Smart Grids（SG）

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Smart grid (SG), an evolving concept in the modern power infrastructure, enables the two-way flow of electricity and data between the peers within the electricity system networks (ESN) and its clusters. The self-healing capabilities of SG allow the peers to become active partakers in ESN. In general, the SG is intended to replace the fossil fuel-rich conventional grid with the distributed energy resources (DER) and pools numerous existing and emerging know-hows like information and digital communications technologies together to manage countless operations.

smart microgrids | modern power system | power infrastructure | distributed energy resources | machine learning | deep learning | Internet of Things | blockchain | electricity system networks | peer to peer network | renewable energy resources | electric vehicle as DER | cyberse

1. Overview of a Smart Grid

Today, there is no generally acceptable SG definition. Its description and definition are not unique. It is still evolving, developing, and the concept is becoming more and more mature with time. The SG combines DER-based micro, mini, and nano-grids and supply systems control with a fine branch [1]. SG incorporates technology, structures, and protocols to make the ESN more intelligent and efficient. It is merely a radical modification of the existing ESN. In general, the SG is intended to substitute the fossil fuel-rich CEG with the DER and pools numerous existing and emerging know-hows like information and digital communications technologies together to manage countless operations [2]. The SG features such as computational ability, controllability, self-diagnosis, and healing pave the way for broader incorporation of RER, more active consumer and prosumer participation, the implementation of energy efficiency initiatives, and the consequent possible reduction of greenhouse gas (GHG) emissions. The SG enables the two-way flow of electricity and data between the ESN peers and its clusters. SG's self-healing capabilities allow the peers to become active partakers in ESN [3]. With this, the SG will be able to "detect, react, and pro-act" to disparities in usage and manifold issues and enhances the reliability, availability, resilience, stability, security, and, at the same time, ensures grid operations sustainably and affordably [4][5].

2. Role of Smart Grid in the Existing Power System and Its Implementation Barriers

As mentioned earlier in Section 1.1, SG is an intelligent digital electric grid with a pool of technologies and services. Depending upon the load type served and ESN type (e.g., residential, commercial, and industrial), the technologies and services used in SG vary, and they are clearly shown in Figure 1.

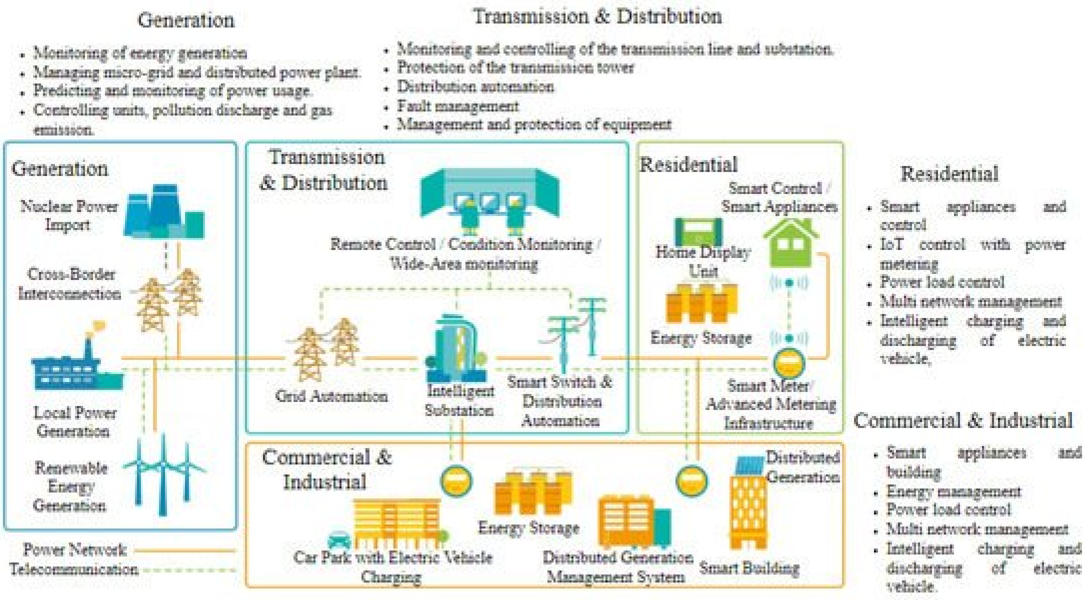

Figure 1. Smart grid services conceptual representation highlights renewable energy resources, energy storage systems, power electronics, information and communication technologies, energy management platforms, and cyber technologies.

From Figure 1, it can be understood that SG facilitates the consumers and prosumers to have increased choices in terms of controlling their electricity use and production. The SG also helps prosumers respond to electricity prices based on the changes in consumption and generation patterns. Not only the residential, commercial, and industrial loads, SG also facilitates connection and integrated operation with electric vehicle (EV) charging systems. In brief, “SG brings all elements of the electricity system production, delivery, and consumption closer together to improve overall system operation for the benefit of consumers and the environment.” Overall, the SG enhances ESN operation and control in the three significant domains (generation, transmission, and distributions) [6].

The existing SG framework is combined with multiple design scenarios and varies based on the operational area or the deployed application. Few of those operations and applications include energy-dependent operations in smart cities, energy-related home operations computerization, and energy conservation schemes by considering metering and tracking processes [7]. SG technologies and concepts will significantly reduce RER barriers and allow power grids to support a more significant percentage of variable and intermittent supplies from RER [8]. SG is crucial for the efficient use of DER and provides management of demand and supply of electricity from RE technologies and ESS by both users and suppliers of electricity.

