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Review

A Review on Communication Standards and Charging Topologies of V2G and V2H Operation Strategies

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Abstract: Electric vehicles are the latest form of technology developed to create an environmentally friendly transportation sector and act as an additional energy source to minimize the demand on the grid. This comprehensive research review presents the vehicle-to-grid (V2G) and the vehicle-to-home (V2H) technologies, along with their structures, components, power electronic topologies, communication standards, socket structure, and charging methods. In addition, the charging topologies in V2G and V2H are given in detail. This study is planned as a useful guide for future studies that can be achieved in that it compares the results obtained and analyzes the studies in the literature, finding the advantages and disadvantages of charging topologies in V2G and V2H.

Keywords: vehicle-to-grid (V2G); vehicle-to-home (V2H); bi-directional charging topologies; communication standards; battery cycle

1. Introduction

The vehicle-to-grid (V2G) and vehicle-to-home (V2H) technologies refer to the transfer of electricity from vehicles to the grid and the home, respectively. To learn how these technologies have come about, we have studied some of the background literature on the topic. In recent years, because of the newly emerging needs parallel to developing technology and industrialization, the increasing awareness of global energy consumption, global warming, and environmental issues has in many countries forced authorities to make decisions about greenhouse gas emissions. In addition, the constant increase in crude oil prices has led societies to look for alternative fuel types and seek ways to rescue them from oil dependence [1]. Hydrogen fuel cells are a solid option for the future of fuels. Hydrogen is being seen opportunistically by many gas and water companies in Germany for its economic potential in gas-grid networks, facilitating what is known as power-to-gas [2]. Although the hydrogen economy seems propitious, hydrogen itself causes some unresolved problems. Fuel cells are expensive and require a completely new distribution network. Moreover, hydrogen storage also causes certain difficulties, as it is an explosive and a sensitive gas that further limits the large-scale prevention due to its low density [3]. Hydrogen is not found in pure form such as with oil or coal. Thus, hydrogen is bound to another element in nature. For example, water is obtained from the chemical reaction of hydrogen with oxygen, aided by a spark of energy. For this reason, pure hydrogen must be produced in a way that requires energy, such as gasoline. Because of the high energy losses within a hydrogen economy, the synthetic energy carrier cannot compete with electric energy [4]. Thus, electric energy may be considered as an alternative to conventional fuels. There are both advantages and disadvantages of electricity when it is stored. However, electricity is the most exceptional technology for the future because its infrastructure is ready and its technology is considered to be safe and reliable technology. Moreover, constant increasing fuel prices and emerging environmental awareness have forced societies to look for alternative transport solutions [5]. In the past, electric vehicles (EV) were not a strong alternative for internal-combustion engines (ICE) because of their weak batteries. However, recently batteries and EVs have been developed that have become important alternatives for conventional vehicles. Although battery prices are high and driving ranges are lower compared to conventional vehicles, EVs offer many direct and indirect benefits for society. There are many electricity transportation projects running all over the world, and EV technology and its trade are developing rapidly [6]. For this reason, it is extremely important to act in line with this technology and to obtain further innovations and concept developments [7].

Currently, transportation infrastructure consumes 26% of the annually produced energy; almost all of these energies are from fossil fuels. A total of 11% of the CO_2 emission of the world is caused by individual use on roads. The current CO_2 concentration that exists in the atmosphere is 286 ppm, and it is increasing at a rate of 2 ppm each year. Under normal conditions, it is predicted that it might be 700 ppm in some regions by 2100 [8]. It is thus of crucial importance that radical changes be made in the usage of fossil fuels to lower CO_2 emissions in the atmosphere, otherwise the earth will soon perish. The existing manufacturers must enforce new solutions to ensure efficient fuel consumption with legal restrictions on CO_2 emissions. The most important factor that will support these efforts is the widespread use of EVs for individual use [9]. Mass shifting to EVs, although a time-staking initiative, will significantly reduce CO_2 emissions, also having numerous added benefits.

EVs store large amounts of energy in a reliable form. Classic electric vehicles may be considered a form of load that charges and uses the batteries from the electricity grid, and charging is a one-way process from the grid to the vehicle [10]. The rate of using electric vehicles increases with each passing day and constitutes an additional burden on the existing grid. In this case, there is a need for extra investment in the infrastructure, and costs are quite high. At this point, the idea of using EVs as an energy source has come to the agenda. In this way, additional investment will be avoided in the existing system [11]. Today, electric vehicles transfer energy to the grid when the vehicle will not be used for a long time or when the electricity sales price is at its highest. This technology is called V2G. Users can charge the battery when energy prices are low and provide both the current energy demand of the grid and gain financial benefits. In the literature, this process is named grid-to-vehicle (G2V) technology. If the energy of the electric vehicle battery is supplied to individual houses instead of the grid, it is called as the V2H technology [12]. A general operation mode of the G2V, V2G, and V2H technologies are given in Figure 1.

