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Review

Smart Grid Communication Networks for Electric Vehicles Empowering Distributed Energy Generation: Constraints, Challenges, and Recommendations

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Abstract: Modern communication networks and digital control techniques are used in a smart grid. The first step is to classify the features of several communication networks and conduct a comparative investigation of the communication networks applicable to the smart grid. The integration of distributed generation has significantly increased as the global energy demand rises, and sustainable energy for electric vehicles and renewable energies worldwide are being pursued. Additional explanations for this surge include environmental concerns, the reforming of the power sector, and the advancing of small-scale electricity generation technologies. Smart monitoring and control of interconnected systems are required to successfully integrate distributed generation into an existing conventional power system. Electric-vehicles-based smart grid technologies are capable of playing this part. Smart grids are crucial to avoid becoming locked in an obsolete energy infrastructure and to draw in new investment sources and build an effective and adaptable grid system. To achieve reliability and high-quality power systems, it is also necessary to apply intelligent grid technologies at the bulk power generation and transmission levels. This paper presents smart grid applicable communication networks and electric vehicles empowering distributed generation systems. Additionally, we address some constraints and challenges and make recommendations that will give proper guidelines for academicians and researchers to resolve the current issues.

Keywords: smart grid; communication network; electrical vehicle; EV empowering; distribution generation

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1. Introduction

Modern civilizations have developed more significantly in recent decades due to technological advancements. There has been a massive demand for affordable, clean electric energy worldwide. The rising energy consumption and the unpredictable, non-linear electrical power distribution have brought about genuine device blockage issues. In this overemphasized situation, the current power system also suffers from a lack of necessary and convincing interchanges, checks, and fault diagnostics, which increases the possibility of a localized system breakdown due to the falling impact caused by a single fault. The 21st century's renewable and nonrenewable energy generation has brought about several new problems, including control network reconciliation, energy stockpiling, and system stability, which all needed to be addressed as additional challenges [1,2].

The integration and transmission of renewable energy, fossil fuel, and storage energy based on automated control and contemporary communications networks is the key to the efficient transfer of a smart grid (SG) from distributed energy resources (DER) to end customers. Smart, inexpensive controlling and monitoring made possible by internet technology detections have been crucial in guaranteeing SGs' security, effectiveness, and working time. Wired communications are typically used to identify conventional monitoring for grid integration and analytical systems. However, wired monitoring systems are not generally used nowadays due to their high costs. They need the installation and ongoing maintenance of complex contact lines [3,4]. As a result, there are fundamental requirements for effective wireless controls and processes to boost system dependability and efficiency while expanding administrative authority.

Electric vehicles (EVs) and hybrid electric vehicles (HEVs) are becoming increasingly prevalent worldwide and in the interests of governments, corporations, and consumers due to rising energy costs, energy security concerns, fossil fuel supply shortages, and increased customer expectations. Because EVs are more expensive than traditional internal combustion engine (ICE) vehicles, they are not generally used due to vehicle components, technological limitations, societal hurdles, and other factors. The EV sector has several benefits, including when compared to ICE cars and HEVs. In discharge mode, EVs can function as vehicle-to-grid (V2G) systems connecting to an electrical power grid [5,6]. To digitalize and decentralize the conventional power grid system, decrease emissions of greenhouse gases, and achieve the sustainable development goal, the EV is the most convenient and strong candidate [7,8]. Many studies have been conducted on EVs to ensure the highly efficient implementation of V2G technology besides integrating it into already-existing networks such as SGs, wherein power is generated and delivered to the consumers [9–12] and flexible transmission and distribution systems [13].

According to recent studies, EVs are more significant than other conventional energy saving technologies in terms of their simplicity of use and ability to ensure an environmentally pleasant environment. EVs will probably expand significantly as the market accepts them because of their superior efficiency, especially in metropolitan areas. For instance, preliminary estimates indicate that France's 15% electric vehicle convoy will expand energy use by just 3% while reducing 90% of CO_2 emissions. The most recent industrial shift focuses on using sustainable or eco-friendly energy technologies, the benefits of urban decarbonization, and the ability to utilize local energy resources to improve environmental health. These three focuses are all connected. Thus, solar- and wind-based generators are sustainable resources that, if kept in use, can encourage traditional energy generators to reduce pollution during periods of high demand. They provide a potential safety net for renewable energy sources (RES) such as solar and wind energy, enabling the effective integration of sporadic power generation [5,9,11]. EVs are recognized as one of the most effective tools for reducing gasoline use, promoting urban decarbonization, and enhancing human well-being.

On-grid EVs are those that use vehicle-to-vehicle (V2V), vehicle-to-home (V2H), and vehicle-to-grid (V2G) technologies when they are linked to the grid for charging. Most people are aware of the numerous environmental advantages of EVs. Few people know that these cars can operate the electric grid effectively. Although more expensive than traditional cars, they necessitate flexible grid demand fulfillment during off-peak times. Additionally, EVs require more batteries because of their greater battery capacity, backup power during shut offs, and ability to export to the grid. When power consumption is at its highest, the power grid is protected from overload, and V2G charging systems (CS) might be employed. The energy source of full-battery EVs is rechargeable battery packs. Motors and controls drive battery EVs in place of ICEs [14,15]. We perform a thorough analysis of the effects of V2G technologies and CSs, their controls, operations, and unaddressed problems.

The survey methods are described in Section 2. The communication networks are presented in Section 3. In Section 4, we describe electric vehicle-to-grid empowering. Section 5 presents the discussion. Issues and challenges are listed in Section 6, and the conclusion is presented in Section 7.

2. Survey Methods

The survey methodology was based on content understanding to achieve this study's goal. The literature review and citations were accomplished through the Scopus database, Google Scholar, ResearchGate, and the Web of Science. The relevant published materials used several keywords for this study, including smart grid communication network, technology, vehicle to the grid, V2G distribution generation, and V2G issues and challenges. The suitable papers were selected based on the journal, impact factor, title, abstract, and relevant field. Figure 1 illustrates the search, selection, review method, and funding. The survey method is accomplished in two parts, which are summarized below.

