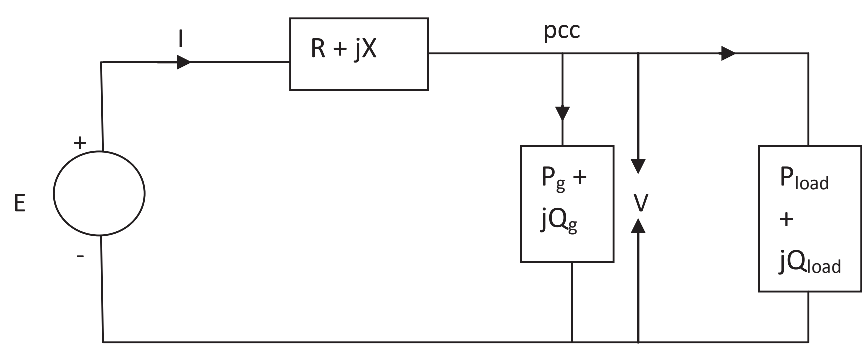

Figure 3.3: Connection of distributed generation and load at common coupling point

The variation of the voltage can be expressed as:

$$\Delta V = E - V = (R + jX)\,I = (R + jX)\frac{P - jQ}{V} = \frac{RP + XQ}{V} + j\frac{XP - RQ}{V}$$

Where P and Q are the total active and reactive power absorbed from the power system (load + generation), respectively. The variation of the voltage at the PCC of the wind farm to the grid can be calculated by solving the following equation:

$$V^4 + [(RP + XQ) - E^2]V^2 + [(XP - RQ)^2 + (XP + RQ)^2] = 0$$

From the above expressions, the voltage at the point of common coupling is the result of the combination of several parameters and variables such as the active and reactive powers, and the characteristics of the network. Positive values of K and L imply injected powers. The management of Q permits adjustment of the voltage at the PCC to the required level.

3.3.2.2. Economical

Renewable distributed generations can generate required demand of electricity by increasing installation of units at certain locations near to load sites, so they can reduce or avoid the need for building new transmission and distribution lines and upgrade the existing power systems (Andersen, 2001; Capehart, 2010; and Voorspools and D‘haeseleer, 2003). Investment point of view, it is easier to find sites for renewable distributed generation units as compared to a large central power plant and such units can be online in much less time. Unnecessary capital expenditure avoided and capital exposure and, risk are reduced by matching capacity increase with local demand growth. Renewable distributed generations can be assembled easily anywhere as modules for power generation which have many advantages as (Bayod-Rújula, 2009):

- In a very short period, they can be installed at any location. Each modular operation can’t be affected by other modular operation failure and operated immediately and separately after its installation independent of other modules arrival.

- The total capacity can be increased or decreased by adding or removing more modules, respectively.

Due to deregulation of electricity in many countries, renewable distributed generations will be of great importance in generating power locally especially if the location margin pricing (LMP) is applied for independent transmission operators (ISO's) and regional transmission organizations (RTO's). Location margin pricing (LMP) can indicate where renewable distributed generations should be installed. Also by supplying power to the grid, renewable distributed generations can reduce the wholesale price of power, which leads to the reduction of the demand required. Renewable distributed generation can stimulate competition in supply; adjusting price via market forces. In a free market environment, renewable distributed generation operator can buy or sell power to the electricity grid, purchasing power at off-peak prices and exporting only at peak demand. Renewable distributed generations are decentralized power systems, so this has the advantage to place anywhere as per the demand. The flexibility of location for the renewable distributed generation has a great effect on energy prices. For the exactly required customer load demand, renewable distributed generations are well sized to be installed in small increments. However, renewable distributed generation technologies such as solar, wind, biomass and geothermal units require certain geographical and climatic conditions.

As the demand for more and better quality electric power increases, renewable distributed generation can provide alternatives for cost-effective, reliable, premium power for domestic use and industrial use. When a power outage occurs at home or in the neighborhood, restoring power in a short time, renewable distributed generation can provide customers with continuity and reliability of supply. Renewable distributed generation increase the system equipment’s as well as the transformer’s durability and provide fuel savings. Installation of renewable distributed generation can reduce the construction schedules of developing plants. Hence, the system can track and follow the market's fluctuations and the peak-load demand growth. All these technologies offer new market opportunities and enhanced industrial competitiveness.