One of SG’s crucial aims is to encourage peer’s active participation with automated transactions [7][9]. For building an automated distributed energy distribution network, data and data-driven decisions are needed. SG provides such data-driven decisions as they provide a two-way flow of electricity and the associated data. The SG's smartness will allow for the time-shifting of electricity demand as influenced by RE's intermittent nature and incorporation of ESS [10][11].

Overall, using SG, the CEG services will be replaced with high-level automation services, control techniques, sensors, computer servers for energy transaction record-keeping, power asset management platform, and many other new and emerging technologies, and all these are expected to operate collectively, thereby enhancing the power grid operations [9]. SG's components will respond intelligently and digitally on time to the grid conditions based on energy demand, supply, and fault occurrences on the system working hand-in-hand to produce, deliver, and utilize energy most efficiently and reliably. With this, SG can automatically locate the fault, isolate it, and even restore services once the fault is cleared and record its activities on the grid performance data. This helps the grid reduce the number, impact, and duration of outages and interruptions [12].

Overall, the SG offers many benefits to the CEG. Here, the benefits associated with the renewable-based SG are summarized as follows.

- It enables a broader range of RER, DER, and ESS technologies that allow higher RE deployment with cost-effectiveness while increasing reliability and quality of power.
- Rapid response to ESS, such as flywheels, can address intermittency problems, enhancing the grid's overall reliability and power.
- Exchanges of real-time information make for a more flexible grid, achieving almost complete forecasting.
- Greater visibility enhances strategies for the price of forecasting.
- Assimilating clients into the power network as active players; energy savings made by reducing the peak demands and increasing energy quality and lowered GHG emissions.
- Regulation of voltage and subsequent load allows operating costs to be minimized based on the marginal output cost.

Even though SG offers many benefits, its implementation is also a challenging one. The challenges mainly lie with technology use. In addition to the technology, for the successful implementation of SG, each country needs to develop and articulate its SG vision, strategies, and means of achieving it. This helps to motivate fervor and resources (both technical and capital) toward modernizing the existing electric grid infrastructure.

Digital energy vision and its full understanding are fundamental for a smooth transition from conventional to SG systems and deploying existing and emerging technologies. Change to SG can be gradual and piecemeal until its full implementation is realized. It can start from the existing grid by introducing each of the SG technologies one at a time. It can also begin with a small pilot project as a nano grid, mini-grid, or microgrid in a remote geographical location and gradually be improved and extended. There are already numbers of such SG pilot projects worldwide in the USA, South Korea, Austria, and Canada. Furthermore, most countries in the advanced world are already gradually upgrading their existing grid to SG.

The obstacle to implementing SG reflects the preposition of interest by the provider and the consumer, accompanied by regulatory restrictions and technical norms obstructing SG solutions [13]. On the other side, issues associated with information flow, communication between the peers, and ESN resources management must be addressed. The question is, who will be managing these, the human workforce, or the digitalization? What would be an efficient way?

Furthermore, the questions related to ensuring reliability, resilience, and security should be considered while designing SG. Additionally, ensuring the computational and energy efficiency of the SG operations as it undergoes digitalization becomes critical. For handling such digital operations, computational tools are suggested. Possibly, fast computing methodologies have become one of the most vital tools in determining an SG service’s success in the market. There exist numerous computational and digital tools, which include artificial intelligence (AI) [14][15], Internet-of-Things (IoT) [16][17][18], Big Data analytics [19][20][21], machine learning [22][23], deep learning [24][25][26], cloud computing [27][28][29], and Blockchain (BC) [30][31][32]. These technologies have been intelligently applied with various applications in networking, manufacturing, building management, transportation, and shipping to construct energy-efficient and sustainable systems. We believe such technologies can be leveraged in the energy sector, especially in the SG operations.

In the literature, few studies were carried out by the researchers, and they showed the roles of these technologies in ESN operations [14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][31][32]. On the other side, these promising technologies have gone through fast technological evolution in the past decade, and their applications have increased rapidly in ESN. Furthermore, new technologies are emerging, which enable data-driven decisions. Hence, this study discusses the SG and applications of AI, the IoT, and BC.

2. Distributed Energy Resources in Smart Grids

The DER-based power system is a small to medium-scale decentralized power generation system that uses RER, and mostly these DER are located close to the load centers. DER provides an alternative or enhancement to the conventional power grid and can feed entire distribution systems [33][34].

DER-based onsite power generation is a less expensive option and a quick process, especially with the PV, wind turbine (WT), fuel cells, etc. Whereas the central power generating systems are relatively more extensive in installed peak capacities, their erection time is also relatively high compared to onsite DER-based power plants. The high-voltage transmission lines erection also takes more time [35]. DER reduces the load on electrical transmission lines. Besides, the DER-based ESN would offer energy to consumers at a lesser price.

At the same time, the DER-based ESN provides higher service reliability, improved power quality, and ensures consumer’s energy independence. When DER uses any renewable technology, it has an excellent contribution to the power generation mix and is a part of the green solution for a sustainable environment. Government, policymakers, and power engineers worldwide are encouraging the incorporation of DER, primarily RER-based MG and SG, into power distribution systems. In recent years, nano-grids and mini-grids have also become quite popular in the ESN.

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