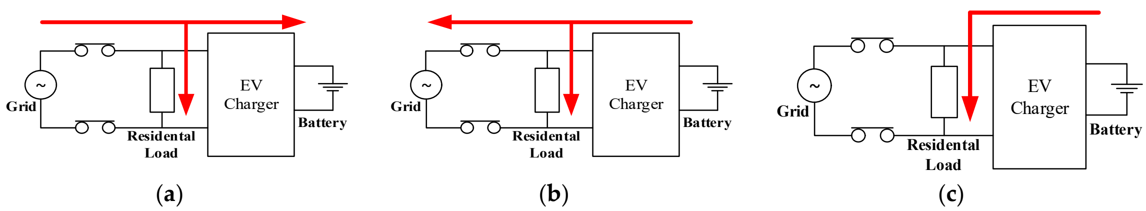

Figure 1. Operating modes of the bi-directional electric vehicle (EV) charger. (**a**) grid-to-vehicle (G2V) mode; (**b**) vehicle-to-grid (V2G) mode; (**c**) vehicle-to-home (V2H) mode [12].

Because V2G and V2H technologies are the fastest methods of meeting the increasing energy demand and can make an investment in the existing infrastructure, internationally recognized standards have been established. Thanks to these standards, a common language has been created among countries [13].

With the use of EVs together with renewable energy sources, the micro-grid structure is diversified in terms of relevant energy sources [14]. In this respect, as illustrated in Figure 2, the vertical bold line represents the grid, to which several power converters are connected, which converts the AC power of the grid into AC or DC of suitable magnitude for a device or machine connected to it, such as solar array, windmill, vehicles, uninterrupted power supplies (UPS), motor, lighting, appliances, generator, or FACTS devices. The figure shows that EVs are used as an energy source as well as a load when the user desires. This has also established a dynamic grid structure that ensures energy continuity [15].

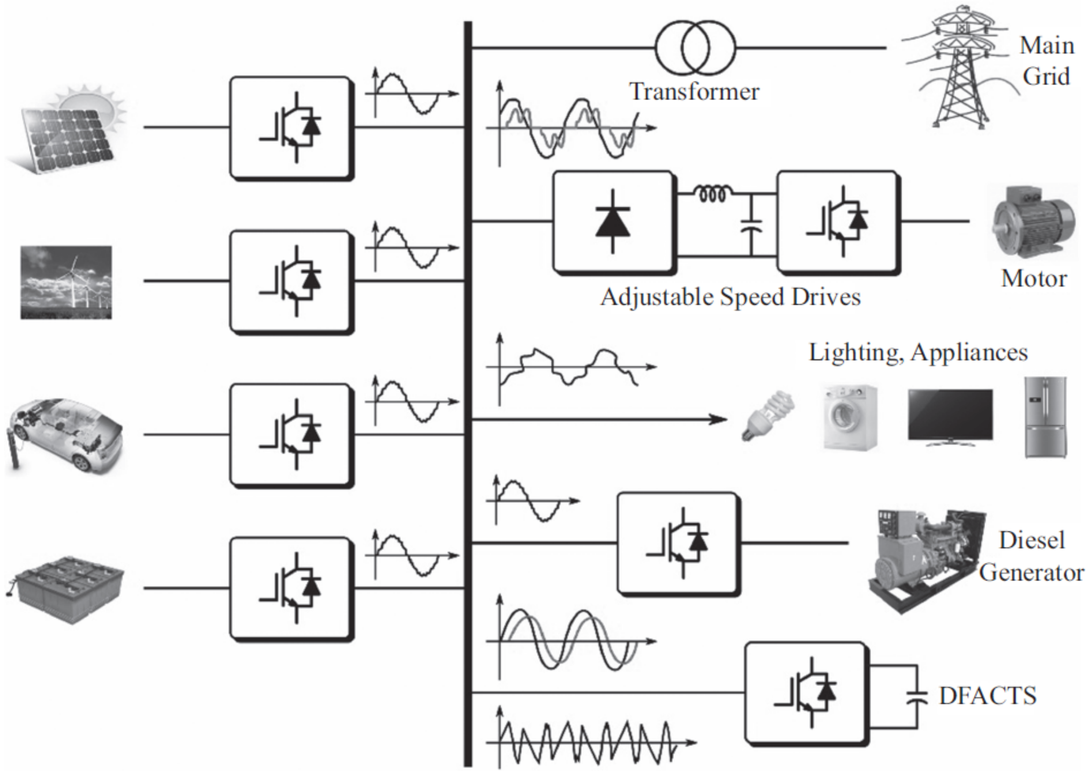

Figure 2. A general system structure for microgrid.