3.3.2.3. Environmental

Development of highly environment friendly renewable energy sources has attracted significant attention around the world. About, environment and society, renewable distributed generation eliminate or reduce the output process emission (Bayod et al., 2003). This is due to the increased awareness of the detrimental effects of the emissions from hydrocarbon-based power stations on the environment, which has led to the commitment of many countries to comply with the Kyoto protocol (Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1997) and reduce their GHG emissions. Power generation systems that use renewable resources like solar, wind, geothermal energy, and organic matter have some advantages over traditional fossil-fuelled generation systems. For example, most renewable distributed generation technologies do not produce green house gases and emit far less pollution compared to burning oil, coal, or natural gas to generate electricity. It is widely recognized then the green house gas intensity in hydro-electrical systems is about 15 gCO_2 / kWh on average, 20 gCO_2 / kWh in the case of wind turbines and 100 gCO_2 / kWh for photovoltaic. Where as in classical thermal systems burning natural gas it is around 577 gCO_2 / kWh (combined cycle) or 750 gCO_2 / kWh (open cycle) and in burning coal, the values are greater than 860 gCO_2 / kWh (Bayod-Rújula, 2009).

The environmental load is also reduced due to the avoidance of additional energy required to compensate transmission losses. Studies report that reduction of losses by

1% in the UK system reduces emissions by 2 million tonnes of CO_2 per year (Microgrids, 2005a). Moreover, in the UK, reduction by 1 GWh from the hydrocarbon can reduce emissions up to 400,000 tonnes per year. In selected Portuguese networks of various types, ranging from rural LV networks to HV ones, 20% penetration of renewable distributed generation reduces CO_2 emissions by 2.07–4.85% (Microgrids, 2005b). It is demonstrated that on the European scale, 65 million tonnes of CO_2 per annum can be saved by 50 million installations of domestic renewable distributed generation units. A significant impact of increased efficiency in the domestic utilization of gas and electricity on the reduction of CO_2 emissions is claimed in Pudjianto (Pudjianto and Strbac, 2006). Next, to the potential environmental benefits of renewable distributed generation, their economic evaluation is critically influenced by the developing CO_2 emissions trading markets (Laurikkaa and Koljonen, 2006), which also affect production costs of electricity generated by thermal (hydrocarbon) units.

3.4. Smart grid integration

The electrical grid is expected to evolve to a new grid paradigm: the smart grid, an enhancement of the 20th-century electrical grid. The traditional electrical grids are used to carry power from a few central generators to a large number of users or customers. In contrast, the new emerging smart grid uses two-way flow of electricity and information to create an automated and distributed advanced energy delivery network. Integration of decentralized power generation units is key in smart grid management (Roncero, June 2008). Many research projects have been conducted to explore the concept of the smart grid. According to the newest survey on smart grid, the research is mainly focused on three systems in smart grid- the infrastructure system, the management system, and the protection system (Fang et al., 2012).

The infrastructure system is the energy, information, and communication infrastructure underlying of the smart grid that supports

a) advanced electricity generation, delivery, and consumption;
b) advanced information metering, monitoring, and management; and
c) Advanced communication technologies.

In the transition from the conventional power grid to smart grid, we will get to replace a physical infrastructure with a digital one. The needs and changes present the power industry with one of the biggest challenges it has ever faced.

A smart grid would allow the power industry to observe and control parts of the system at higher resolution in time and space. It would allow for customers to obtain cheaper, greener, less intrusive, more reliable and higher quality power from the grid. The legacy grid did not allow for real-time information to be relayed from the grid, so one of the main purposes of the smart grid would be to allow real-time information to be received and sent from and to various parts of the grid to make operation as efficient and seamless as possible (Farhangi, 2010). It would allow us to manage logistics of the grid and view consequences that arise from its operation on a time scale with high resolution; from high-frequency switching devices on a microsecond scale, to wind and solar output variations on a minute scale, to the future effects of the carbon emissions generated by power production on a decade scale.

