Future Electrical Grid: Smart Grid

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***Abstract* -- The Smart regarded as the next generation power grid, uses two-way flows of electricity and information to create a widely distributed automated energy delivery network. Creation of a Smart Grid provides utilities and their customers a significant improvement in power reliability and services. This paper presents a review on Smart grid technologies. One can see the characteristics, benefits, and challenges in the field of Smart grid. This paper gives brief discussion about the smart infrastructure system. Two-way flows of electricity and information lay the infrastructure foundation for the smart grid. This paper explains works on smart infrastructure system and outline of research directions and challenges.**

***Keywords*-- advanced metering infrastructure (AMI), distributed energy resources (DER), Smart Grid (SG), smart infrastructure system, smart distribution, smart generation, smart transmission.**

I. Introduction

The electric grid delivers the electricity from generating station to consumers. The electricity delivery system consists of two primary systems. They are transmission system, distribution system. Transmission system delivers power from generating stations to distribution substations. Distribution system delivers the power from distribution substation to consumers [1]. Traditionally electrical grid refers to interconnected transmission system. But smart grid refers to entire electrical system, which includes generation, transmission [2], distribution as well as into the home or building. It is well known for the distribution system and complex part of the entire electrical system [3].

A smart grid is also called smart electrical grid, intelligent grid, intelligrid, futuregrid, intergrid, or intragrid, is an enhancement of the 20th century power grid. Smart grid delivers electricity from suppliers to consumers using digital technology to save energy, reduce cost, increase reliability and transparency [4]. Smart grids increase the connectivity, automation and coordination between suppliers, consumers and networks that perform either long distance transmission or local distribution tasks [3, 4].

There are few visions to develop smart grid are: it should be designed from scratch, and existing system should be modified into smart grid [5]. Though the first is complex but manageable while second will take few decades. Solution is to make short term decisions that incrementally transform existing distribution systems into this smart future vision.

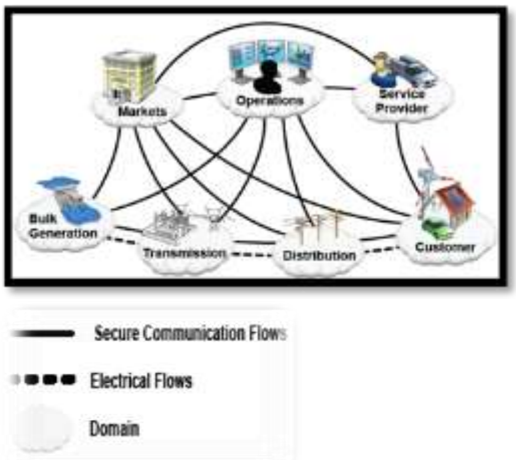
II. Smart Grid and Its characteristics

The Smart Grid can be defined as an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, substations, distribution and consumption to achieve a system that is clean, safe, secure, reliable, resilient, efficient, and sustainable. This definition covers the entire spectrum of the energy system from the generation to the end points of consumption of the electricity. The ultimate Smart Grid is a vision, and it will require cost justification at every step before implementation, then testing and verification before extensive deployment. Nonetheless, in order to qualify as a smart grid, it is neither necessary nor feasible to incorporate all features at once, but rather incorporation of each new feature can be carried out independently. Each will require cost justification and reasonable pay back on investments. However, interoperability of open systems will allow each addition to “Plug-and-Play” into the smart grid once the technologies have been validated. Assuming fully realized, the smart grid will have the following characteristics [9]

- Self healing: automatic repair or removal of potentially faulty equipment from service before it fails, and reconfiguration of the system to reroute supplies of energy to sustain power to all customers.
- Flexible: the rapid and safe interconnection of distributed generation and energy storage at any point on the system at any time.
- Predictive: use of machine learning, weather impact projections, and stochastic analysis to provide predictions of the next most likely events so that appropriate actions are

taken to reconfigure the system before next worst events can happen.

- Interactive: appropriate information regarding the status of the system is provided not only to the operators, but also to the customers to allow all key participants in the energy system to play an active role in optimal management of contingencies.
- Optimized: knowing the status of every major component in real or near real time and having control equipment to provide optional routing paths provides the capability for autonomous optimization of the flow of electricity throughout the system.
- Secure: considering the two-way communication capability of the Smart Grid covering the end-to-end system, the need for physical- as well as cyber-security of all critical assets is essential.



