

# Modernization Of Traditional Grid Into Smart Grid Through Renewable Sources

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**Abstract:** Smart grid technology aims to reconstruct traditional power grid into sophisticated, digitally enhanced power system where the use of modern communications and control technologies allow much greater robustness, efficiency and flexibility than traditional power systems. A smart grid impacts on all the components of power system. However much of the smart grid focus in a power system is at distribution level. This paper presents the historical background and motivation for smart grid, features of smart grid and challenges in smart grid. It also summarizes major requirements that smart grid communication must meet and at the same time discusses the current progress of this technology in Europe, U.S.A. and India. A novel idea of implementing a smart home is also presented to emphasize its feasibility and reliability even at micro level.

**Index Terms:** Smart Grid, Renewable Sources, Communication Infrastructure, Power Electronics, Control, Distributed Generation (DG), Storage

## 1. Introduction

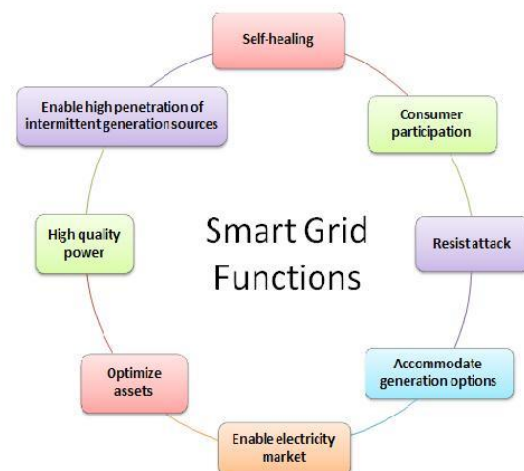
Over the last few decades, the average temperature of earth has risen by 0.74 degree Celsius, which has caused a variety of environmental problems, such as change in climate and rising sea levels etc. Furthermore, fossil fuel is being run-down because of a sharp increase in the consumption of energy due to the industrial revolution. The environmental experts expect that fossil fuel will run out completely in the near future [1]. Coal and gas power plants cause environmental concern. Carbon emission, greenhouse gas (GHG) emissions have forced us to aim at more aggressive goals of deep integration of large amount of renewable generation, especially wind and solar, to meet our electric energy needs [2][3][4]. We are fortunate to have about 300 days in a year of good solar energy in India.

An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations, high-voltage transmission lines and distribution lines that connect individual customers.

In traditional grid, power flow is from a few central generators to a large number of users or customers. The inability of generation to supply 100% demand causes load shedding. More clearing time during fault conditions, lack of provision for automatic fault healing, voltage sag, voltage swell and power theft are the important worries related with power quality and energy security. These problems of traditional grid can be minimized by updating the existing grid into smart grid.

Smart grid is a modernized electrical grid that uses information and communication technology to gather and act on information to improve the efficiency, reliability,

economics & sustainability of the production and distribution of electricity. The general functions of smart grid are illustrated in Fig. 1.



**Fig.1.** Functions of smart grid

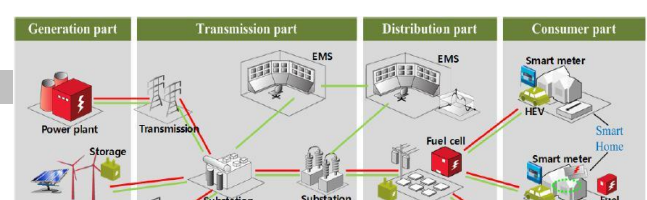
The objectives of smart grid are (i) two-way flow of electricity and information to create an automated and distributed advanced energy delivery network, (ii) peak load management, (iii) loss reduction, (iv) reduce supply shortfalls, (v) improve customer satisfaction, (vi) integration of renewable sources, and (vii) forecasting of generation and demand. In addition, flexible operation of distributed generation (DG) units is a major objective of future smart grid. The majority of DG units are interfaced to grid/load via power electronics converters. Current-controlled, voltage-

