
# Handbook of Sustainable Development through Green Engineering and Technology

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## A Taxonomy on Smart Grid Technology

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# 6 A Taxonomy on Smart Grid Technology

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## 6.1 INTRODUCTION

The conventional system had evolved when energy was low cost to satisfy the need of the world's electric power transmission. The distribution system in earlier times was the centralized, unidirectional, and demand-driven control system. To meet the increasing demand for electricity consumption, more power stations came into existence. This scenario of generation, distribution, and transmission is shown in Figure 6.1 (Farhangi, 2009).

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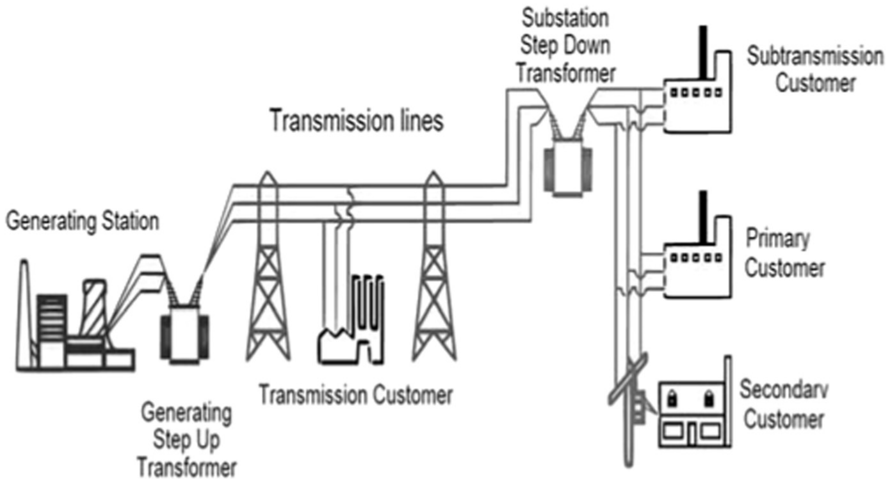


**FIGURE 6.1** The conventional electricity grid system.

Over time, local grids expanded and had become interrelated. The load centers receive the power from vital power-generating stations via high-capacity transmission lines, which is further divided to meet the power requirements over the entire supply area. The user had to pay bills according to the single tariff because of the system's limited data collection and processing capabilities. The lower night demand motivated for dual-tariff arrangements means using low-cost power at night. However, having extensive load during the daytime means that the supply of electricity gets interrupted in some areas, resulting in power cuts and even blackouts. To handle this situation, electricity demand patterns were recognized. The daily domestic demand peaks were controlled by an arrangement of high-power generators that were switched on for a short span per day. However, their low utilization could not meet their initial cost of integration, resulting in high costs to the electricity companies and high electric bills for consumers.

Highly polluting power stations were situated possibly far away from populated areas, but they were located near fossil fuel reserves. The structure of the emerging grid was influenced by hydroelectric dams in mountain areas and nuclear power plants. The conventional grid has upgraded to meet up with the expanding energy demand and to overcome the limitations. The lousy impact of fossils on the environment has motivated the use of renewable energy instead. Because of the variable nature of wind and solar power, more refined control systems are needed to assist the connectivity of renewable sources to the grid. The conventional grids were considered soft targets for potential attacks. The need for a robust power grid was felt in some countries for this concern (Fang et al., 2011).

Smart grid (SG) evolution has taken place because it is a key that integrates a vast collection of IT resources that allow the primitive and smart grids to lower electric wastage and cost. Smart grid technology has been implemented in many developed countries, and still, many are moving slower to accept and implement this technology (Gungor et al., 2011).

The chapter highlights the emergence of the smart grid as a call to update the existing grid. Multiple research papers have been studied to extract accurate knowledge of the basics of the smart grid. Several of the various components of smart grid technologies and the application and the role of different tools in implementing the smart grid, its functions, needs, characteristics, and opportunities in this domain have also been highlighted.

## 6.2 SMART GRID

A smart grid is a network or an electrical grid that integrates the performance and operation of smart devices and energy-efficient resources, especially renewable sources, in a cost-effective way. A smart grid is capable of controlling the generation and distribution of electronic power. High standards and supply with security and safety of power with low losses are key smart grid features. The schematic representation of the smart grid is shown in Figure 6.2 (Gungor et al., 2011).