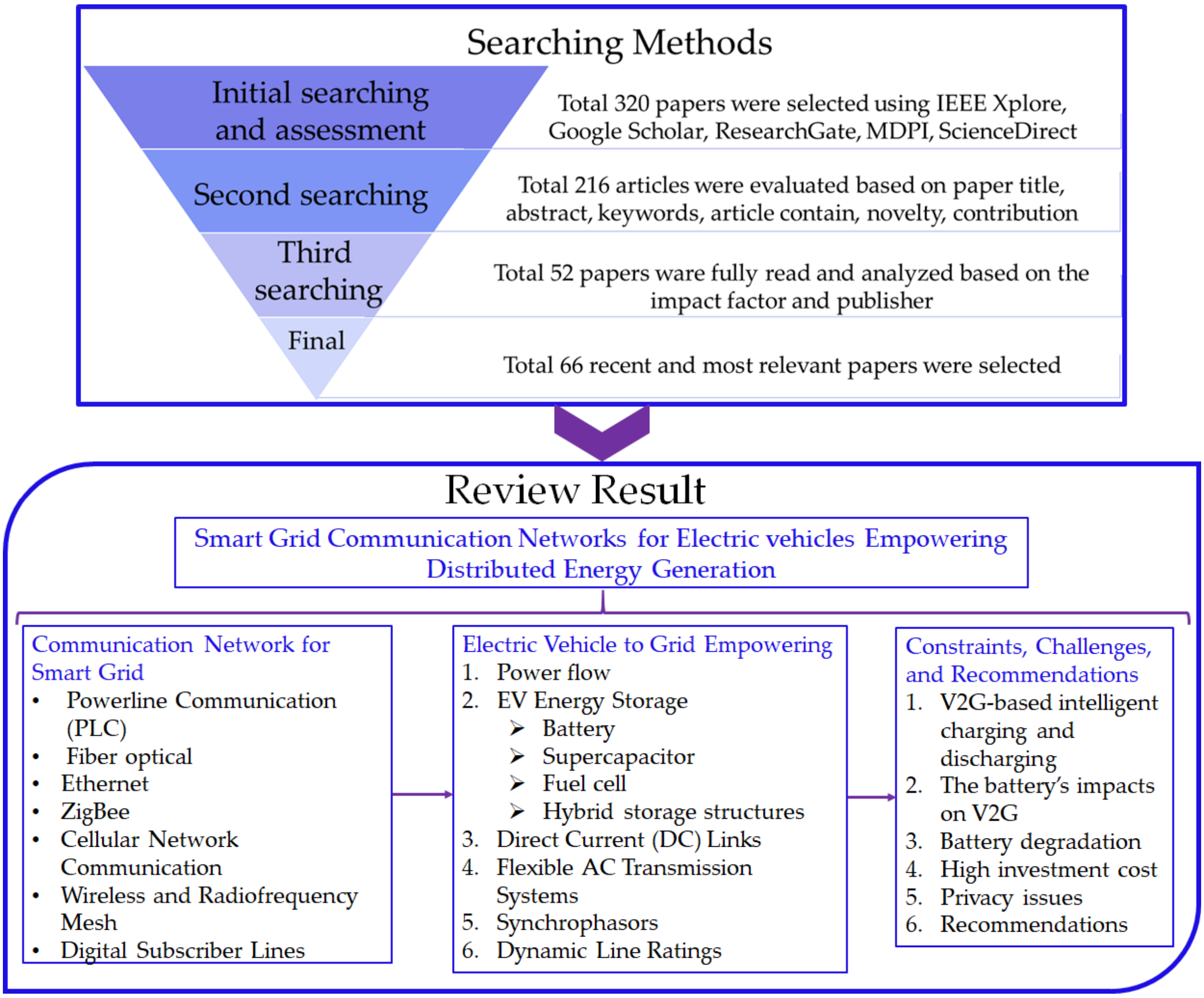

Figure 1. Schematic diagram of reviewing methodology and the funding result of the review.

2.1. Search Method

- Initial search and assessment: a total of 320 papers were selected using IEEE Xplore, Google Scholar, ResearchGate, MDPI, and ScienceDirect.
- Second search: a total of 216 articles were evaluated based on paper title, abstract, keywords, article content, novelty, and contribution.
- Third search: a total of 52 papers were thoroughly read and analyzed based on the impact factor and publisher.
- Final selection: a total of 66 recent and most relevant articles were selected.

2.2. Review Results

Upon finishing the literature review, the manuscript title was defined as "Smart Grid Communication Networks for Electric vehicles Empowering Distributed Energy Generation: Constraints, Challenges, and Recommendations," and the manuscript structure was developed as follows:

- Communication network for SG: powerline communication, fiber optical, Ethernet, ZigBee, cellular network communication, wireless and radiofrequency mesh, digital subscriber line, advantages, and disadvantages.
- Electric vehicle to grid empowering: power flow, EV energy storage (battery, supercapacitor, fuel cell, and hybrid storage structures), DC links, flexible AC transmission systems, synchrophasors, and dynamic line ratings.
- Constraints, challenges, and recommendations: V2G-based intelligent charging and discharging, battery's impacts on V2G, battery degradation, high investment cost, and privacy issues.

3. Communication Network for Smart Grid

One of the main goals of this study is to present an overview of the opportunities and challenges in many understudied research areas for communication networks used in SGs. These systems implement communication networks with multi-functional sensor nodes on an SG's hardware. ZigBee, Bluetooth, WiMax, Wi-Fi, GPRS, PLCC, GSM, 3G, 4G, and currently 5G are the innovations of SG networks. Their professional successes demonstrate the advantages of communication networks over wired ones [16,17]. We continue to share expertise on employing efficient wireless smart grid technologies. This section briefly summarizes several wireless links, their advantages, disadvantages, and a comparison.

A communication network is the mainstay of the SG infrastructure. A significant quantity of data for monitoring, further study, and continuous estimating approaches might be engendered from various applications by fusing advanced technology applications with an SG system. The interrelation of a communication network is presented in Figure 2. Then, it is crucial to identify electric utility companies' communication needs, determine the appropriate communication method for handling the production of information, and offer a compact, comprehensive, and accurate supervision approach to be used throughout the system.

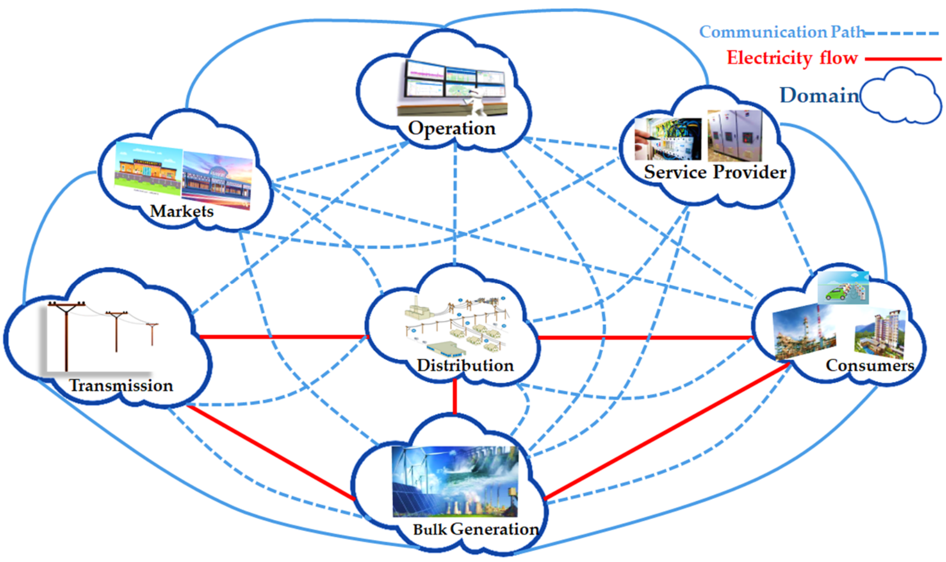

Figure 2. SG communication network architecture [16].