In this study, research in the literature and application types and standards have been investigated in order to operate EVs interactively with the grid and with houses. The grid-interactive bidirectional charging topologies are examined, and the advantages and disadvantages of these topologies are determined. Moreover, the system components are examined, and information on these components are given in detail. The rest of the sections are arranged as follows: Section 2 provides an overview of and introduction to the vehicle-to-X (V2X) technology in general, along with specific description of the V2G and V2H technologies. Section 3 outlines the many different charging topologies of the batteries of the EVs used in V2X technology. Section 4 contains an introduction to the communication standards used in V2X technologies, along with specifications of several such standards. Section 5 is composed of an elaborate discussion about the different types of AC/DC and DC/DC power converters, along with a comparative view of the types. This section is also embellished with a SWOT analysis of the V2G and V2H technologies. Next, the outcomes of this paper is discussed in Section 6. Finally, the conclusions are drawn in Section 7.

2. Vehicle to X (V2X)

Prior to learning about the V2G and V2H technologies mentioned in the title, it is important to know about their brothers, generalized by the term V2X, where X is a variable. When studies conducted in the literature are examined, it is seen that the name of the energy transfer technology depends on the target system to which the energy produced by the electric vehicle is transferred, that is, the recipient of energy [16]. As depicted in Figure 3, if an electric vehicle transfers the energy to another electric vehicle, the technology is called vehicle-to-vehicle (V2V); if the electric vehicle charges an electronic device, the technology is called vehicle-to-device (V2D); if the electric vehicle transfers the energy to the grid, the technology is named V2G; if the electric vehicle provides energy to a house, the technology is called V2H, or if the energy is transferred to a building, the technology is referred to as vehicle-to-building (V2B) [17]. In general, V2X technology provides a safe, sustainable, and competitive energy supply [18].

Figure 3. Different interaction modes of electric vehicles [18].

The amount of energy transferred from the vehicle to the grid depends on the number of vehicles in connection. For instance, V2H requires at least 1 or 3 vehicles, V2B requires at least 1 or 30 vehicles, and V2G requires at least 5 or 50 vehicles. The energy transfer from vehicle to the grid has to be achieved smoothly without changing the voltage, the power factor, or the frequency of the grid [19].

2.1. Vehicle to Grid (V2G)

V2G is the technology consisting of energy transfer in two directions, either from the vehicle to the grid if the energy stored in the battery is high, or from the grid to the vehicle when the energy stored in the battery is low [20]. The general block diagram of V2G structure is depicted in Figure 4. Since the energy flows to the vehicle from the grid, and from the grid to the vehicle, there occurs a bi-directional energy flow. During the energy flow, conversion operations are made with power electronics circuits to fit the type of power [21]. For the purpose of taking the voltage level of the current grid voltage to the appropriate level, firstly an AC/DC conversion system is carried out, and then the reduction is done with a descending converter. To transfer the DC energy in the battery to the grid, firstly, an additional operation is done with an increasing converter, and then the DC/AC conversion process is carried out. These operations are performed bi-directionally depending on the amount of energy in the battery. The purpose is to meet the energy demand by managing the energy in the battery or the grid [22].

The integration of plug-in hybrid vehicles (PHEV) with smart grids is also drawing significant attention of the scientific community because of its potential role in enhancing grid efficiency [23,24]. Hybrid electric vehicles usually charge their batteries through fuel, whereas electrical vehicles charge their batteries from the grid, thus having significant differences in charging circuitry and strategy [25]. However, both are of considerable interest in V2G technology. The EV is plugged into a charge station, which is connected to a power converter, followed by a transformer connected to the main grid. A control and monitoring unit is present to provide accurate input to the converter by comparing the reference signal and the outputs of the power converter (because the converter is bidirectional, both its sides can be considered as the output side). Given that electric vehicles are integrated into electric energy, they are considered as an alternative energy source for the grid. Moreover, they are also used as uninterrupted power supplies (UPS) [26]. The vehicles consisting of V2G technology are generally charged at times when electricity production is higher, or at times when the price of electricity is low at peak load times, selling the energy to the grid at peak load times with high prices or when there is energy demand. In addition, this system also provides extra energy to the grid, increasing the reliability and efficiency of the energy system [27]. The carbon emission level of V2G technology is very low, and it also works in compliance with renewable energy sources. One of the problems experienced by electric vehicles in transferring energy to the grid is the coordination with the grid operators, and another problem is the bidirectional energy and communication infrastructure [28]. Several modes of communication, such as global positioning systems [29,30] and cellular networks [31–33], are merged with the vehicles to take advantage of the vehicles in every way possible. Different intra-vehicle and inter-vehicle communication and wired or wireless protocols are established to analyze the viability, although they are still at their primary stage, requiring more contribution for greater enrichment [34].