The management system is the subsystem in the smart grid that provides advanced management and control services. Most of the existing works aim to improve energy efficiency, demand profile, utility, cost, and emission, based on the infrastructure by using optimization, machine learning, and game theory. Within the advanced infrastructure framework of the smart grid, more and more new management services and applications are expected to emerge and eventually revolutionize consumers' daily lives.

The protection system is the subsystem in the smart grid that provides advanced grid reliability analysis, failure protection, and security and privacy protection services. The advanced infrastructure used in the smart grid, on the one hand, empowers us to realize more powerful mechanisms to defend against attacks and handle failures but opens up new vulnerabilities. For example, National Institute of Standards and Technology pointed out that the major benefit provided by the smart grid, the ability to get richer data to and from smart customer meters and other electric devices, also gives major privacy concerns, since the energy use information stored at the meter acts as an information-rich side channel. This information could be mined and retrieved by interested parties to reveal personal information such as individual's habits, behaviours, activities, and even beliefs.

Developed nations are increasingly aware of the potential of renewable energy to both reduce the nation’s dependence on fossil fuels, both foreign and domestic sources, and decrease emissions of climate-changing greenhouse gases and other pollutants. As a result, renewable energy technologies, particularly, solar and wind power, are the fastest growing sources of electricity in the USA (Apergis and Payne, 2011). Furthermore, environmental and security concerns have sparked increased interest in small-scale, “distributed” sources of renewable electricity generation like rooftop solar panels, to reduce our reliance on large, centralized power plants. However, individual homeowners and small business owners looking to invest in these new sources of energy often face bureaucratic red tape when trying to install their own small-scale, distributed renewable energy systems.

The greatest barriers to renewable distributed generation systems are not technical obstacles, but financial, political, and social hurdles. System installers often face planners and building inspectors with little renewable energy experience and no formal education for certifying system safety and reliability. Complex permitting requirements and lengthy review processes can delay installations and add significant costs to distributed renewable energy systems. Permitting standards that vary across city and town borders create additional complications and inefficiencies. In many cases, these bureaucratic hurdles stymie efforts by homeowners and business owners to install systems and hinder the development of a national market for the renewable distributed generation.

The next-generation energy grid will be characterized by a high penetration of renewable energy resources, distributed generation, energy storage, and a drive to control cost and carbon emissions. The next wave of smart grid technology deployment will focus on advanced big data analytics, grid management, and distribution network innovations that integrate and facilitate clean energy, efficiency, and proactive customer engagement. Utilities around the world are looking at integrating more distributed solar, the wind, biomass, and other renewable sources into the energy mix, leveraging smart grid and microgrid investments to deliver advanced services and improved network performance.

Increasing renewable electricity generation is an essential component in achieving a doubling of the renewable energy share in the global energy mix. Such a transition is technically feasible but will require upgrades of old grid systems and new innovative solutions to accommodate the different nature of renewable energy generation. In particular, smart grids can incorporate the following characteristics:

- Variability- Some forms of renewable electricity, notably wind and solar, are dependent on an ever-fluctuating resource (the wind and the sun, respectively). As electricity supply must meet electricity demand at all times, efforts are required to ensure that electricity sources or electricity demand is available that can absorb this variability.
- Renewable distributed generation- Decentralized renewable energy based generation, smaller-scale systems, usually privately owned and operated, represent a new and different business model for electricity. Traditional utilities are often uneasy about allowing such systems to connect to the grid due to concerns over safety, effects on grid stability and operation, and the difficulties in valuing and pricing their generation.
- High initial cost- Renewable electricity generating technologies typically have higher first costs and lower operating costs than fossil-fuelled electricity generating technologies. Although renewable may be "cost-effective" on a lifecycle basis, some electricity systems, particularly in developing countries, simply do not have access to sufficient capital to invest in renewable.

Smart grid technologies can directly address these three challenges of renewable electricity generation. Also, smart grids offer added benefits that can further ease the transition to renewable. This chapter explains how smart grid technologies enable renewable distributed generation.