Electric utilities work to consider customers to improve the quality and dependability regarding participation in an SG. In-depth communication networks reinforced with two essential mediums (wired and wireless communication) are utilized to send data between smart meters (SMs) and the power supply. Certain exciting wireless communication features, such as quick connectivity to difficult-to-reach locations and affordable infrastructure, relate to wireless growth. However, unlike wireless solutions, which frequently cause issues, wired arrangements try to avoid doing so, and their capability is unquestionably independent of this. Two different data infrastructure forms are needed for transmitting data in an SG system. The second flow is from electrical machines and sensors to SMs and between SMs and a utility's data servers. Power lines and wireless communication networks, i.e., Z-wave, 6LowPAN, ZigBee, and others, can leverage this essential information source. The second data source can be the internet or cell technology [16,18,19]. The SM organizing process should include documentation of all significant restricting factors, including scheduling time, operating costs, technological access, and indoor/outdoor or rural/urban circumstances. Technology that is suitable for one condition may not be enough. A portion of the SG communication networks is outlined in the companion article, along with their focus areas and burdens.

3.1. Powerline Communication (PLC)

A high-speed data signal (2–3 Mb/s) is transmitted from one device to another using PLC technology. PLC was the first option for interacting with power meters due to the direct connection to SMs. SMs connect a conventional PLC network to the concentrator over power lines, sending data to data centers using mobile technologies. To send metered data to a central location, any electrical equipment, for instance, a smart transceptor-based meter, may be linked to the powerline. France has been executing the "Linky meter project", which involves converting 35 million conventional meters into Linky's SMs. A PLC network is used for data exchange between SMs and a data concentrator, while GPRS technology sends data from a data concentrator to a utility's data center [3,20,21]. The Italian electricity provider ENEL has decided to use PLC technology to transfer PLC data to the closest GSM technology and data concentrator.

Advantages: PLC is an excellent technology for SG applications since the present basis reduces the cost of establishing the communications system. The grounds for the effectiveness and appeal of PLCs are their institutionalization, functioning, pervasive existence, and the broad availability of their base. Since PLC data transfer is communicated by nature, security considerations are crucial. The HAN application is one of the primary uses for PLC technology [22,23]. Additionally, PLC has now incorporated the environments outside the administrative field of service organizations. A PLC network might be perfect for intelligent technology solutions in urban environments, such as control applications, observation, and intelligent measurement.

Disadvantages: There are particular unique challenges associated with the idea of powerline networks. It is tough to prove the channels because the power distribution medium is raucous and bumpy. The low-transmission capacity (20 kb/s for neighborhood zone systems) typically limits a PLC network to high-speed applications for data transfer. Additionally, the signal quality conveyed through power lines is influenced by the system topology, quantity, powerline devices, and the cable connection between the transmitter and receiver [22,23]. Information cannot be transmitted with PLC technology because of the limitations of its perturbation capabilities and reliance on signal quality.

3.2. Fiber Optical

High-speed and secure data transmission for long-distance communication is supported with fiber optical communication (FOC). The running cost of FOC systems has been successfully decreased through extensive research. Additionally, there has been a noticeable improvement in the signal quality SNR. As a result, an SG cyber-physical system (CPS) implementing FOC is a better option for a mission-critical application. FOC structures are used in various industries, including automation, tele-control, and substation protection. Even though SGCPS selected an FOC infrastructure, it encountered some problems, including scalability, lengthy installation times, high installation costs, and the supported nature of the infrastructure [16,24].

3.3. Ethernet

Ethernet communication technology is applied for a wide area network (WAN) between substations and control centers. The high availability and reliability of Ethernet communication technology are a benefit. Additionally, it is utilized in home network communication systems that link with SMs and home centers [16,24].

3.4. ZigBee

ZigBee is a wireless communications network that uses power, unpredictability, and information speeds, and has generally affordable setup costs. Smart lighting, energy monitoring, home automation, and programmed meter reading are applications for this network technology. The National Institute for Standards and Technology (NIST), ZigBee Smart Energy Profile (SEP), and the United States have referred to it as the most logical connectivity principle in an SG private system area. For a communication network between smart home appliances and house vitrines, communication between SMs is essential [3,25]. Using integrated SMs, ZigBee can talk to and watch over synchronized ZigBee devices. ZigBee SEP provides notifications to households so that property owners can learn more about their ongoing energy usage.

Based on the IEEE 802.15.4 standard for wireless local area networks (LAN), media access control and physical layers were developed with Zigbee technology for sensor networks and control systems. Converting primary sensor data enables short-range two-way communication between sensor networks and control systems. Its architecture consists of a coordinator, router, and end devices. Zigbee is a communication channel for multi-functional electronic current transformers (ECTs) for underground and overhead line monitoring and the highly effective and initial advance meter infrastructure (AMI) network construction following LAN connection loss. In addition, it is simpler to produce than Wi-Fi and Bluetooth. The Zigbee network might be expanded using routers to create more large area networks [16,24].

Advantages: ZigBee has a 5 MHz, 2.4 GHz spectrum, and 16 transmission speed diverts. The maximum power output of radio is 0 dBm (1 mW), with a communication range of 1–100 m, a transmission rate of 250 Kb/s, and OQPSK modulation. ZigBee is regarded as a good measurement choice and an excellent option for implementing an SG due to its specific features, low capability requirements for data transmission, flexibility, minimal setup effort, task within a non-licensed range, institutionalized convention, and easy device utilization with the IEEE 802.15.5 standard. ZigBee SEP has a few focus points for the water, gas, and electricity utilities, such as load control and reduction, request responsiveness, ongoing evaluation programs, sophisticated metering support, and constant monitoring observation.

Disadvantages: ZigBee has numerous limitations. For instance, with limited processing powers, small memory capacities, short time requirements, interference caused by multiple devices using the similar communication medium, and free industrial and science applications, ZigBee as well as Bluetooth, WiFi, and IEEE 802.11 wireless local networks (WiLANs) all have several practical use restrictions.

3.5. Cellular Network Communication

Cellular networks may be a good substitute between distant and established nodes, such as SMs and utilities. The new connectivity base keeps a reasonable distance from utilities to prevent them from devoting extra resources and maintenance expenses to building a dedicated communications infrastructure. Mobile network agreements also allow SM businesses to spread over a large area. With the help of cellular networking services, such as 2G, 3G, 4G, 5G, and WiMax, LTE is also available for SM programs. A significant volume of information was produced. The maximum information connection rate was required to share the information with the utility, using a typical 15-minute interlude between the meter and the utility [26,27].

General Electric has created a WiMax-based center energy SM and collaborated with Motorola, Smart Net, and Intel in WiMax network agreements. To connect the back-pullup network with focus collectors that gather data from center point SMs, it will deploy MDS Mercury 3650 radios based on WiMax for the General Electric SM project at center energy. Additionally, some sizable businesses—including Silver Springs, Cisco, and Verizon—upgrade smart applications for WiMax. Alvarion operates a WiMax-based smart network commercial partnership with a US utility company, National Grid, and is WiMax's most extensive global merchant. Adequate data processing capabilities, concentrated scheduling and managing expenses, streamlined communications, legal security requirements, quick information speeds (up to 75 Mb/s), and adaptability are the advantages of the current WiMax technology [3,26,27].

In an SGCPS, cellular communication technology provides a workable alternative communication method. The data transfer rate in these technologies consistently reaches 100 Gbps. Due to its ability to carry data at a more incredible pace with less delay, cellular technology has gained popularity over the past few decades in various applications. Its usefulness is waning due to security concerns and network accessibility [16].