Fi.1 NIST Conceptual Model for Smart grid [7]

As indicated by the above characteristics, the Smart Grid involves installation of much new, intelligent equipment at all critical generation, transmission, distribution, and consumption points. For this equipment to become an effective part of the operations of an integrated Smart Grid, fundamental control technologies for communications, data management, diagnostic analysis, and work management are also required. It is expected that the Smart Grid will change the conventional concept of energy management and operations. This is mainly due to the fact that traditional demand and generation concepts are evolving into distributed resources where demand can change into generation and energy storage can locally complement supply needs.

III. Benefits and Requirements of Smart Grid

The initial concept of SG started with the idea of advanced metering infrastructure (AMI) with the aim of improving demand-side management and energy efficiency, and constructing. However, new requirements and demands drove the electricity industries, research organizations, and governments to rethink and expand the initially perceived scope of SG. Although a precise and comprehensive definition of SG has not been proposed yet, according to the report from NIST [7], the anticipated benefits and requirements of SG are the following:

- Improving power reliability and quality
- Optimizing facility utilization and averting construction of back-up (peak load) power plants
- Enhancing capacity and efficiency of existing electric power networks
- Improving resilience to disruption
- Enabling predictive maintenance and self-healing responses to system disturbances
- Facilitating expanded deployment of renewable energy sources;
- Accommodating distributed power sources
- Automating maintenance and operation
- Reducing greenhouse gas emissions by enabling electric vehicles and new power sources
- Reducing oil consumption by reducing the need for inefficient generation during peak usage periods
- Presenting opportunities to improve grid security
- Enabling transition to plug-in electric vehicles and new energy storage options;
- Increasing consumer choice
- Enabling new products, services, and markets.

IV. Smart Grid Technologies

There are different technologies that play vital role in the smart grid technology are smart protection system, smart information system, smart infrastructure system.

- Smart Infrastructure System
  - Smart information subsystem
  - Smart energy subsystem
  - Smart communication subsystem
- Smart Protection System
  - System reliability and failure protection
  - Security and privacy
- Smart Management System
  - Management objectives

- Management methods and tools

This includes: Power generation, transmission grid, distribution grid, microgrid and grid-to vehicle/ vehicle-to-grid system, Information metering and measurement, wireless, wired, end-to-end communication management reliability, failure protection mechanism, Information metering and measurement Information transmission Energy efficiency and demand profile, utility, cost, and price, emission, optimization, machine learning, game theory, auction, a true Smart Grid will not utilize these technologies as separate issues. Instead, it will integrate in order to maximize the benefits.

A. Smart Infrastructure System

The traditional power grid is unidirectional in nature [10]. Electricity is often generated often generated at a few central power plants by electromechanical generators, primarily driven by the force of flowing water or heat engines fueled by chemical combustion or nuclear power. In order to take advantage of the economies of scale, the generating plants are usually quite large and located away from heavily populated areas. The generated electric power is stepped up to a higher voltage for transmission on the transmission grid. The transmission grid moves the power over long distances to substations. Upon arrival at a substation, the power will be stepped down from the transmission level voltage to a distribution level voltage. As the power exits the substation, it enters the distribution grid. Finally, upon arrival at the service location, the power is stepped down again from the distribution voltage to the required service voltage.

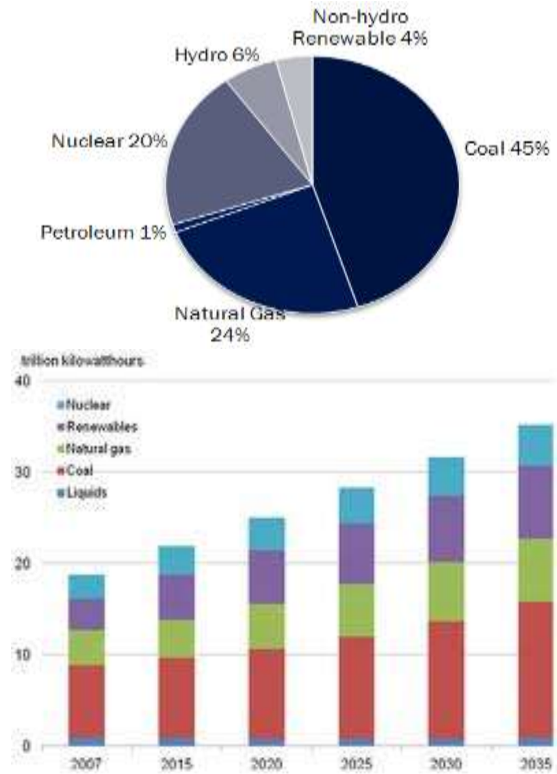


Fig.2 Power generated by different sources and growth in the generation year by year