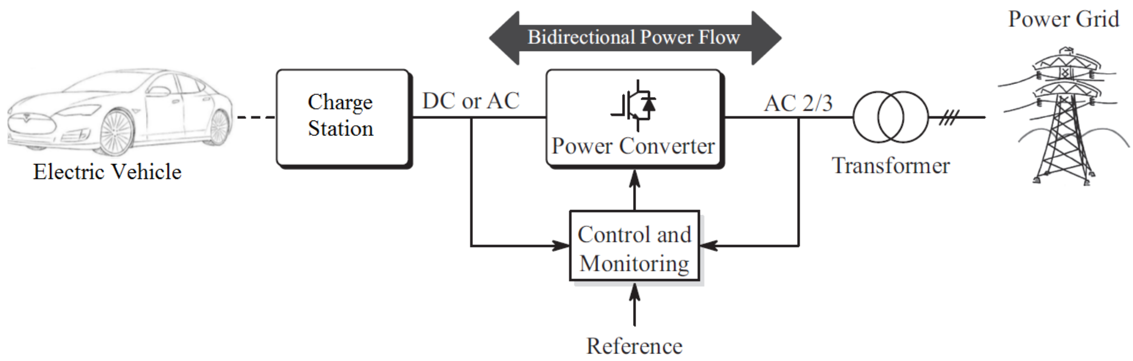

Figure 4. Block diagram of the V2G structure [22].

2.2. *Vehicle to Home (V2H)*

This technology refers to the systems in which the energy stored in batteries of the electric vehicles can be used as an energy source for houses [35]. For example, during the night, when power consumption is low on the grid, the battery can be charged and the stored energy can be sold to the grid when the energy consumption is high on the grid [36]. The V2H block diagram is shown in Figure 5. The electric vehicle is plugged into a charging station from where it gets energized. An energy management system and a home load manager are connected in parallel to the vehicle. The controllable switch before the transformer with the main grid controls whether power will be exchanged with the main grid or not. When the switch is open, the vehicle transfers energy to the home loads. The energy management system serves to supervise the energy transfer to ensure that everything is working normally. The size for a battery energy storage system in residences can vary from 3 to 30 kWh depending upon the manufacturer [37]. Therefore, V2H technology can play a significant role in exploiting EV energies to power up residential loads.

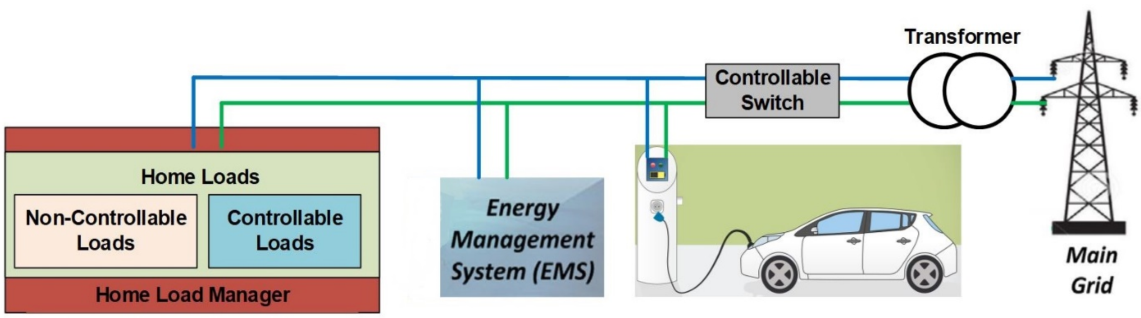

Figure 5. Block diagram of the V2H structure [36].

The infrastructure of V2H technology is similar to the V2G structure. The main activity in this case is to transfer energy from vehicles to houses, buildings, or other electrical vehicles in line with the existing energy capacity [38]. However, there are critical conditions for energy transferring. The most important of these conditions is the amount of energy.

As depicted in Table 1, if the energy is to be transferred to a detached house from an electric vehicle, the amount of power in the electric vehicle must be between 5 and 10 kW. In case of transferring from an electrical vehicle to a building, it must be between 10 and 15 kW. Or, if the energy is transferring from an electrical vehicle to another electrical vehicles, this value must be between 15 and 30 kW [39]. These standards are very important for energy efficiency, continuity, and reliability [40].