### 6.2.1 Characteristics of Smart Grid

The smart grid is the evolution of the primitive energy system to a new period of a reliable and more efficient system. The characteristics of the smart grid have to be

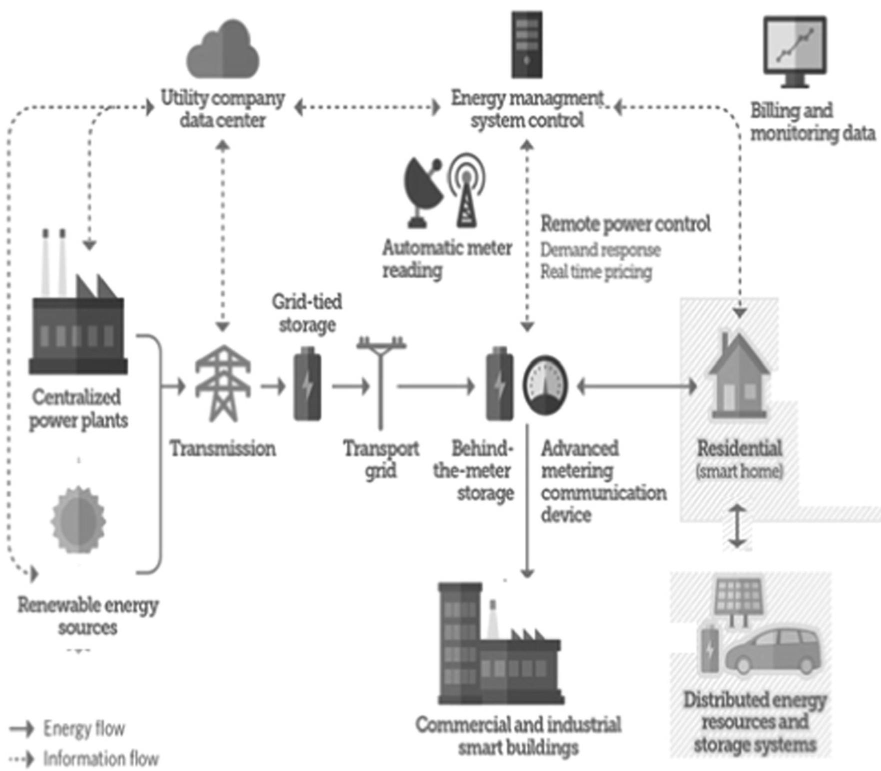


**FIGURE 6.2** Conceptual view of smart grid.

defined for proper communication between the projects. Accordingly, the smart grid is designed for the generation of cleaner energy and is characterized by the following parameters:

**Consumer Participation:** Consumers are the key to any power system because they help maintain a balance between power generation and consumption. Their behavior to modify the usage of electricity may increase system reliability. The choices include the implemented technology and new tariffs.

**Distributed Generation:** Assimilation of various renewable-energy resources ultimately into the grid. A smart grid integrates large, centralized power plants and the distributed-energy generating sources, which rapidly increases the value chain from suppliers to customers via marketers.

**Power System Efficiency:** An efficient power system is attained by working with smart technologies that use its resources to the fullest. When the assets are used dynamically at higher loads by incessantly sensing and ranking the capacities, the maintenance effectiveness can be enhanced.

**Prediction of Disturbances:** The smart grid smartly isolates the challenging elements and the normal working of the remaining system to attain resiliency. The self-healing characteristic of the smart grid facilitates the provider to manage the delivery infrastructure in a better way, thereby providing the consumer with disruption-free service.

**New Products and Services:** Smart grid enables the markets for the consumers where they can select from the competing services. Markets play an important role in managing the variables like location, time, capacity, changing rate, and quality of power. The markets should be flexible enough to alter businesses' rules and operating conditions to attract regulators and consumers.

**Power Quality for Various Requirements:** The power requirement is different for different consumers. SG enables the consumer to use varying power as per their needs. The cost of multiple grades of power is also different and allows the consumer to select the use and pay option. The automatic monitoring components are deployed to diagnose and solve power consumption and issues that affect the quality of power for natural or artificial disasters (Cecilia & Sudarsanan, 2016; Edris & D'Andrade, 2017).

### 6.2.2 Components of Smart Grid

A smart grid includes subsystems with layers of technology together with intelligent monitoring, innovations, and new tools. It involves the production, distribution of sustainable power. An essential component of the smart grid are as follows:

**Smart Device Interface:** Smart devices are the ones that connect with other independently operating devices via various wireless methods. Smart cars, doorbells, meters, phones, etc., are capable of monitoring and controlling real-time information processes.

**Storage Component:** The disparity between energy consumption and availability leads to finding energy storage methods for future use to improve reliability and grid resiliency.