Advantages: Utility companies do not need to add additional operational expenses for the interchange structure essential for an intelligent network. One of the most significant communications advancements with smart advantages is cell communications, which is available now. Cellular networks have enough data processing power for these applications since data are stored at more frequent intervals. They attributed this to the volume of information. Cellular systems are prepared to validate the transmission of information through reliable security checks when security is an issue. If cell system cover reaches approximately 100%, an SG's broad-based organizational capacity becomes crucial to managing safe communications with SMs in rural or metropolitan locations. The GPRS and GSM allow AMI and load management applications in the home network and have a maximum data rate of 14.4 kbps and 170 kbps, respectively. Namelessness, certification, consumer information security authorities, and signage safety are among the security features of GSM technology. The advantages of cellular systems include their potential to be the most competitive technology for applications, as well as their cheaper costs, more excellent coverage, easier maintenance, and quicker installation.

Disadvantages: Various SG operations demand accessible and dependable connectivity. The consumer market shares cellular system management, and when a crisis occurs, this can result in system congestion or a decline in system efficiency. Utility companies might then organize their private communications due to these reflections. For instance, a cellular network may not always ensure suppliers in unusual circumstances such as a windstorm.

3.6. Wireless and Radiofrequency Mesh

A mesh network is a versatile system composed of nodes that may be expanded by adding more nodes, and each node can function independently as a router. In the PG&E system, each SM is prepared through a radio module, and they all use data from nearby meters. Each meter acts as a sign repeater until the information acquired passes through a coordinated electrical system. At this point, the contact agency has sent the service provider the information it has collected. A private company called Sky Pilot Networks adopted an SG work organization since mesh technology is highly usable. Utilities use radiofrequency (RF) mesh as a communication network in their network systems. It provides the framework for putting in an AMI so an extensive service area can obtain daily meter readings. RF mesh networks are reliable and economical for building dispersed networks across great distances. They can adjust to shifting demands on the electric grid [3,16,28]. Because RF mesh self-heals when nodes fail, this technology can be used locally rather than throughout the entire service area. A signal can discover the best route back to the head-end system using RF mesh technology, even in obstacles such as mountains or tall buildings. In remote areas with great distances, RF mesh may require additional infrastructure. Unlicensed RF mesh frequencies might cause interference.

Advantages: Mesh communication is cost-effective because it uses dynamic self-association, self-retrieval, and self-arrangement in addition to diverse administrations that provide a range of benefits, including improved system efficiency, heap adjustment, and increased system coverage. Broad coverage can be offered in rural and urban regions through inter-routing. A mesh system's design also enables meters to be employed as signal repeaters and accumulating additional repeaters will increase the system's maximum coverage. Furthermore, among the technologies for which wireless mesh networking could be applied are specialized computers.

Disadvantages: The issues in wireless and RF mesh systems are process performance issues, including network impedance, blurring, and network limits. The coverage issues with mesh systems in metropolitan settings were noted since the meter thickness could not reach the full interchange. To balance stable and flexible guidance, working methods must include adequate smart nodes considering node costs. Additionally, the system must be handled by a third-party entity. For security reasons, various encryption processes are connected to the system, so the data are considered during each transit. Additionally, cyclical issues will lead to higher overheads in distractions while information parcels are traveling among different neighbors, decreasing the useable data transmission capacity.

3.7. Digital Subscriber Lines

The high-speed information transmission technique Digital Subscriber Lines (DSL) uses voice network lines. Frequencies more significant than 1 MHz are frequently observed with an ADSL-enabled phone line. The present DSL line technology reduces installation expenses. As a result, DSL technology has been chosen by several enterprises as their SG solution. The current community, a provider of SG solutions, is working on an SG project with Qwest. The security, low-inertness DSL infrastructure from Qwest is being used for data transfer [29–31]. Additionally, demonstrating the technology's compatibility with the Open Grid Stage, current smart sensors, and Qwest's DSL was Xcel Energy's SG City project. A smart measuring project for Stadtwerke EmdenCity Utilities and Deutsche Telekom in Germany has been completed. German Telekom is committed to communicating the project's electric and gas meter information [3]. The customer's location will have a contact box forwarded to Emden over DSL. Deutsche Telekom participates in this initiative by offering a variety of administrations, including information use, establishment, operation, information transmission, etc. However, the effectiveness of the DSL Association depends on how disconnected the follower is from the phone service industry, which makes it challenging to describe how DSL technology is used.

Advantages: Due to its widespread accessibility, low costs, and fast information transmission speeds, DSL technology is the primary exchange option for power providers to implement SG systems using smart data transmission and SM systems applications.

Disadvantages: The dependability and potential downtime of DSL technology may make it unsuitable for simple operations. Additional issues could arise if a dependency on separation and institutionalization is absent. The wired DSL communication systems frequently require continually maintaining and installing communication connections and thus cannot be adopted in rural areas due to the unexpected strain of establishing a permanent basis for low-thickness locations. Additionally, wired technologies, such as DSL, PLC, and FOC optics, are expensive for large-scale arrangements even though they can increase interchange caps, steady efficiency, and security. Wireless advances can further reduce the cost of establishment, and can also offer compelled data transfer and safety options.

3.8. Comparison of Communication Networks

The WiMax range and bandwidth make it suited for SG applications. A rapid application deployment is made possible by cellular networks through high data rates, widespread coverage, bandwidth, good security, and few maintenance costs. These cellular networks will also accept investment ventures in utility-specific communication infrastructure. Utilizing current cellular networks would result in higher operating costs for ongoing monthly fees. A customized communication network can provide good quality and dependability with less expensive running costs, as demonstrated in Table 1.

Table 1. Comparison of different communication networks.

Technology	Spectrum	Data Rate	Coverage Range	Limitations
PLC	1–30 MHz	2–3 Mbps	1–3 km	Noisy channel environment
ZigBee	2.4–915 MHz	250 Kbps	30–50 m	Low data rate, short range
WIMAX	2.5 GHz, 3.5 GHz, 5.8 GHz	Up to 75 MBps	1–5 km	Not widespread
GSM	900–1800 MHz	Up to 14.4 Kbps	1–10 km	Low data rates
3G	2.11–2.17 GHz	384 Kbps–2 MBps	1–10 km	Costly spectrum fees
GPRS	900–1800 MHz	Up to 170 Kbps	1–10 km	Low data rates

4. Electric Vehicle to Grid Empowering

4.1. Power Flow

In V2G connections, EVs can charge and discharge energy while parked. Electric grid contact through an electric grid operator and effective energy metering is necessary to prevent issues; better management entails acquiring more precise data. Bidirection is a feature of all general-purpose contact devices. The grid's and EVs' bidirectional power flow has benefits such as a high power density, high efficiency, good dynamic performance, wide output voltage range, isolation, and low cost [32,33]. SMs allow EVs to be integrated with renewable energy sources and for EV loads to be controlled. SM-connected sensors may receive and transmit data from the networked electricity sources under control, increasing the active effectiveness of V2G.