source inverters (VSIs) are commonly used for grid connections [5]. The integration of generation, transmission, distribution and consumer in a smart grid is shown in Fig. 2. Over last decade, the novel concept of smart grid has triggered interest amongst many researchers across the globe. Reference [2] presents different enabling technologies like distributed generation, Energy storage, power electronics, control-automation-monitoring, demand-side management (DSM), distribution automation & protection, and communication system, in order to make the smart grid a reality. In [5] the author has proposed a control scheme which utilizes a fixed power-voltage-current cascaded control structure with robust internal model voltage controller to maximize the disturbance rejection performance within the DG interface, and to minimize control function switching. This scheme enhances the flexibility of micro-grid operation under the dynamic nature of distribution systems. Integration of new-renewable energy system, dynamic pattern based intelligent services, and adaptive demand management to make the distribution more energy efficient and intelligent is presented in [1]. The practical results after real-time implementation has shown reduction in service response time and the power consumption are approximately 45.6% and 9-17% respectively. Investigation on how to minimize the electricity cost by jointly considering energy storage, local distributed generation such as photovoltaic (PV) modules or small wind turbines, and inelastic or elastic energy demands has been carried out in [3]. The authors have formulated this problem as a stochastic optimization problem and solved it by using the Lyapunov optimization approach. From the theoretical analysis, they have found a good tradeoff between the cost saving and storage capacity. A salient feature of their approach is that it can operate without any future knowledge of distribution and is easy to implement in real time. Chen, Wei and Shiyang Hu have proposed a stochastic energy consumption scheduling algorithm based on the time-varying pricing information released by utility companies ahead of time [6]. The proposed energy consumption scheduling scheme achieves up to 41% monetary expenses reduction when compared to the traditional scheduling scheme that models typical appliance operations in traditional home scenario. The result also demonstrate that when compared to a worst case design, the proposed design achieves up to 24% monetary expenses reduction without violating the target trip rate 0.5%. In [4], the authors have proposed a method that solves the voltage fluctuation problem in distribution networks with high penetration of PV systems by using customer-side energy storage systems. The distribution network operator (DNO) is allowed to control the output of the energy storage systems of customers during a specific time period in exchange for a subsidy covering a portion of the cooperative operation for both customer and DNO. This is elaborated by numerical simulations based on minute-by-minute solar irradiation data. Results have clarified the possibilities of making voltage management more economical in distribution networks. Qinran Hu and Fangxing Li have presented a hardware design of a smart home energy management system (SHEMS) with the

application of communication, sensing technology, and machine learning algorithm [7]. With the proposed design, consumers can achieve a RTP-responsive control strategy over residential loads including EWHs, HVAC units, EVs, dishwashers, washing machines, and dryers. Also, they may interact with suppliers or load serving entities (LSEs) to facilitate the management at the supplier side. Further, HEMS is designed with sensors to detect human activities and then apply machine learning algorithm to intelligently help consumers reduce total electricity payment without much involvement of consumers. In [8], the author has dealt with the development of a new class of sensors called the smart "Stick-on" sensors. These are low cost, self-powered, universal sensors that provide a flexible monitoring solution for grid assets. These sensors can be mass deployed due to low cost, need low maintenance as they are self-powered, and can be used for monitoring a variety of grid assets. This paper also presents the details on the network architecture, interoperability and integration and different design aspects of the stick-on sensor, such as novel energy harvesting techniques, power management, wide operating range, and reliability. It is envision that the smart stick-on sensor shall be an enabling technology for monitoring a variety of grid assets and prove to be an essential element of the smart grid. Aditya Mishra and David Irwin have explored an alternative approach that combines market-based electricity pricing model with on-site renewable and modest energy storage (in the form of batteries) to incentivize DG [9]. They propose a system architecture and optimization algorithm, called Green-charge, to efficiently manage the renewable energy and storage to reduce a building's electric bill. To determine when to charge and discharge the battery each day, the algorithm leverages prediction models for forecast both future energy demand and future energy harvesting. They show that Green Charge's saving for a typical home today are near 20%, which are greater than the savings from using only net metering. In [10], the author has focused on two exemplary battery storage systems, including the required power electronics. The grid integration, as well as the optimal usage of volatile energy reserves, is presented for a 5-kW PV system for home application, as well as for a 100-MW medium-voltage system, intended for wind farm usage. The efficiency and cost topologies are investigated as a key parameter for large-scale integration of renewable power at medium and low-voltage.