**Transmission System:** The adaptive transmission lines provide the interconnection between the primary substations and the load centers. Their adaptive nature allows them to tolerate eventual and vibrant changes in the load without interrupting the service, making them the backbone of the integrated power system. Being efficient, reliable, and cost-effective is the main aim of the transmission subsystem.

**Monitoring and Control Technology:** The smart monitoring devices are attack-resistant, capable of self-healing, predictable, adaptable, and can smartly handle reliability issues and instability issues to avoid congestion. These devices are self-aware and can take independent decisions according to real-time changes.

**Demand-Side Management:** These components are deployed for reliable generation and distribution of power and to reduce greenhouse gas emissions. Such components reduce the use of expensive generators, thereby lowering the operation cost as demanded by the consumer.

**Intelligent Grid Distribution Subsystem:** Distribution of power to the consumers is the final step of the grid network, which is accomplished by distribution feeders that deliver power to residential areas, small industry and business areas. The distribution subsystem should be capable of monitoring and utilizing the communication links between utility control and consumers. Furthermore, they must detect the faults and restore, optimize the voltage, transfer the load, and produce the automatic bills in real-time (Ghosal & Conti, 2019; Kabalci & Kabalci, 2019).

### 6.2.3 Functions of Smart Grid

The integration of innovative products and services with intellectual monitoring, managing, communication, and self-healing properties make the smart grid able to:

- Connect the generators of various sizes operating on different technologies.
- Allow the consumers to participate in optimizing the working of the system.
- Make the consumers aware of various use and pay policies.
- Relax the consumers by lowering the electricity prices paid by them, which made the technology highly affordable.
- Employ renewable DERs leading to the reduction in emission of CO2 and other harmful gases and carbon particles that reduce the pressure on the environment, thereby providing cleaner power.
- Maintain and improve the reliability and security of the system together with upgrading the existing services, which in turn reduces the occurrence of natural and artificial attacks.
- Lower the power quality disturbances and probability of blackouts that improve the reliability of the grid.
- Reduce the injuries and loss of life, thereby enhancing safety concerns.
- Revolutionize the transport sector by the deployment of electric vehicles for generation and storing purposes.
- Improve efficiency by reducing electricity losses and energy wastage (Bayindir et al., 2016; Gonzalez-Longatt & Torres, 2018).

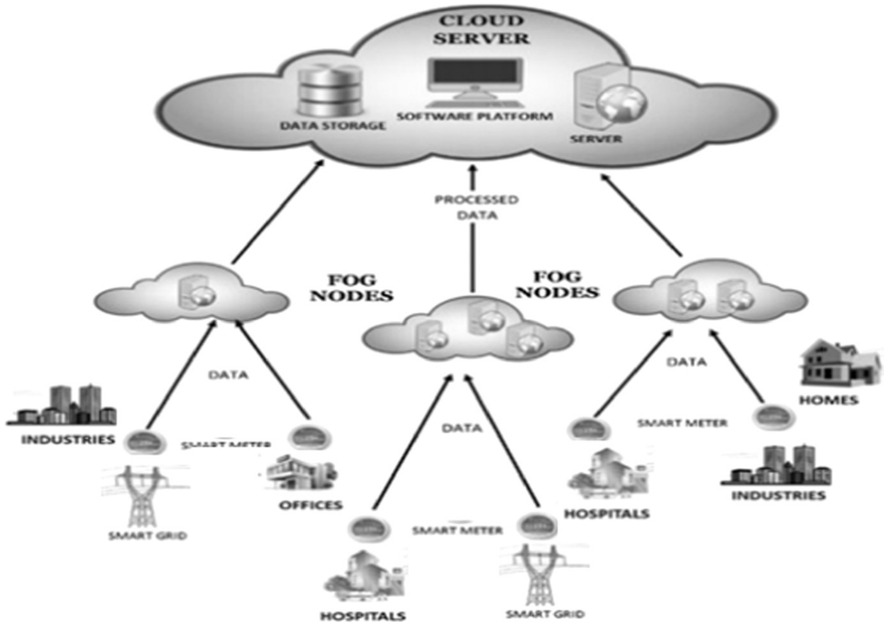


**FIGURE 6.3** Usage of different technology in smart grid.

## 6.3 ROLE OF TECHNOLOGY IN SMART GRID

Many technologies are used in the realization of the smart grid concept. Figure 6.3 shows the usage of other technologies in the implementation of the smart grid concept. Some of them are listed below with their role:

**Integrated Communications:** Such communications will permit real-time management, exchange of information, resource utilization, and theft prevention to make the system more consistent.