A few networking strategies, such as ZigBee, Bluetooth, and Z-Wave, have been studied [34–36]. The Institute of Engineers and the Society of American Engineers define and specify the necessary contact specifications in the United States. The National Electric Infrastructure Working Council also developed a communications protocol allowing EVs to interact with chargers [5]. An expansion-capable SG can distribute device noise, which can be harmful, but they lack the newest and most advanced control electronics. The processes for EV charging are included in the standards addressing EV control systems. High-voltage batteries and direct-current-to-direct-current (DC-to-DC) and DC-to-alternating-current (AC) (DC-to-AC) converters all benefit from isolation. Additionally, this works well for EV features such as the isolator charger. Figure 3 shows the V2G and G2V power transfer relation with communication networks.

The EV supply through a high-frequency transformer or line transformer may be utilized to deliver galvanic isolation for battery-charging steps if employed with high-frequency insulation. A higher precision, better equipment safety, and smaller size are all possible with an expanded voltage range. On-board chargers are typically evaded due to the extra cost, even though electrical isolation is a desirable option for safety. When an inverter and traction engine loader circuit offer an integrated drive system and loader, these problems can be avoided. There have been numerous attempts to use unique machine configurations with additional windings to address the isolation issue.

Unidirectional power flow: the unidirectional V2G battery charging technique has the potential to deliver reactive power and dynamic rate change-dependent services.

Beyond this, there is no computer, other hardware is needed, and cycling will not further discharge EV batteries. This structure can be built at a relatively low additional cost. Absolute control and time-sensitive energy pricing are both allowed for. A diode bridge filtered and driven as a DC–DC converter makes up the fundamental circuit. These converters are frequently implemented to reduce losses, volume, cost, and weight [37,38]. When increased isolation is required, high-frequency transformers are recommended. To control the reactive power flow to charge the batteries properly, unidirectional chargers are used for generating the highest power to become AC.

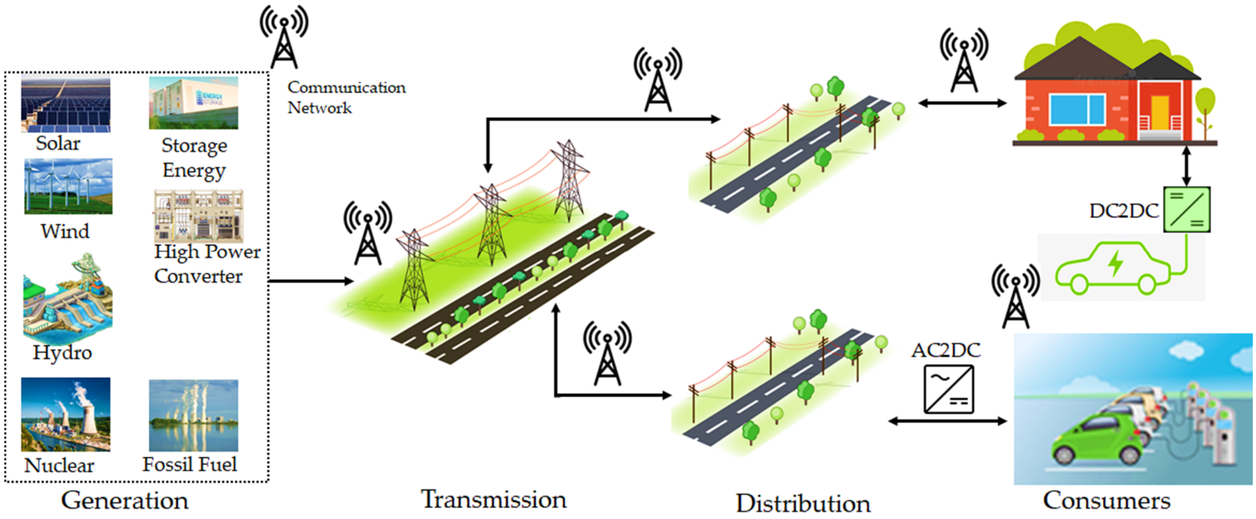

Figure 3. V2G and G2V power flow and communication system in smart grid.

Figure 4 depicts the block diagram of a V2G system power flow and components.

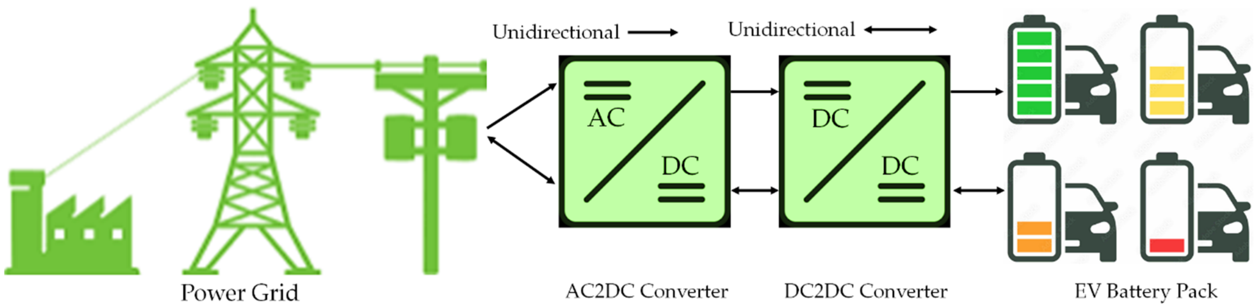

Figure 4. Power flow topology.

Bidirectional power flow: Bidirectional chargers running in equal directions are typically composed of three phases. An active power factor adjustment is required for a bidirectional AC–DC converter grid connection. Second, a bidirectional DC–DC converter controls the battery's charging/discharging current. The charger might produce the sinusoidal voltage through a set phase angle during charging. The charger is in discharging mode, but the output must be returned in a sinusoidal waveform. While most of the studies on bidirectional power transfer have concentrated on V2G, it is not widely used due to several fundamental difficulties. A bidirectional electrolytic capacitor-free charge controller is advised for grid-connected EV applications [38–40]. The grid and the bidirectional EV charger are connected in series to reduce switching losses and improve system performance. Batteries fall into this category since they need to be regularly charged and discharged to be managed. In this context, a bidirectional charging control solution for EVs considers the battery's state of charge (SOC) and simultaneously controls the voltage and frequency [41,42]. Additional costs include bidirectional converters, metering difficulties, and setup difficulties. This suggests that the islands' anti-laying and other connectivity difficulties should be considered. A comprehensive V2G model cannot be adopted without these guarantees, which ultimately hinders the viability of the V2G concept. A high-speed charger is required for bidirectional charging to function.

4.2. EV Energy Storage

An EV-applicable energy storage system (ESS) for battery, supercapacitor, chemical, and hybrid storage systems is presented in Figure 5. Based on the ESS properties, different implementations should be held responses. In addition to storing electricity for a longer time, an appropriate ESS saves costs. Manufacturing companies and researchers have worked to improve ESS performance and create a cost-effective storage device [6].