Table 1. Vehicle-to-X energy transfer range [39].

Power Flow	kW	Vehicle-to-X	Objective
Bi-directional	5–10	Vehicle-to-home (V2H)	It is used in case of emergency energy demand and for storage energy in the battery
Bi-directional	10–15	Vehicle-to-building (V2B)	It is used in case of emergency energy demand
Bi-directional	15–30	Vehicle-to-grid (V2G)	It is used to participate in the large scale energy market

3. Charging Systems of the Batteries of Electrical Vehicles

It is very important to store as much of the energy produced as possible. V2G technology works with specially designed bidirectional charging stations that allow the electrical vehicle owners to charge their vehicles while discharging the vehicle battery. The electricity in the batteries of electrical vehicles is transferred to the grid to compensate for the supply–demand balance in the electricity grid [40].

The ability of the batteries to charge and discharge depends on many factors, such as the design of the batteries, their charge status, temperature, former cycle history, and use. Depending on the charging strategies and charger size of the electric vehicle batteries, the peak power demand of the grid can vary [41]. This multiple dependency makes the determination of the charge status of the battery and the charging methods complicated. The battery charging methods used in the literature are constant current charging, constant voltage charging, and constant current–constant voltage charging. The charging current in the constant current scheme is equal for all battery groups that are connected in a series. As the charge status increases in batteries, the voltage must be increased in a constant manner to continue charging at constant current as the internal resistance also increases [42]. However, the charging current to be selected is very important in this method. This is because a high value of charging current allows the battery to be charged in a short time; however, it also causes damage to the battery because of overcharging and overheating. Charging the batteries at low current increases the charging times. At constant voltage, the battery charge draws a high current at the initial stage from the source because of the low battery internal resistance. This high current is limited to avoid damage to the elements. In constant voltage charging, the charging is started at full current of the charger by applying voltages that cannot cause damage to battery elements. After reaching the voltage level, called the float voltage, the current gradually begins to decrease. The charging current decreases in time because of the increasing battery internal resistance that stems from the increase in the charge [43]. This allows the charge to be completed with the leakage current, and in this way, the possibility of overcharging the battery is reduced. Because of the reduction in the charging current, the charging time of the battery becomes longer. Constant current–constant voltage charging is applied in two steps. For the purpose of eliminating the negative conditions, such as the overcharging of the batteries and pulling the overvoltage from the batteries, the battery is charged with a constant current until it reaches the preset voltage level; then, charging is continued with the constant voltage level [44].

The discharge levels, temperatures, and charge method parameters of the batteries of electrical vehicles affect the battery life cycle. To protect the battery life cycle, it is necessary to have a charging topology with a high efficiency or to select proper charging topology befitting the characteristics of the battery. The most important characteristics of these charge topologies are to provide the proper voltage level according to the energy flow direction and bidirectional energy flow [45]. Also, the methods are standard for battery charging of electrical vehicles. There are three main charging methods, named Type-1, Type-2 and Type-3. These are classified on the basis of their usage and applications. Type 1 charging method is used for vehicles, which are usually parked in residences and workplaces for a long time because of its single-phase system. The battery charging time being long and slow does not cause overload to the existing grid. For this reason, overnight charging is carried out to benefit from cheap electricity. When the battery is full, it provides power up to 3.7 kW and a maximum current of 16 A in Type 1 charging mode [46]. Type 2 charging method is used in places where there is heavy density, such as hotels, markets, hospitals, universities, airports, and shopping centers. It provides medium-speed charging within 1–4 hours of periods. It has a three-phase AC grid, and provides power between 11 and 22 kW, and a maximum current of 32 A [46]. Type 3 charging method is also defined as the method of fast charging. The battery charging time varies between 15 and 30 minutes, and these stations offer the possibility of charging batteries within short times in areas such as short breaks where there is an urgent need for energy. Although it has both the AC and DC model, it causes too much load for the network because of its high current value. The technical specifications of the charging stations used to charge batteries of EVs are categorized according to the type of the charging stations. They provide powers up to 43 kW for AC, and the maximum values for DC are 500 V and 125 A. In Type 3 charging method, there are safety measures present, such as the verification of the cable connection, not giving voltage when the cable is not connected, checking the ground connection, and reporting the maximum current capacity of the charger [47,48].