**Sensing and Measurement:** They sense the stability of the grid by monitoring congestion, the health of the equipment by making use of various technologies like smart meters, large-area monitoring systems, EM signature analysis, real-time measurement and pricing tools, RF technology, sophisticated switches, cables, and defensive relays.

**Smart Sensor:** Smart sensor integrates sensors and the processing elements on a single chip that can record, process, compute, and communicate the analog signal and the digital representation of derived signals via a bidirectional digital bus. The smart sensors are required to be integrated with the system to support smart grid monitoring applications so that they can integrate and support the distributed sensor system, and monitor the main substation and line equipment.

**Sensor and Actuator Networks (SANET):** SANET in smart grid are used for managing and optimizing the flow of energy by using the flow of information. SANETs to work effectively require the sensing of parameters, device control, and decision-making powers. The information flow is used to transmit the sensed data to controllers for decision making, where the controller issues control commands to the actuators and execute the task accordingly.

**Smart Meters:** The meters that can record the readings and can communicate are termed a smart meter. The meter can be operated remotely from a distant location to read and measure energy consumption units, and the same is safely displayed on a device. It is also capable of two-way communication and can receive information regarding payment modes or tariff updates. Smart meters help lower the cost and consumption of energy units by making the consumers aware of the same. It also sends data to calculate the peak-load demands, take necessary measures to control the load, and form pricing policies based on consumption data. Smart meters are deployed for measuring gas, water, or electricity consumption. Smart meters inform the consumers about the best pricing strategies, and more accurate bills will be generated.

**Distributed Power Flow Control:** For controlling the power flow in the existing transmission lines, the control devices fasten on them. Such transmission lines sustain the use of renewable sources by facilitating the real-time control of power flow in the grid, thereby enabling the grid for efficient storage of irregular renewable energy for future use.

**Smart Power Generation Using Advanced Components:** Load balancing refers to the concept of a match between supply and demand of power generation. Any mismatch would result in frequency variations causing blackouts. The load balancing has become a challenging task as more variable generators are incorporated into the grid, compelling other producers to adjust their output more often than in the past. In smart power generation, balancing is achieved by using numerous similar generators that can operate automatically and efficiently at the chosen load.

**Power System Automation:** The automation system provides diagnosis and solutions to explicit grid interruptions. The technologies that rely on and contribute to each other for highly developed control methods are distributed intelligent agents, analytical tools, operational applications, and artificial intelligence.

**Vehicle to Grid (V2G):** V2G utilizes electricity-driven vehicles to supply power to specific electric markets. The prime advantage of this technology is that it can store renewable energy. It also sustains the generation of large-scale wind energy via direction. To store power in a vehicle's fuel cells, a battery or hybrid of both is used.

**Plug-in Hybrid Electric Vehicle (PHEV):** PHEV is a hybrid electric vehicle with a larger pack of batteries charged by a plug during off hours. The vehicle uses electric power if the battery is fully charged; otherwise, it uses the alternative petroleum-based source. PHEV helps cut down the emissions of gases because of its ability to use hybrid sources of energy. PHEV is equipped with a device to establish a connection with an external electrical source for charging. These vehicles are beneficial in emergencies when fuel prices spike or supplies decline, as they then use the stored energy preserved by the utilities during off-peak hours.

**Automated Meter Reading (AMR):** AMR devices in smart grid perform communication in full-duplex mode and let the utilities read meters from distant locations. Their home display allows the consumer to either lower their consumption or reschedules it in off-peak hours to reduce the bills. AMR collects the data of consumer's energy consumption from electric meters or smart meters and processes it for bill generation (Ma et al., 2016; Tuballa & Abundo, 2016).

## 6.4 APPLICATIONS OF SMART GRID

The new technology permits the efficient use of smart devices and detects and isolates the faulty devices for the smooth functioning of the rest of the system. Applications of smart grid in various areas are described below:

**Automation of Building & Home:** A smart home is an automated home in which the energy sources and equipment are controlled and coordinated using smart controllers and meters to fulfill the objectives of the smart grid.

**Smart Substation:** The workstations and the protection devices, and the small transducers carry out communication with fiber optical networks that have emerged with digital technology advancements. The communication process in the substation system takes place in three stages:

i. Operations and reporting takes place at the station level
ii. Bay level deals with the control and protection functions of the system
iii. Third process level deals with signal transmission from VTs, CTs, and other transducers.