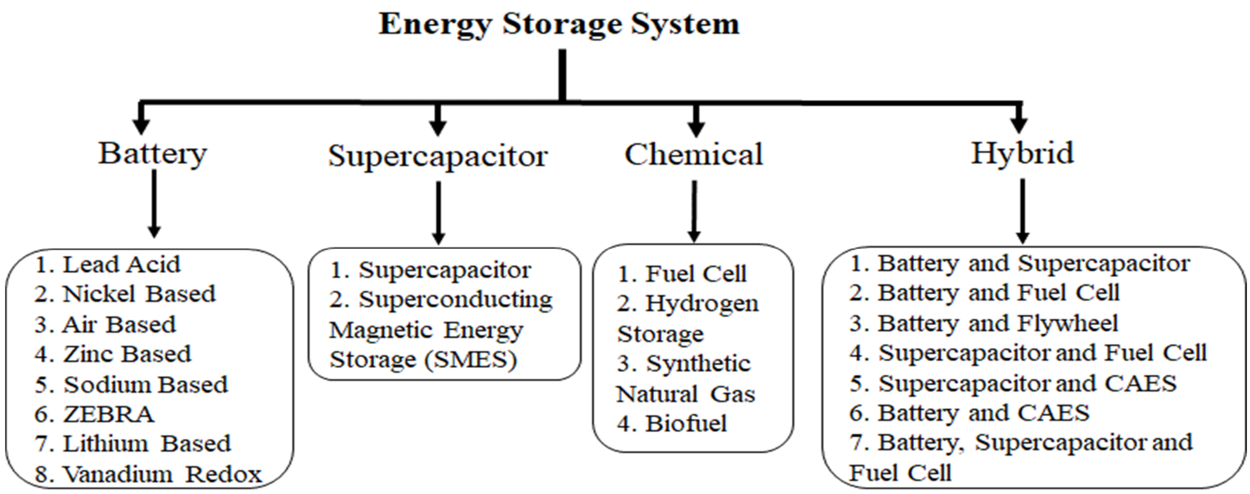

Figure 5. EV-applicable energy storage system [2].

4.2.1. Battery

There are two types of electrochemical batteries: primary and secondary. A battery stores chemical energy and generates electricity. In EVs, a secondary battery with higher specific energy is used. Because batteries are the only source of driving power for EVs, advancements in battery technology significantly impact the market. The early EV system makes use of a lead–acid battery. Researchers continued to work on the EV system and suggested storage batteries with better power densities and specific energy [43,44]. High specific energy and power, a high energy density and capacity, extended cycle life, high temperature tolerance, and an effective battery are required for EVs. Lead–acid, sodium–sulfur, zinc–air, nickel, and Li-ion batteries are among the various rechargeable batteries used in EVs [45,46]. In the modern EV system, Li-ion-based batteries are most suited and relevant.

4.2.2. Supercapacitor (SC)

Electrodes and electrolytes store static energy in an SC, which is an electromagnetic storage system. The mix of the electrode and electrolyte materials, ionic size, and electrolyte decomposition voltage level all affect an SC's energy storage capacity. An SC is also known as an ultracapacitor (UC). Activated carbon is typically used as an electrode in SCs due to its increased specific energy and surface area. A high-conductive substance is employed between the electrode and the contact to collect the current in an SC. The electrode serves as a channel for supplying ions to other electrodes. Electrodes that permit ion-charge mobility and prevent electronic communication are separated by an electrolyte membrane [1,6,45,46]. The demand for SCs has increased, and they are now considered a battery substitute because of their greater specific power, first charge, extended cyclic life (up to one million times), and low weight [34,47]. SCs can be divided into three categories: hybrid SCs (HSCs), pseudo-SCs (PSCs), and electrochemical double-layer SCs (EDLSs). An EDLS is divided into carbon nanotubes, activation carbon, and carbon aerogels. Metal oxides and polymers are two PSC kinds in addition to metals and conductors. Battery types, asymmetrical, and composite are the three different types of HSC [6,47,48].

Based on several key points, a comparative analysis between a battery and SC is shown in Table 2. This analysis focused on specific energy, power, life cycle, efficiency, charge and discharge time, storage mechanism, charge rate, and the advantages and limitations between a battery and SC.

Table 2. Comparison between batteries and SCs [6].

Characteristics and Parameters	Battery	SC
Specific energy (Wh/kg)	10–100	1–10
Specific power (W/kg)	<1000	500–10,000
Cycle of life (80% DOD)	<4500	>500,000
Efficiency (%)	60–85	85–98
Charging time	1–5 h	Second–minute
Discharging time	0.3–3 h	Second–minute
Storage mechanism	Chemical	Physical
Charge rate	Kinetically limited	High in charge and discharge
Advantage	Higher energy and power density, specific energy, good efficiency, no memory effect, low self-discharge, and higher discharge profile	Higher specific power, quick charge, higher temperature tolerance, excellent efficiency, long life cycle, and lightweight
Limitation	Required thermal management, overcharge and undercharge protection, limited life cycle, bulk size, and heavy weight	Low power density, low discharge profile, self-discharge, and costly

4.2.3. Fuel Cell

Over the past few epochs, the need for fossil fuels has gradually expanded around the planet. However, the reliance on fossil fuels for future energy needs is unsustainable. As a result, adequate environmentally friendly alternative energy sources are needed. One of the significant contributors to fuel consumption is ICE-based transportation. As a greenhouse gas, it is also the cause of the weak fuel market and one of the main contributors to environmental problems. Fossil fuels will meet about 75% of the world's energy needs even in 2050. In a fuel cell electric vehicle (FCEV), fuel cell (FC) technology provides the vehicle's driving electric power [1,49,50]. Hydrogen is used in FCs to address the BEV problems and can serve as a potential future transportation fuel.

4.2.4. Hybrid Storage Structures (HSS)

A HSS comprises two or more EESs, such as a battery and an SC, a battery and an FC, an SC and an FC, or a battery, an SC, and an FC. Each combination has advantages, such as a high power density, capacity, specific power, high-temperature tolerance, low discharge rate, and long life. SC and battery comprise the most prevalent HSS. A large storage capacity, a long-life cycle, cost-effectiveness, and increased system performance are all key benefits of HSSs. The battery and SC or battery and FC-based HSSs are used in EV systems [6,51,52].

Figure 6 depicts numerous ESSs and their power and energy densities, longevities, standard discharge times, and efficiencies. Different kinds of batteries are used in an EV system, depending on consumer demand and EV specifications. Researchers and automakers are focusing on the future development of high energy storage, low-cost, and environmentally friendly EV-applicable ESSs. An EV system necessitates an appropriate ES and promotes an ideal management system.