## 2. Features Of Smart Grid

Smart grid integrates the generation, transmission, distribution and utilization at consumer end in one-fold. The details are illustrated in Fig.2.



**Fig.2.** Integration of generation, transmission, distribution, and consumer in a smart grid

For proper functioning of smart grid, some requirements need to be fulfilled. They include forecasting of generation and demand, stability of grid parameters (frequency, voltage, current), generation and consumption of power at peak demand & off-peak demand be maintained same, higher scalability and security, and bandwidth must increase faster than the demand of intelligent element in the network [11]. In today's smart grid the second, third and fourth requirements have much scope of fulfillment and hence is attracting the attention of many researchers.

The Features of smart grid are multi-fold as follows:

**A. Reliability:** The smart grid uses different technologies that improve fault detection and allow self-healing of the network without the physical presence of technicians. This increases reliability of supplied electricity, and reduced vulnerability to natural disasters or attack.

**B. Flexibility in network topology:** Next-generation transmission and distribution infrastructure will be better able to handle possible bidirectional energy flows, allowing for distributed generation such as from photovoltaic panels on building roofs, but also the use of fuel cells, charging to/from the batteries of electric cars, wind turbines, pumped hydroelectric power, and other sources. Classic grids were designed for one-way flow of electricity, but if a local sub-network generates more power than it is consuming, the reverse flow can raise safety and reliability issues. A smart grid aims to manage these situations.

**C. Efficiency:** Valuable contributions to overall improvement of the efficiency of energy infrastructure is anticipated from the deployment of smart grid technology, in particular including demand-side management, for example turning off air conditioners during short-term spikes in electricity price. The overall effect is less redundancy in transmission and distribution lines, and greater utilization of generators, leading to lower power prices.

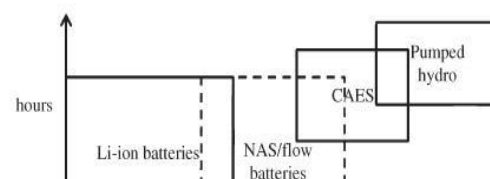
**D. Sustainability:** The improved flexibility of the smart grid permits greater penetration of highly variable renewable energy sources such as solar power and wind power, even without the addition of energy storage. Current network infrastructure is not built to allow for many distributed feed-in points, and typically even if some feed-in is allowed at the local (distribution) level; the transmission-level infrastructure cannot accommodate it. Rapid fluctuations in distributed generation, such as due to cloudy or gusty weather, present significant challenges to power engineers who need to ensure stable power levels through varying the output of the more

controllable generators such as gas turbines and hydroelectric generators. Smart grid technology is a necessary condition for very large amounts of renewable electricity on the grid for this reason.

**E. Market enabling:** The smart grid allows for systematic communication between suppliers (their energy price) and consumers (their willingness-to-pay), and permits both the suppliers and the consumers to be more flexible and sophisticated in their operational strategies. Only the critical loads will need to pay the peak energy prices, and consumers will be able to be more strategic in when they use energy. Generators with greater flexibility will be able to sell energy strategically for maximum profit, whereas inflexible generators such as base-load steam turbines and wind turbines will receive a varying tariff based on the level of demand and the status of the other generators currently operating. The overall effect is a signal that awards energy efficiency and energy consumption that is sensitive to the time-varying limitations of the supply. At the domestic level, appliances with a degree of energy storage or thermal mass (such as refrigerators, heat banks, and heat pumps) will be well placed to 'play' the market and seek to minimize energy cost by adapting demand to the lower-cost energy support periods. This is an extension of the dual-tariff energy pricing mentioned above.

### 3. Electrical storage systems

Electricity is highly perishable commodity that must be consumed within a very short span of production and cannot be easily stored, particularly in high quantities. Alternatively, it may be converted into other forms such as mechanical or electrochemical energy. Storage technologies enable these processes and are among the desired features for the smart grid. Multiple existing technologies are compared in Fig.3. Storage, which can be distributed in the grid, provides the following advantages: 1) make the grid more efficient; 2) enables load leveling and peak shaving, while it reduces dependence on spinning reserve; 3) improves grid reliability and power quality; 4) provides ancillary services, supplying reactive power for voltage regulation; 5) supports transmission and distribution investment deferral. Energy storage with power electronics interfaced units can create virtual rotational inertia, the so called virtual synchronous generators, which can reduce the rate of change of frequency and frequency deviations.