3.4.1. Smart Grid

The smart grid is the future of power distribution system, which will help in the generation, transmission, and distribution of power to overcome the challenges of present power grid system (Colak et al., 2015; and Fang et al., 2012). Developing nations have a potential opportunity to develop them with this new technology (Colak et al., 2014; and Fadaeenejad et al., 2014). Amongst these challenges like the blackout, voltage variability, overloads, and carbon emissions are the major ones to overcome by the smart grid technology. This connects advanced technologies of generation and distribution to supply power with advanced communication technologies. It gives customers more visualization to participate in a distribution system. Smart grid mostly gives an advantage over environmental emission and energy efficiency (Gopakumar et al., 2014). Stability, security and economical benefits are also achieved by using smart grid technology. With the penetration of renewable distributed generation and two-way power and data sharing, the conventional grid system has changed. Modern smart grid architecture is given below in Figure-3.4 which supports these changes.

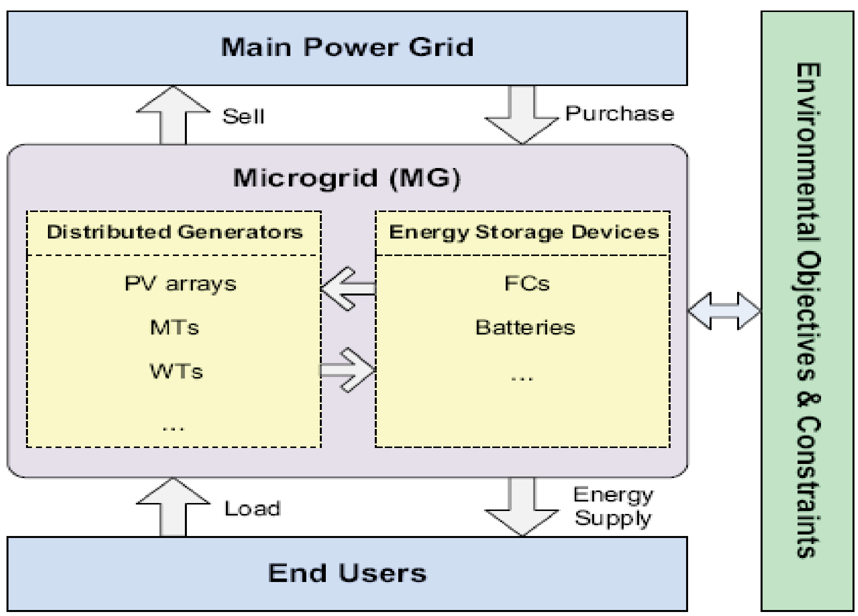

Figure 3.4: Functioning of smart grid in power distribution system (Zhou et al., 2014)

With advanced communication system, smart grids provide more reliable and secure power supply. Use of a smart grid will require infrastructure up-gradation like smart meters which gives more flexibility and visibility in energy management. Welsch et al.

(2013) in their work mentioned factors which cause acceleration of the use of smart grid are:

a) a design of transmission and distribution system,
b) a design of distribution system,
c) smart distributed generation,
d) load side management,
e) local charging stations,
f) billing service,
g) information system architecture,
h) financing

3.4.2. Benefits of integration

Leading characteristics of renewable resources that impact their integration into power grids are their size (generation capacity as compared to other sources of power generation on a system), their location (both geographically and concerning network topology), and their variability (minute-by-minute, daily, seasonally, and intermittently) (Ochoa and Harrison, 2011). Integration of renewable distributed generation technologies reducing our nation's dependence on foreign coal by enabling the seamless integration of cleaner, greener energy technologies into our power network.

- Future energy sustainability: Renewable sources of energies are making a significant contribution to climate protection, diversify resources, ease dependence on fossil resources, not produce any contamination, domestic energy carriers and therefore contribute to regional value creation and help to secure employment. Hence renewable sources as future energy provide sustainability.