Overcharging of the batteries causes disruptions in the chemical structure and shortens their usage of life cycle. Charging systems have to work together with the battery management system to avoid overcharging. In addition, energy management systems are needed to ensure that batteries can be used safely under normal operating conditions and even in the event of accidents. The basic functions of battery management systems are to provide protection for the cells, heat management, charge/discharge control, data collection, communication with modules, data storage, and cell balancing [49]. In the case of the battery of the vehicle wearing out, the battery becomes eligible for a second-time use. The batteries are known as 'second life batteries', of which their major source is EVs. Such batteries can be repurposed for use in residences, telecommunication towers, building loads, and in power and transmission support [50]. They are very much cost-effective for their use in residential areas for following loads and backing-up the systems, the same as in other commercial and industrial areas [51].

The general energy flow diagram of charge/discharge processes of V2G and V2H structures is given in Figure 6. Different AC/DC and DC/DC topologies are used to increase the efficiency and performance of this system. There is a need for the control system to manage the energy flow, and, for this reason, all these topologies are employed in this respect. The charging time of electrical vehicles is longer when compared with fuel filling time. Fast charging methods are employed to shorten this time. In this method, the energy flow-control is applied up to 80% of the battery, and voltage control is applied over 80% [52].

The Li-ion battery pack is the battery of the vehicle, which is connected to a charger module. The grid supplies power to other loads and, by means of a suitable transformer to alter the magnitude, to the charger module. The charger module has two converters, firstly an AC/DC converter to convert the AC grid power into DC required by the battery, and secondly a DC/DC converter to change the magnitude of the DC power as necessary. Both these converters are controlled by the mechanism of pulse width modulation (PWM). This system is bidirectional and can work in either V2G or G2V technologies [52]. Li-ion batteries used in electrical vehicles have approximately 5000 life cycles. One charging and one discharging of the battery constitutes a cycle [53]. In Figure 7, when the number of cycles increases, the energy holding capacity of the battery decreases. Reduction of capacity also means shortening of battery life. A battery management system is needed to increase the operating time [54].

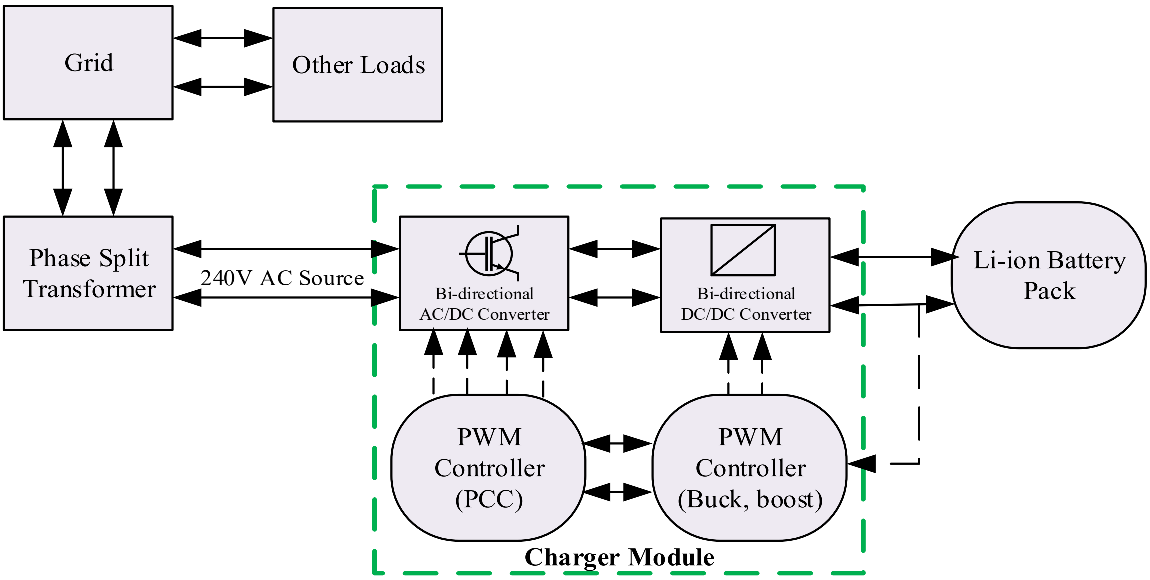

Figure 6. Generalized energy flow diagram for V2G and V2H system [52]. PWM: pulse width modulation.