**Feeder Automation (FA):** Distantly control and monitor the distribution of power is the critical aspect of the feeder automation system. It also facilitates consumers to collect and provide the data efficiently. It manages the voltage and reactive power for automatic switching in transmission lines, monitoring the health equipment. It uses switches and digital sensors, which are equipped with communication and control technologies. FA products can be easily induced in the existing grid as they are interoperable and designed to reduce the functioning costs, thereby satisfying the consumers (Dileep, 2020).

## 6.5 ADVANTAGES, OPPORTUNITIES, AND CHALLENGES IN SMART GRID

### 6.5.1 Benefits of Smart Grid

**Self-Healing:** The smart grid detects and responds to usual issues and quickly recovers from any short fault in transmission lines or other components, thereby reducing downtime and economic losses.

**Inspire and Invite the Consumers by Cost Reduction:** Visibility into synchronized pricing allows consumers to select the level of consumption and pricing option according to their needs.

**Distributes High-Quality Power to Compete with the Needs of the New Era:** The smart grid provides quality power free from any turbulence and interruptions.

**Boost Up Assets and Efficient Operation:** Enable cost reduction by transmitting power through existing infrastructure to operate and maintain the grid efficiently.

**Grid Resiliency:** Enhance grid reliability and shrink the occurrence of power blackouts.

**The Decline of Peak Demand:** Share and reduce the load on a large scale by integrating it with renewable energy resources.

It facilitates the smart devices to charge during low load hours to reduce the bills. It also assimilates imperishable resources like solar and winds energy entirely into the grid (Taha, 2020).

### 6.5.2 Opportunities in Smart Grid

Smart Grid Technologies Help in:

- Enlarge and advance the infrastructure to improve connectivity and communications among multiple parties.
- Assemble smart tools to utilize DR, power efficiency demand load control.
- Educate consumers through training sessions.
- Promote the investments in the smart grid, and create regulatory framework models.
- Ensure the cybersecurity and grid resilience infrastructure must be built up (Yoldaş et al., 2017).

### 6.5.3 Critical Challenges in Smart Grid

**Strengthening the Grid:** The utility grid must be capable enough to have room for additional energy resources, especially renewable resources.

**Offshore Movement:** To reduce pollution and utilize offshore energies' random behavior (tidal and wave), effective and efficient connections should be developed. Development of a decentralized structure to promote the smooth functioning of small power generating systems with the larger systems.

**Communications:** Development of a strong structure for communication to allow millions of parties to operate and trade in a single market.

**Involvement of Consumers:** Enabling the consumers to play a dynamic role in the system's operation to be aware of all new tariffs with or without their generation.

**Stability Factors:** Assimilation of distributed generation from renewable sources and micro-grids on a massive scale.

**Preparing for Electric Vehicles:** Electric vehicles are pretty prominent because of their mobility and dispersive characteristic that will help them to deploy in bulk in the coming years.

**Inadequacies in Grid Infrastructure:** The grid network should provide clean and distributed power generation, which may pose several challenges in terms of architecture design, formation, operation, and maintenance.

**Cybersecurity:** The development of an advanced tool for handling the growing cyber threats is a significant issue for smooth functioning.

**Storage:** Proper storage of renewable and power generation from renewable sources must be ensured.

**Data Management:** Voluminous data from smart devices like sensors, controllers, cameras, meters, and from sources like weather forecast systems has to be appropriately managed to avoid breakdown or damage before occurrence.

**Stakeholder's Engagement and Capital Investment:** Awareness programs should be carried out for organizations and individuals; to make them know the smart grid benefits and utilities to induce the faith of stakeholders in the smart grid.

**Trained Workforce:** The success of a smart grid depends upon the empowered human resource of various sectors that may be prepared through suitable training sessions (Piricz, 2020; Rathor & Saxena, 2020).

## 6.6 CONCLUSION

Limitations of the conventional grid, increasing & fluctuating power demand, the need for a more transparent & robust system, more pollution due to usage of fossil fuels, and high cost & less availability of fossil fuels are some of the motivating factors behind the emergence of the smart grid system. The emergence of high-speed internet technology, sensor technology, machine learning, big data, and cloud computing has helped realize this concept. Its integration with renewable energy resources will help to prevent climate change conditions. Many developed and developing countries are adopting a smart grid system. An initial investment in the upgrade of the conventional grid and security of user data are critical challenges in the widespread adaption of the smart grid system. Using renewable energy resources available at the diversified location may reduce the upgrade cost. Also, installing different cybersecurity and big data tools will help manage consumer and grid information more securely. In the future, the authors have planned to work for the usage of machine learning in the estimation of the consumer demand and assessment of power generation from renewable energy resources.

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