**Fig.3.** Comparison of discharge duration versus rated power for some grid energy storage technologies

#### 4. Challenges in smart grid

The current smart grid technology faces some challenges which needs to be addressed. They are listed below.

- 1) There is always some difference in the generation and demand. During off-peak hours generation is more and demand is less whereas during peak hours generation is less and demand is more this leads to load shedding. This necessitates the use of energy storage devices so that the electricity stored during off-peak hours could be used during peak-hours.
- 2) Transmission of power is the biggest challenge in the smart grid. While transmitting generated power, sending end and receiving end parameters (voltage, current, and frequency) should be same. In other words power grid should be stiff.
- 3) Energy security (power theft) is top most priority in the smart grid. Based on the evolution of power system communication infrastructure and the concern of cyber security, many new issues have arisen in the context of smart grid like information security, SCADA security issues [11].
- 4) Forecasting of generation of power and demand, to avoid load shedding.
- 5) Technical challenges: The electrical network is combination of a large number of very distributed nodes that are tightly coupled and operating in real time. Since all the parts of this network have organically grown over many years, even decades, figuring out where intelligence needs to be added is very difficult.[12]
- 6) Standards and interoperability: The biggest challenge is to integrate interchangeable parts from a variety of different providers worldwide. There is a huge need for interoperability standards that will allow utilities to buy pieces of equipment from any vendor knowing that they will work with each other and with existing equipment at every level. We are not simply talking about interfaces one plug fitting with another. We need interoperation at all levels in a given system.
- 7) Lack of awareness: Mature standards and best practices are available and can be readily applied to facilitate Smart Grid deployment. The main problem

with adoption seems to be a lack of awareness of those standards by people involved in designing Smart Grid systems at a high level and a lack of best practices and regulatory guidelines for applying them.

#### 5. Current Scenario In United States & Europe

The U.S. smart grid takes initiative in the official policy of grid modernization in the U.S. as formalized by the 2007 Energy Independence and Security Act (EISA07). Under this act, the U.S. smart grid is characterized by the following [2]:

- a) increased digital information and controls;
- b) dynamic optimization of grid operations, including cyber security;
- c) deployment of distributed resources, including renewable resources;
- d) incorporation of demand-side resources and demand response;
- e) deployment of “smart” technologies and integration of “smart” appliances and consumer devices;
- f) deployment of storage and peak-shaving technology, including plug-in hybrid electric vehicle(PHEV);
- g) provision of timely information and control options to consumers;
- h) standard development for communication and inter- operability of equipment;
- i) identification and lowering of unreasonable barriers to adopt smart grid technology, practices, and services.

The U.S. National Institute of Standards and Technology (NIST) provides a conceptual model that defines seven important domains: bulk generation, transmission, distribution, customers, service providers, operations, and markets.

The European energy policy relies on security of supply, sustainability, and market efficiency. In addition, six goals have been set for the EU energy strategy: 1) to achieve the highest levels of safety and security; 2) to achieve an energy-efficient Europe by improving buildings, transportation, and distribution grids; 3) to extend Europe’s leadership in energy technology and innovation; 4) to empower consumers; 5) to build a European integrated energy market; and 6) to strengthen the external dimension of EU energy market.

#### 6. Current scenario in India

Over the last few decades, Indian Power Sector has made rapid changes in the field of generation, transmission, distribution and utilization of electricity. The installed generating capacity in India was 1362 MW in 1947, which serves power requirements of urban and remote areas with electrification of around 1500 Villages. The power generating capacity in the country has increased to 173626 MW at the end of March 2011. The Rajiv Gandhi Grameen Vidyutikaran Yojana aimed at providing access to electricity to all the villages in a time bound manner is under implementation. The

programmers have to been introduced to improve the energy conservation and reduction in the AT & C losses [13]. Hon'ble Power Minister Sh. Jyotiraditya Scindia released Smart Grid Vision and Roadmap for India at the Power Minister's conference in Sept 2013. The roadmap drafted by the India Smart Grid Task Force (ISGTF) and India Smart Grid Forum (ISGF) is in alignment with Ministry of Power's overarching policy objectives of "access, availability and affordability of power for all". The smart grid vision of India is:

- 1) End of Load Sharing- peak load shifting through a combination of direct control and differential pricing;
- 2) Reliable Power- Robust systems with Self-healing capabilities through monitoring;
- 3) Cheaper Power- Dramatic improvement in AT&C losses, real time monitoring load sources;
- 4) Shifting the Peak away from Costly Power- Better utilization of Assets;
- 5) More Sustainable Power- Integration of green and renewable resources at a massive scale, enough to increase energy independence;

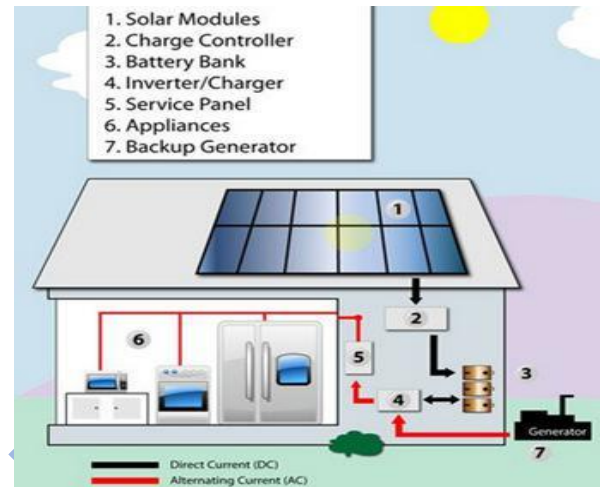
The all India installed power generation capacity as on 30.11.2012 was 2, 10,936.72 MW out of which 1, 40,976.18 MW Thermal, 39,324.40 MW Hydro, 4,780.00 MW Nuclear and 25,856.14 MW R.E.S. In India, in National Thermal Power Corporation (NTPC), Renewable Energy (RE) is being perceived as an alternative source of energy and is planning for "Energy Security" and "Energy Independence" by 2020. Renewable energy technologies provide not only electricity but offer an environmentally clean and low noise source of power. NTPC plans alternate sources of energy to ensure long term competitiveness and mitigate fuel risks. NTPC 89 has taken various initiatives to implement the Renewable Energy Projects. The brief status of these initiatives is as given below:

- 1) Solar projects (Photo Voltaic (PV) and Thermal)
  - Under Execution: 10 MW (PV)
  - Under Tendering: 100 MW (PV)
  - Feasibility Report(FR) stage : 350 MW ( PV & Thermal)
- 2) wind Power Projects
  - Under Tendering : 80 MW
  - MOU signed
    - a. With Govt. of Karnataka : 500 MW
    - b. With Govt. of Kerala : 200 MW
    - c. With Govt. of Gujarat : 500 MW

## 7. Smart Home

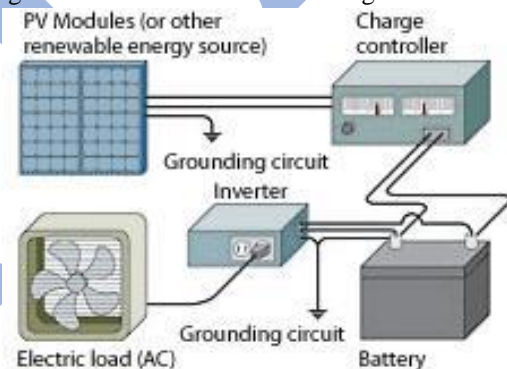
Fig. 4 shows a smart house where solar energy is stored in battery and then used to run the home appliances and also for charging electric vehicle, the system can be operated either in stand-alone mode or grid-connected mode, to condition the electricity, safely transmit the electricity to the load that will use it, and/or store the electricity for future use [20]. With stand-alone systems (those not connected to the electric grid) the required equipments depends on what we want our system to do. In the simplest systems, the current generated by

system is connected directly to the equipment that it is powering (load).



**Fig.4.** Smart House (PV panel Connected to home appliances)

However, if we want to store power for use when system isn't producing electricity, we need to purchase batteries and a charge controller. This is shown in Fig. 5.