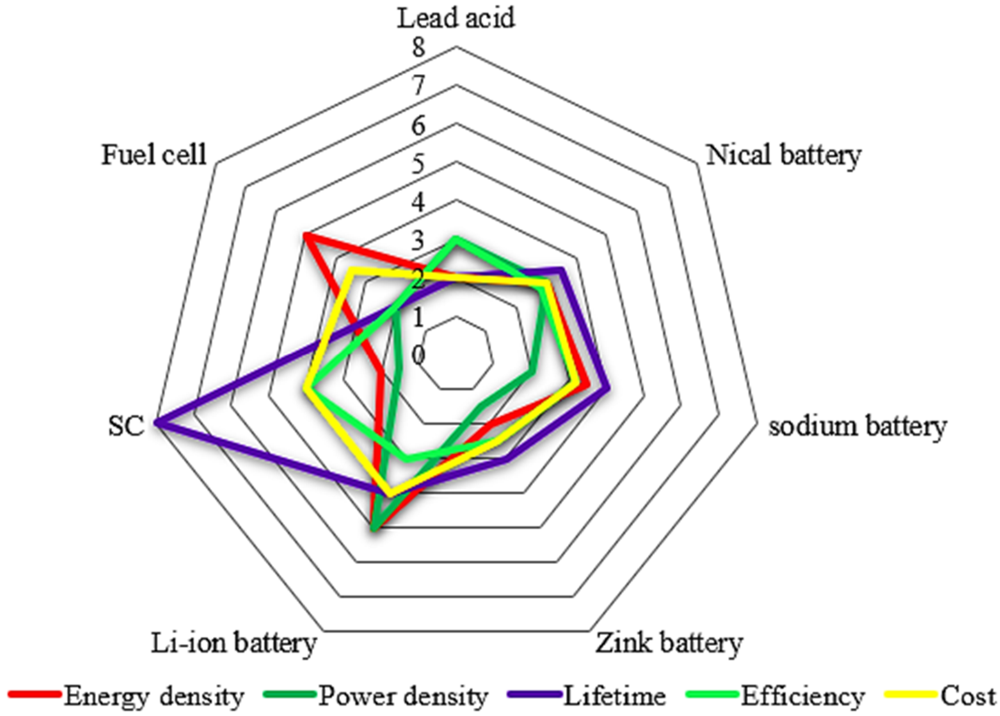

Figure 6. Comparison between different ESSs [1].

4.3. Direct Current (DC) Links

Typically, AC is used to transport electric power. The efficient conversion of AC to DC is made possible with modern power electronics. Utilities now use a small amount of high-voltage DC (HVDC) distribution. Although HVDC lines are less expensive and have fewer losses, switching to HVDC is only financially advantageous in certain circumstances due to the high cost of the AC–DC converters at each end [53–55]., principally the following circumstances:

Long commutes: Although electricity cannot be accessed halfway along an HVDC line without trying to add another expensive conversion station, HVDC lines are more cost-effective for very long node transmission applications (over 500–1000 km). The high price of the power converters at each end is offset by reduced transmission losses and lower conductor costs [54,55].

Underwater: Because of the capacitance between AC electric lines and water and protective metal enclosures, there are more significant losses while running AC electric lines underwater. This drawback is not present with DC transmission lines.

Connecting separate AC grids: Due to discrepancies in phase and minute variations in frequency, two independent AC grids cannot share AC electricity even though they are of the same nominal frequency. Power can move between asynchronous AC electric grids thanks to DC ties. The DC tie also aids in preventing grid instability from spreading to the opposite grid. One can accurately control the amount and direction of electricity delivered through a DC wire [55].

4.4. Flexible AC Transmission Systems

Power transistors are used by a group of devices known as flexible AC transmission systems (FACTSs) to control grid voltage or power factor, enhancing flexible system stability and power quality [56,57]. Static synchronous compensators (STATCOMs) and static VAR compensators (SVCs) are two FACTS family members that are employed more frequently. To change the grid voltage and power factor, SVCs shunt grid current to capacitors (or occasionally inductors) using thyristor switches. Since the 1950s, synchronous condensers, which are rotating machinery that were once used to produce reactive power, have been increasingly replaced with SVC technology [55,58]. STATCOMs accomplish the same thing, but they shunt current using voltage-sourced inverters. Compared to SVC technology, STATCOM technology is more recent, quicker, and expensive. These products are commonly sold commercially and enhance power transmission capacity by supplying nearby reactive power. Large wind farms occasionally use FACTSs, mainly when using older turbine technologies. Smart inverters can also offer reactive power to regulate voltage and power factors, as mentioned above. A STATCOM is a smart inverter without a power supply. Wind and solar power plants do not need utilities to install wiring when smart inverters are employed with an FACTS.

4.5. Synchrophasors

Phasor measurement units (PMUs) are commonly used as synchronizers to monitor transmission line current, voltage magnitude, and phases of 25–120 times per second. A precise, near-real-time representation of an entire transmission system is produced by synchronizing data from all PMUs using a measurement of time delivered by a global positioning system (GPS). A phasor data concentrator gathers the PMU readings and relays them to the grid management system, enabling improved grid control and optimization [16,59,60], which provides control center operators with a view of the grid at least five minutes old. PMU systems are anticipated to be placed at wind farms in the future, and it is expected that their ability to give a wide-area situational awareness will make it easier to integrate variable RE sources. Higher RE penetrations are possible with synchrophasor systems without new transmission system enhancements. Early users of PMU technology included Brazil and Mexico, and China may now lead the number of installations. PMU data models and communication methods are not standardized. The progress of synchrophasor technology is advancing quickly.

4.6. Dynamic Line Ratings

An increased conductor temperature reduces the ability of power lines to carry current (in the air); conversely, conductor temperature rises with solar radiation, and the ambient temperature falls with wind speed. Since power lines typically only have one power rating depending on the worst-case weather situation, they are rarely used to their full potential. Transmission line tension, directly correlated with a line’s average temperature, is actively sensed with dynamic line rating (DLR) technology. This enables transmission grid operations to incorporate real-time line rating values. As a result, line capacity rises by at least 10% and occasionally up to 40% over 90% of the time. DLR works particularly well with wind power since the latter cools the lines and boosts their capacity [55,61,62]. DLR can reduce line congestion without requiring costly and time-consuming line modifications, which typically result in unwelcome wind constraints in many places. Additionally, DLR provides grid operators with essential, not always accessible real-time knowledge of power transmission power flows. However, the DLR system is not new and is cost-effective.

4.7. Energy Market

For a SG system, the energy market and trading are necessary for alternative power generation (bulk and consumer-side), transmission, and distribution. For trusted and secure energy, trading e-certificates are issued for consumers and generators. The energy market and trading system becomes easy, minimizing time and marketing efforts, when using blockchain technologies. The peer-to-peer trading technique provided by blockchain technology for regional customers consumes less energy. These data are handled automatically by the peer-to-peer topology and kept on the blockchain network, where all instances are reflected across the communication network. Through the SG system in a block node, the communication network delivers real energy market or trade data. Every device communicates its address and other information with earlier devices because all nodes are connected through of communication network.

5. Discussion

Several SG-applicable communication networks in the current standards and norms that might govern the control, order, timing, and repair of faults during information transmission are significant features that transfer energy information over an SG infrastructure. The advantages and limitations of communication technologies are described in Section 3. WiMax's capacity and coverage area make it suitable for SG applications. Cellular networks' high data rates, extensive coverage, bandwidth, security, and low maintenance costs enable a quick application deployment. These cellular networks would also accept investment projects in communications networks tailored to particular utilities. The current cellular network cost would be higher monthly for recurring payments.

Traditional grids depend their power generation and control on just a vertical integrated electrical infrastructure. These power networks face operating difficulties due to generation reserves, schedules, the greater integration of RESs, and a rise in long-distance power transfer. Due to a maintenance company's inadequate understanding and physical damages, various problems produce unanticipated events such as power outages and voltage instability. In the national grid, energy conservation is put into place to balance out demand and supply from a collection of various networks and power generation companies to numerous controllers using different degrees of coordination and communication, the majority of which comprises operation. SGs improve automation, communication networks, and consumer and supplier/generation connectivity. Using SGs improves connectivity, automation, and network coordination between suppliers and customers. Using computers and other intelligent appliances enables protection and autonomous supervision for interrelated components, including power generators (bulk generation and consumer-side small-scale generation, especially EVs), transmissions, and distribution systems, and for businesses and residential users.