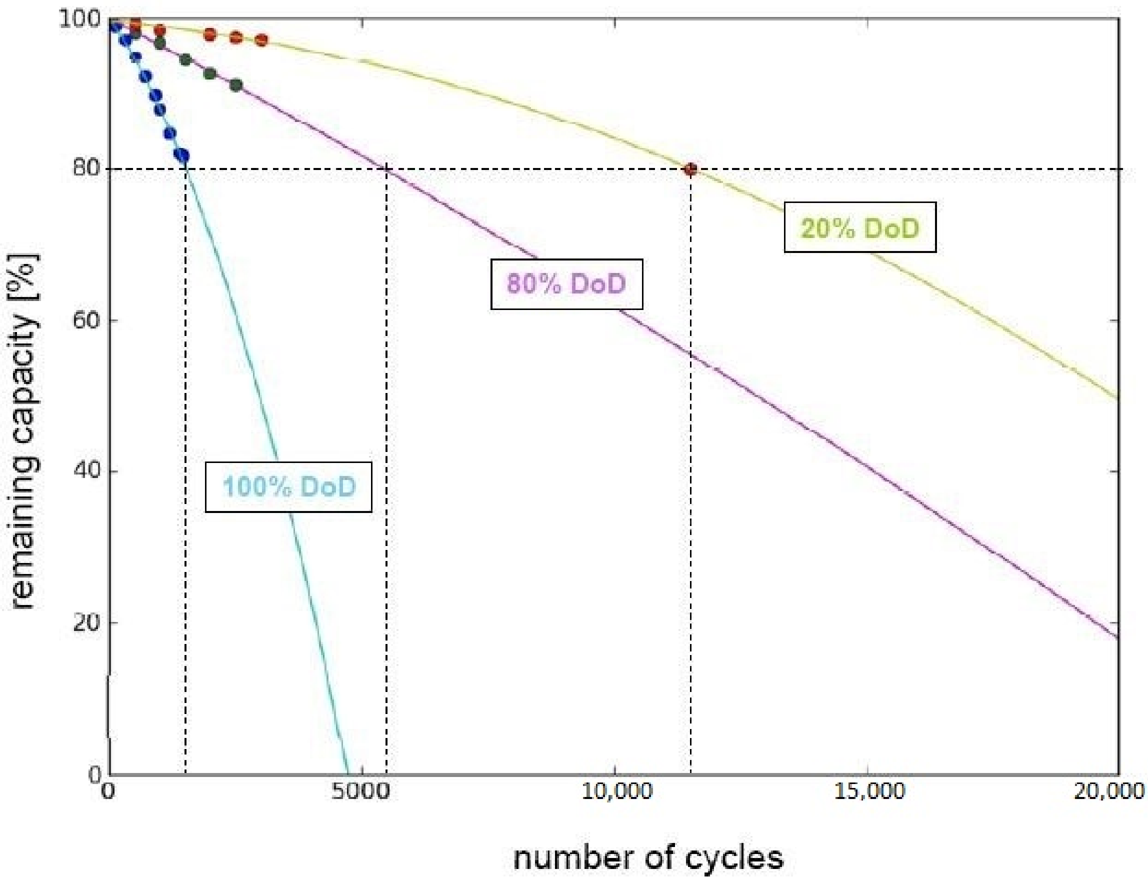

Figure 7. Li-ion battery usage curve: the energy storing capacity of the battery is found to drop with increasing number of charging/discharging cycles [55].

Determining the charging locations has fomented significant research interest among scientists and engineers. Optimum charging points are determined using various heuristic algorithms such as the genetic algorithm [56], non-linear auto regressive [57], flow refueling location model [58], maximum covering location problems [59], and agent-refueling multiple-size location problem [60]. This is usually important for V2B applications, as the buildings are densely located and the intermittency of loads are high. Queuing algorithms are efficient in such cases, wherein the charging stations need to balance the loads to minimize the charging time [61,62]. In such stations, the chargers are specified in three levels on the basis of their charging power and charging circuit [63]. Queuing models according to these levels helps to design the stochastic resource-sharing network to accommodate the convoluted distribution [64] and traffic [65,66] networks to make V2X more accessible.

Battery management systems (BMS) are important components in the provision of conditions such as safe operation, long-term reliability, and low cost of a battery. BMS increase battery life cycle and prevent damage to the battery, ensuring correct and reliable operation of the system [67,68].

The curve showing the relationship between temperature and battery output voltage is depicted in Figure 8. Accordingly, the battery temperature increases when the battery draws excess current. Therefore, the increased temperature also adversely affects the output voltage [69]. For this reason, the current is required to be limited to a certain value when the battery is in constant current mode. The limitation process is performed through BMS.