In contrast with the traditional power grid, the electric energy generation and the flow pattern in an SG are more flexible. For example, the distribution grid may also be capable of generating electricity by using solar panels or wind turbines. In this survey, we still divide the energy subsystem into power generation, transmission grid, and distribution grid.

i. Smart Power Generation:

According to the five year (2012-2017) plan vision for securing and generation of future energy got more priority [14]. Faster and more inclusive growth will require a rapid increase in power consumption. The aim is that at least 10% power generation installed capacity in the country, with 4-5 %share in the electricity mix, should come from renewable. Out of the overall target of 70,000 MW power generation installed capacity addition during the 11^{th} Plan period, 14,500 MW (about 20%) capacity addition is proposed from renewable. 13,500 MW grid-interactive and 1000 MW DRPS (kW –MW). DG Power of 4000-5000 MW (2-5 MW each) from conventional energy sources

Since India has limited domestic resources. So, one way to improve the power is through distribution generation (DG). Most of the energy produced by today is large generating stations, which is transmitted at high voltage to the load centers and transmitted to consumers at reduced through local distribution system. In contrast DG produces power on consumer site or at a local distribution network.

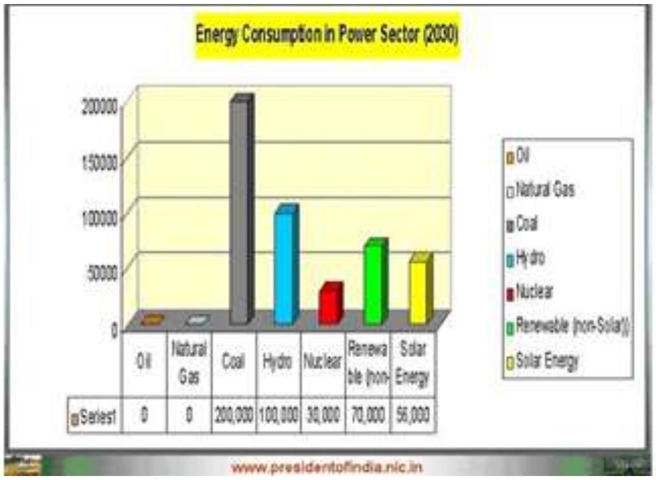


Fig.3 Energy consumption of India by 2030 and the different renewable sources energy production by 2030 [16]

Distribution Generation is defined as generation located at or near load centers [15]. They generate through various small-scale power generation technologies. Distribution energy resources [DER] to variety of small, modular power generating technologies that can be combined energy management and storage systems and used control or improve the energy delivery system.

Smarter power generation becomes possible as the two way flows of electricity and information are supported. A key power generation paradigm enabled by SG will be the distributed generation. Distributed generation takes advantage of distributed energy resource (DER) systems which are often small-scale power generators in order to improve the power quality and reliability. DG includes the commercial energy technologies and renewable energy technologies.

a) Bio Mass:

Small biomass gasifies systems developed indigenously in the range of 3KW to 500KW for thermal, electrical and mechanical applications. Initially, small capacity biomass linked with indigenously developed 100% producer gas engine, were deployed. About, 10-12 biomass manufacturers are engaged in manufacturing in India. Ankur and IISc, Bangalore are the major technology developers. About 89 MW equivalent systems are in place for various electrical and about 100 MW thermal applications in industries. One Grid connected biomass system in the range of 1 MWe has been commissioned. Bio mass based power programs are

IC engines are the most common technology used for the DG. They are proven technology with low capital cost, large size rage, relatively high electric conversion efficiency, fast start-up technology and good operating capability [15]. These characteristics combine with the engine's ability to start up during a power outage, make them the main choice for emergency or standby power supplies. They are by most commonly used power generation equipment under 1MW. The main drawbacks of reciprocating engines are noise, costly maintenance and high emissions particularly nitrogen oxides. These emissions can be reduced, with a loss of efficiency, by changing combustion characteristics.

Small industrial gas turbines of 1-20MW are commonly used in combined heat and power applications. They are particularly useful when higher temperature steam is required than can be produced by a reciprocating engine. The maintenance cost is slightly lower than for reciprocating engines, but so it is the electrical conversion efficiency. Gas turbines can be noisy but emissions are lower than IC engines. These can controlled by cost effective NOx emissions-control technology.