6. Constraints, Challenges, and Recommendations

6.1. V2G-Based Smart Charge and Discharge System

The advantage of instant participants' direct holdings in transactions was limited. It should also be mentioned that this study does not address each EV's V2G communication capability. V2G is frequently used to describe numerous distinct associated EVs. An intelligent charging/discharging management plan should be developed for each type of EV [63,64]. An intermediate system is expected to produce sufficient power to EVs while simultaneously supplying to the grid, depending on the grid requirements. Future studies should concentrate on how different charging techniques affect energy prices and the driving behaviors of an incredible quantity of EVs.

6.2. Transmission and Distribution System Operators

With the flexible generation and consumption of electricity, users of electrical energy are actively participating in the market. Individually or collectively, consumer involvement in the energy sector is anticipated to rise dramatically, necessitating a quicker transition from distributor network operators to distribution system operators (DSOs). As a result of these transformations, DSO interactions between transmission system operators (TSOs) and various stakeholders in the electricity system, such as aggregators, suppliers of balancing services, retailers, fleet operators, and essential grid users, will also need to be significantly changed [13,65]. As a result, DSOs and TSOs will have to change how they communicate with one another and redefine how operational duties and responsibilities are coordinated concerning other new industry participants, such as DER operators and aggregators. Grid operators should respond to this shifting environment and adapt their current operating model to enable quicker responses and adaptable mobility while enhancing their communication networks as the electrical grid transitions from fully centralized to highly decentralized. DSOs and TSOs are facing an unprecedented problem that requires an unprecedented response.

6.3. The Battery's Impacts on V2G

V2G may enable EV owners to gain from an energy response on the power grid. Dealing with the tear and wear brought on by employing V2G technology, i.e., battery depletion and degeneration, generates value. Batteries' lifespans and functionalities may be shortened by repeated charging and draining. Therefore, it is crucial to study how V2G affects battery life., and examine how V2G services affect battery degeneration concerning a battery's capacity, charging schedules, and depth of discharge (DOD). The duration of an EV's connection reduces the impact of degradation. In addition to modeling the collective power of EVs based on their driving behaviors, the economics of various V2G suggestions have been shown. Estimates of battery wear, loss, and profitability have been made for multiple V2G activities [66,67]. Additionally, research has been conducted to determine the expense of regular, extended EV use. The batteries of EV drivers are in a reactive power control mode. The effect of V2G on battery life is not currently reliably measured by any model; therefore, it is necessary to conduct additional analysis to determine whether using reactive power support at a greater power level harms a battery.

6.4. Battery Degradation

A battery's internal resistance will increase, and its usable capacity will decrease. The main factors determining how quickly their voltage and DOD fall are deciding elements. V2G is a technology that permits two-way communication. EVs must perform more battery cycles of charge and discharge. The deployment of V2G is assessed in terms of economic and technological factors. This study suggests that installing V2G is essential to avoid since fast charging/discharging the battery causes more significant degradation over time. Battery life cycle estimates are based on the equivalent series resistance (ESR). A battery's ESR increases, and the number of charging and discharging increases as the time required to charge and discharge the battery increases. Studies show that the ESR of a battery upsurges in short and straightforward charging battery conditions. The battery SoC must remain at intermediate levels to reduce the rate of the rise in ESR. A battery's DOD is a crucial factor in lowering battery degeneration. The DOD should not exceed 60% to achieve battery longevity [67–69]. As a result, between 30% and 90% SOC is where the ideal battery usage range lies. Taking battery life into account when deploying V2G technology is crucial. The V2G management and technique were developed to prevent the misuse of EV batteries and to maximize the benefits of the link between energy users, technological concerns, and the power supply.

6.5. High Investment Cost

Another barrier to the introduction of V2G is the high investment cost required to modernize the power generation structure. A bidirectional battery charger is required for every electric car that links to the V2G network. The complex controller and high-voltage wire parts of a bidirectional battery charger have strict security requirements. Additionally, V2G technology might be linked to higher energy loss, which would be costly. It is necessary to incur additional conversion losses when charging and discharging often since these operations produce energy conversions [70,71]. The numerous energy conversions that occur throughout the charging and discharging procedures of a large fleet of EVs could result in a significant energy loss for the grid.

6.6. Privacy Issues

An aggregator should not be able to identify a car or track its whereabouts. An aggregator who recovers an EV's information might mismanage it by giving the data to an enemy, and the vehicle identification might be exposed. An operator or aggregator might track an EV's detailed information, i.e., the charging station's location and how long a vehicle has been there. If a specific charging station is used frequently by the car to charge or discharge, the timing outlines of the vendor of the EV can also be tracked. Maintaining the confidentiality of other vehicles' preferences is important. The SOC of an individual

EV's battery and the owner's choice of completing charge or discharge operations expose personal data to the aggregator. These data can be obtained by an opponent, who can keep user history. The vehicle owner's frequent daily movements between locations and destinations can be inferred from their user history, including the distance they cover daily, the parking allocation that has been used most frequently, and the bank they use most frequently.

6.7. Recommendations

Based on the critical review, the following recommendations are summarized for the development and forthcoming investigation focus of V2G technology expansion:

- To develop a V2G strategy, strengthen V2G fundamental research, and take more equipment and operating conditions into account while building the smart grid.
- Additional research is needed into V2G modeling, behaviors in steady-state, capacity forecasting, dynamic processes, and transient processes, as well as other relevant fields.
- It is advised to encourage EV drivers to use the V2G system while bearing in mind the social implications of adopting electrified transport coordination, particularly the V2G system.
- When a voltage drop occurs, all EV chargers are in V2G mode, making it impossible to detect and implement proper control adaption and transition. This situation warrants additional research.
- Presently, no model appropriately assesses the effects of V2G on battery life.
- The impact of an EV's charging mode on the system's dependability may be considered in future development. Therefore, more research should be conducted to determine whether using reactive power adjustment at a greater power level harms the battery.
- Smart charging lowers system expenses in V2G systems. Despite the EV system of distributed storage for financial gains, it is clear that smart chargers can absorb excess renewable energy. This problem that has not yet received a thorough economic rationale deserves more investigation.

7. Conclusions

The SG is exceptionally close to replacing the existing power generation and distribution infrastructure. Appropriate communication technology must be combined with internationally conceived and focused architecture for reliable and consistent communication. The choice of technology depends on various factors, such as the SG network's lifespan, data rate, level of security and dependability, available channel capacity, etc. This paper discusses the significant advancements in wireless technology, including wireless mesh networks, ZigBee, WiMax, and their advantages and restrictions associated with intelligent networks. The implementation of a specific wireless network in connection with a SG system spectrum is very well explained in this study. Some wealthy nations have already converted their old power systems to SGs, although they still face significant problems with standards, security, and laws. Less developed countries continue to trail far behind in economic and technological development. Developing nations are making significant efforts to create SG technology due to the advantages of electric system reliability, customer satisfaction, load distribution, and all forms of grid operations. These recommendations shall be helpful to the development and application of advanced V2G control systems through communication networks. Understanding how to assist future V2G production may also provide researchers and academics with a thorough understanding of the V2G communication network and applications.

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