**Fig.5.** Stand-alone system

Depending on the need, balance-of-system equipment for a stand-alone system could account for half of total system costs. But typical balance-of-system equipment for a stand-alone system includes batteries, charge controller, power conditioning equipment, safety equipment, and meters and instrumentation. A grid-connected system is that connected to the electric grid, requires balance-of-system equipment that allows to safely transmit electricity to loads and to comply with power provider's grid-connection requirements. For grid connected systems need power conditioning equipment, safety equipment, and meters and instrumentation.

**A. Batteries for stand-alone systems:** The batteries in stand-alone systems used for store electricity during the time when system is not producing electricity (the resource is not available). Batteries are most effective in case of wind and photovoltaic systems. The "deep-cycle" (generally lead-acid) batteries typically used for small systems last 5 to 10 years and reclaim about 80% of the energy channeled into them. In addition, these batteries are designed to provide electricity

over long periods, and can repeatedly charge and discharge up to 80% of their capacity. Automotive batteries, which are shallow-cycle damage if they discharge more than 20% of their capacity, should not be used. The cost of deep-cycle batteries depends on the type, capacity, and climate conditions under which they will operate, frequency of maintenance, and chemicals used to store and release electricity. Wind or photovoltaic stand-alone system batteries need to be sized to store power sufficient to meet our needs during anticipated periods of cloudy weather or low wind.

For safety purpose, batteries should be located in a space that is well ventilated and isolated from living areas and electronics, as they contain dangerous chemicals and emit hydrogen and oxygen gas while being charged. In addition, the space should provide protection from temperature extremes. The location of batteries should have easy access for maintenance, repair, and replacement. Batteries can be recycled when they wear out.

**B. Charge controllers for stand-alone systems:** For stand-alone systems charge controller plays very important role of controlling the rate of flow of electricity from the generation source to the battery and the load. The controller keeps the battery fully charged without over-charging it. When the load is drawing power, it allows the charge to flow from the generation source into the battery, the load, or both. When the controller senses that the battery is fully (or nearly fully) charged, it stops (reduces) the flow of electricity from the generation source, or diverts it to an auxiliary or "shunt" load (most commonly an electric water heater). Many controllers will also sense when loads have taken too much energy from batteries and will stop the flow until sufficient charge is restored to the batteries. This last feature can greatly extend the battery's lifetime. The cost of controllers mostly depends on the current (ampere) capacity at which the renewable system will operate and the monitoring features we want.

**C. Power conditioning equipment:** The power conditioning equipment is required for both stand-alone and grid-connected systems. Most electrical appliances and equipment in India and other countries run on alternating current (AC) electricity. Virtually all the available renewable energy technologies, with the exception of some solar electric units, produce direct current (DC) electricity. To run standard AC appliances, the DC electricity must first be converted to AC using inverters and related power conditioning equipment. There are four basic elements to power conditioning: 1) Conversion of constant DC power to oscillating AC power. 2) Frequency of the AC cycles should be 50 cycles per second. 3) Voltage consistency i.e. extent to which the output voltage fluctuates, 4) Quality of the AC sine curve i.e. whether the shape of the AC wave is jagged or smooth.

Simple electric devices, such as hair dryers and light bulbs, can run on fairly low-quality electricity. A consistent voltage and smooth sine curve are more important for sensitive electronic equipments, such as computers, that cannot tolerate much power distortion. In case of grid-connected system, the power conditioning equipment that can match the voltage, phase, frequency, and sine wave profile of the

electricity produced by home system to that flowing through the grid is required.

**D. Safety equipment:** Safety equipments protect stand-alone and grid-connected small renewable energy systems from being damaged or harming people during events like lightening events, power surges, or malfunctioning equipment.

**E. Meters and instrumentation:** Meters and other instruments allow monitoring small renewable energy system's battery voltage, the amount of power consuming, and the level at which batteries are charged.

## 8. Conclusion

In this paper, the need, motivation and current research outputs for smart grid as given in literature are presented. The difference between traditional grid and smart grid, objectives, functions, features and challenges of smart grid are discussed. This paper has also given an overview of smart grid technologies and progresses in Europe, U.S. and India. The concept of smart home is discussed in detail for both, stand alone system and grid connected system.

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