One of the most striking technical characteristics of micro is their extremely high rotational speed. The turbine rotates up to 1, 20,000rpm and the generator up to 40,000rpm. Individual units range from 30-200MW but can combined readily into systems of multiple units. Low combustion can assure very low NOx emission levels. They make much less than IC engine of comparable size. Natural gas is expected to be most common fuel but landfill gas or biogas can be used. The disadvantage of it at this stage is short track record and high cost compare to engines.

b) Photovoltaic System:

Photovoltaic systems are a capital-intensive, renewable technology with very low operating costs. They generate no heat and are inherently small- scale. These characteristics suggest that PV systems are best suited to household or small commercial applications, where power prices on the grid are highest. Operating costs are very low, as there are no fueling costs. PV systems also are widely used in developing countries, serving rural populations that have no other access to basic energy services. PV systems can be used to provide electricity for a variety of applications in households, community lighting, small businesses, agriculture, healthcare, and water supply. The other half of existing PV capacity is on-grid, mostly as distributed generation. Most installations to date have enjoyed very large investment subsides or favorable prices for the electricity they generate. The economic viability of PV systems is much higher when they can displace an extension to a distribution line.

c) Wind Energy:

Wind turbines can be used as stand-alone applications, or they can be connected to a utility power grid or even combined with a photovoltaic (solar cell) system. For utility-scale sources of wind energy, a large number of wind turbines are usually built close together to form a wind plant. Several electricity providers today use wind plants to supply power to their customers. Small wind systems also have potential as distributed energy resources. Distributed energy resources refer to a variety of small, modular power-generating technologies that can be combined to improve the operation of the electricity delivery system

d) Small Hydro Power:

Water constantly moves through a vast global cycle, in it evaporates from oceans, seas and other water reservoirs, forms clouds, precipitates as rain or snow, then back to the ocean . The energy of this water cycle, which driven by the sun, tapped most efficiently with hydropower. The advantages of using these are its large renewable domestic resource base, the absence of polluting emissions during operation, its capability in some cases respond quickly to utility load demands, and it’s very low operating costs. These include beneficial effects like recreation in reservoirs or in tail water below dams. The main disadvantages of these are high potential cost and potential site- specific and cumulative environmental impacts. In India capacity lower than 15MW is termed as small hydro plants.

e) Fuel Cells:

Fuel cells are compact, quiet power generators that use hydrogen and oxygen to make electricity. The transportation sector is the major potential market for fuel cells, and manufacturers are making substantial investments in research and development. Power generation, however, is seen as a market in which fuel cells could be commercialized much more quickly. Fuel cells can convert fuels to electricity limits the emissions of greenhouse gases. As there is no combustion, other noxious emissions are low.

f) Ocean Energy :

The ocean can produce two types of energy: thermal energy from the sun's heat, and mechanical energy from the tides and waves. Oceans cover more than 70% of Earth's surface, making them the world's largest solar collectors. The sun's heat warms the surface water a lot more than the deep ocean water, and this temperature difference creates thermal energy. Just a small portion of the heat trapped in the ocean could power the world. Ocean thermal energy is used for many applications, including electricity generation. There are three types of electricity conversion systems: closed-cycle, open-cycle, and hybrid. Closed-cycle systems use the ocean's warm surface water to vaporize a working fluid, which has a low-boiling point, such as ammonia. The vapor expands and turns a turbine. The turbine then activates a generator to produce electricity. Open-cycle systems actually boil the seawater by operating at low pressures. This produces steam that passes through a turbine/generator. And hybrid systems combine both closed-cycle and open-cycle systems. Ocean mechanical energy is quite different from ocean thermal energy. Even though the sun affects all ocean activity, tides are driven primarily by the gravitational pull of the moon, and waves are driven primarily by the winds. As a result, tides and waves are intermittent sources of energy, while ocean thermal energy is fairly constant. Also, unlike thermal energy, the electricity conversion of both tidal and wave energy usually involves mechanical devices [19].

g) Economic Advantages of On-Site Distributed Generation:

Distributed generation has some economic advantages over from the grid, particularly for on-site power production

- On-site production avoids transmission and distribution costs, which otherwise amount to about 30% of the cost delivered electricity.
- Onsite power production by fossil fuels generates waste heat can be used by the customer. Distributed generation may also be better positioned to use inexpensive fuels such as landfill gas.

h) Grid Benefits of On-Site Distributed Generation:

DG’s depending on location, may offer additional value to the Grid

- Deferral of upgrades to the transmission system. When a transmission system is congested, an appropriately located DG can reduce the congestion and thus can defer the need for an upgrade, particularly when the growth in congestion is low.