- Empowering grid in peak hours: Integration of more renewable sources and storage support the smart grid with the real-time information and substituting renewable energy sources whenever possible. Increasing proportion of Renewable sources in generation mix not only improves operational efficiency but also reduces peak demands
- Energy management: Smart metering helps to adopt energy management techniques such as Demand side management at the consumer level, demand response usage leads to optimum utilization and results in saving of energy.
- Independent systems: Renewable energy systems work as an isolated system during grid failure and reduce the impact on the customer. Industrial and commercial consumers adopt grid-connected renewable energy systems which help to reduce power demand. Sometimes isolated system in residential areas conserves the energy.
- Upgrading Electrical market: Power exchange provides an electronic platform to facilitate the trading of electricity at the national level, initiated renewable energy trade since 2011. India ranks fourth in its market potential in renewable energy.

3.4.3. Smart grid in India

Recently India is a growing economy and took some major steps in power sectors to reduce the demand-supply gap and have less carbon emission. Per capita power consumption in India is far less than the developed Nations. India is trying to increase its per capita power consumption. In the Table-3.2 given below, we can see India has 509% growth rate of electricity demand in between the year 2007 and 2050 (Fadaeenejad et al., 2014). For this India is investing in smart technology to meet electricity demand in future.

Table 3.1: Future electricity demand of India along with other major regions and their percentage of growth (Fadaeenejad et al., 2014)

Region	2007 electricity Demand (TWh)	2050 electricity Demand (TWh)	Percent growth 2007-2050 (%)
World	16,999	36,948	117
OECD North America	4664	6252	34
OECD Europe	3136	4071	30
OECD Pacific	1681	2311	37
Economies in transition	1149	2348	104
China	2856	9500	233
India	567	3453	509
Other developing Asia	853	2822	231
Africa	521	1691	225
Latin America	808	2062	155
Middle East	594	2537	327

Before the development of smart grid in India, some pilot projects have been investigated by Indian utilities and Banglore Electricity supply company (BESCOM) (Pawar et al., 2012). Reasons for the demand of smart grid in India are power theft, highest demand growth rate, and transmission and distribution losses. The transmission and distribution loss in India is about 23% of total power generation which is highest in the world (Planning commission government of India, February 2014). An approach taken by Indian power sector for the use of the smart grid is shown in Figure-3.5 (Fadaeenejad et al., 2014).

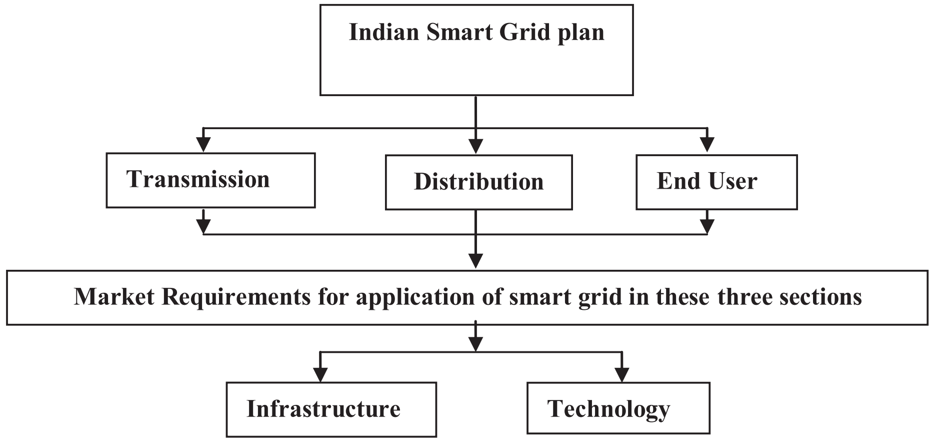

Figure 3.5: Planning of Smart Grid development in India

Samantaray (2014) studied smart grid initiatives in India. Fadaeenejad (2014) developed a methodology for implementing the smart grid project in India. The reliability, quality, and efficiency of power with customer friendly can achieve by use of the smart grid in India. Research conducted in India by the center for the study of science technology and policy (CSTEP) suggested five major factors use smart grid concept in developing countries (Fehrenbacher, 2010)

a) Quality and reliability of power

b) Develop smart grid despite conventional one

c) Optimal investment for growing energy demand

d) Smart grid integrated with renewable distributed generation technology