- If a distribution network is operating near capacity or needs to be upgraded to accommodate power flows from the generator, DG installed at a transformer station, may allow a distribution company to cope with the problem, delaying the need to upgrade distribution assets.
- Reduction of losses in the distribution system. On-site generation will cut system losses by reducing power demand on the system. Furthermore, if a distributed generator located near a large load, then its exported power will also tend to cut system losses. In contrast, power exported to the grid from remote distributed generators may increase these system losses.
- The connection of distributed generators to networks generally leads to rise in voltage in the network. In areas where voltage support is difficult, installation of a distributed generator may improve quality of supply

ii. Smart Transmission:

On the power transmission side, factors such as infrastructure challenges and innovative technologies drive the development of smart transmission grids. As shown in [12], the smart transmission grid can be regarded as an integrated system that functionally consists of three interactive components: smart control centers, smart power transmission networks, and smart substations. Based on the existing control centers, the future smart control centers enable many new features, such as analytical capabilities for analysis, monitoring, and visualization. The smart power transmission networks are conceptually built on the existing electric transmission infrastructure. However, the emergence of new technologies can help improve the power utilization, power quality, and system security and reliability, thus drive the development of new framework architecture for transmission networks. The vision of the smart substation is built on the existing comprehensive automation technologies of substations. Although the basic configurations of high-voltage substations have not changed much over the years, the monitoring, measurement, and control equipment have undergone a sea change in recent years. Major characteristics of a smart substation shall include digitalization, coordination, and self-healing. By supporting these features, a smart substation is able to respond rapidly and provide increased operator safety.

In brief, with a common digitalized platform, in the smart transmission grid it is possible to enable more flexibility in control and operation, allow for embedded intelligence, and foster the resilience and sustainability of the grid.

iii. Smart Distribution:

For the distribution grid, the most important problem is how to deliver power to serve the end users better. However, as many distributed generators will be integrated into the smart distributed grid, this, on one hand, will increase the system flexibility for power generation, and on the other hand, also makes the power flow control much more complicated, in turn, necessitating the investigation of smarter power distribution and delivery mechanisms.

An interesting research work was done by Takuno et al. [13]. Takuno et al. proposed two in-home power distribution systems, in which the information is added to the electric power itself and electricity is distributed according to this information. The first one is a circuit switching system based on alternating current (AC) power distribution, and the other is a direct current (DC) power dispatching system via power packets. Note that the packetization of energy is an interesting but challenging task since it requires high power switching devices. Researchers have shown that silicon carbide junction gate field-effect transistors are able to shape electric energy packets. Hence, the proposed system has the potential as an intelligent power router. More specifically, supplied electricity from energy sources is divided into several units of payload. A header and footer are attached to the unit to form an electric energy packet. When the router receives packets, they are sorted according to the addresses in the headers and then sent to the corresponding loads. Using energy packet, providing power is easily regulated by controlling the number of sent packets. In addition, many in-home electric devices are driven by DC power and have built-in power conversion circuits to commutate AC input voltage. Thus, DC based power distribution is feasible. These systems will make in-home power distribution systems more efficient and easier to control energy flow.

V. Challenges in Smart Grid

Metrics, cost and benefits analysis of Smart Grid field projects has some major challenges. These challenges include, enabling a fair comparison of baseline performance and smart grid performance, collecting proper data at appropriate frequency and location, determining societal benefits, monetizing benefits, extrapolating results from a few circuits to larger control area, interpreting smart grid response to electrical disturbance, recognizing regional differences for electric service provider and consumer, using appropriate assumptions and calculation methods.

More discussion is warranted for some of these challenges. For example, to enable a fair comparison of baseline and the SG system, it may be necessary make adjustments to account for differences in weather conditions, abnormal system disturbances, maintenance, load and other factors between the base period and the SG demonstration/deployment period.

Appropriate field data needs to be collected in the proper frequency and location as it provides the raw information that must be used in calculations to determine performance metrics and benefits. Since these SG projects represent the first large opportunity to collect field data, we must be prepared to adjust our data collection requirements as we learn more about operation of the Smart Grid system. Among the societal benefits of SG is cleaner air, improved safety, reduced dependency on foreign oil, and reduced costs of goods and services. These benefits are real, but difficult to calculate and monetize based on field data from SG projects. However, it is important to account for these improvements made possible by Smart Grid in the business case and decision making for SG. We will be exploring the underlying assumptions and calculation methods for determining societal benefits to assure that they are as credible as possible.

VI. Conclusion

What is needed now is an effort to develop an integrated vision for Smart Grid. A wise management is also needed to establish this vision. As shown in this literature review, one can see that Smart Grid is a hot and open research area. It has many research aspects. Many research teams all over the world have some contribution in this field.

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