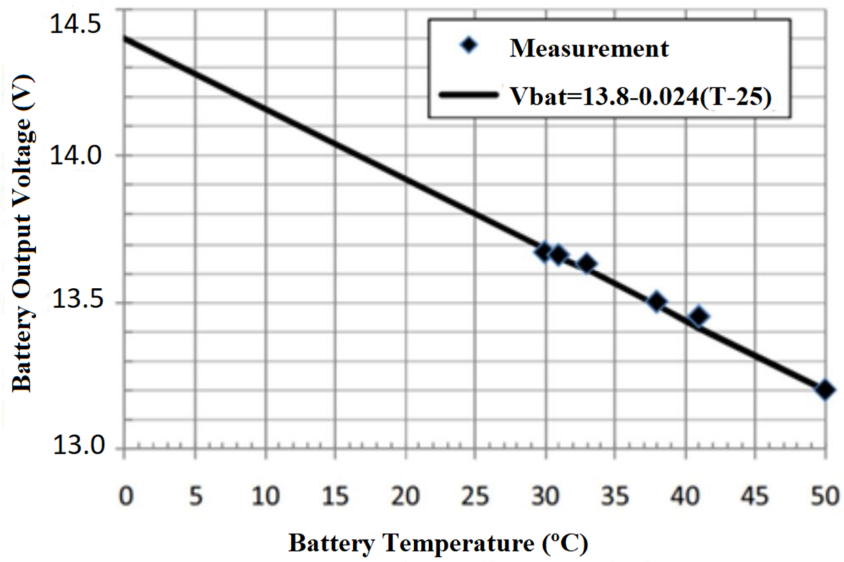

Figure 8. Relationship between temperature and battery output voltage: the output voltage reduces linearly with increasing battery temperature [69].

The BMS provide the balance of the voltage values of each cell that makes up the battery pack in order to maximize the capacity of the batteries and to prevent overcharging when charging [70]. In case of over voltage or under voltage in any cell, the system interferes in case of unbalanced voltage balances and the system enters the cutting [71]. When necessary, it provides balance by transferring the energy from the most filled cell to the least charged cell. In this way, BMS intervene in the system and prevent damages in the statement of system failure by interrupting. This is an extremely important system for the protection of high capacity and high cost battery packs [72].

BMS provide the protection of the system by interfering with the system when optimal values are exceeded, done by measuring the values presented to the user. BMS interfere with the high current which is drawn from batteries and interfere with the system during the high charge, the low voltages during discharge, the high temperature, the low temperature, and the leakage current formation. [73].

3.1. Various Converter Topologies Used in V2G and V2H Technologies

3.1.1. Isolated and Non-Isolated Converters

The magnitude and type of electrical energy changes according to the flow direction of the energy in the battery or in the grid. Power electronics topologies are employed for this change.

The bidirectional AC/DC power converter topologies used in the charging–discharging systems of batteries in V2G and V2H technology are classified as illustrated in Figure 9. The converters used for charging or energizing the grid operate in a bidirectional way. Converters have advantages as well as disadvantages in terms of quality of energy compared to preferred topologies [74].

Figure 9. Classification of bidirectional AC/DC power converter topologies: the bidirectional AC/DC power electronic converters are mainly of two types, isolated and non-isolated converters.

Non-isolated converters are obtained in structural terms by connecting an active and a passive semiconductor switching power element and an inductance in different ways. The operating mode of inductance converters is based on the transfer of energy that is stored in the inductor. As long as the semiconductor switching power element is actively transmitting, the energy that is provided by the source that is stored in the inductor being transferred to the cut-off by the semiconductor switching element, which results in the transfer to the load. The important disadvantage of these converters is the lack of isolation between the output and the input [75].

Isolated converters are used in situations when the electrical isolation is required in DC/DC transducer applications or where there is a high rate between input and output. Here, a transformer is used to provide isolation. In essence, the working principle of the isolated transformers is the same as the non-isolated converters. In other words, it is based on the logic of transferring the energy that is stored in the inductance. As long as the semiconductor switching element is actively transmitting, the energy that is provided by the source and stored in the inductor is transferred to the cut-off by the semiconductor switching element, which results in the transfer to the load.

The DC/DC or DC/AC power converters that are employed in charging topologies are usually controlled with two different methods, these being pulse width modulation (PWM) and frequency modulation (FM). In the FM technique, the output value is controlled by changing the pulse frequency of the semiconductor switching element, in other words, by changing its period [76]. However, this technique is mostly used in compulsory situations such as in temporary and low load situations. In addition, as a result of using this technique, fluctuations and noises occur in the output voltage. The PWM technique is widely used in industrial applications as it allows filtering of the fluctuations and noises at the input and output and because of its constant frequency operation. The PWM technique is a method in which the output value is controlled by adjusting the operating time of the semiconductor switch by changing the pulse width at constant frequency. Here, the determination of the operating time of the key by producing a control signal that is needed for the semiconductor switching element with PWM is shown in Figure 10 [77].

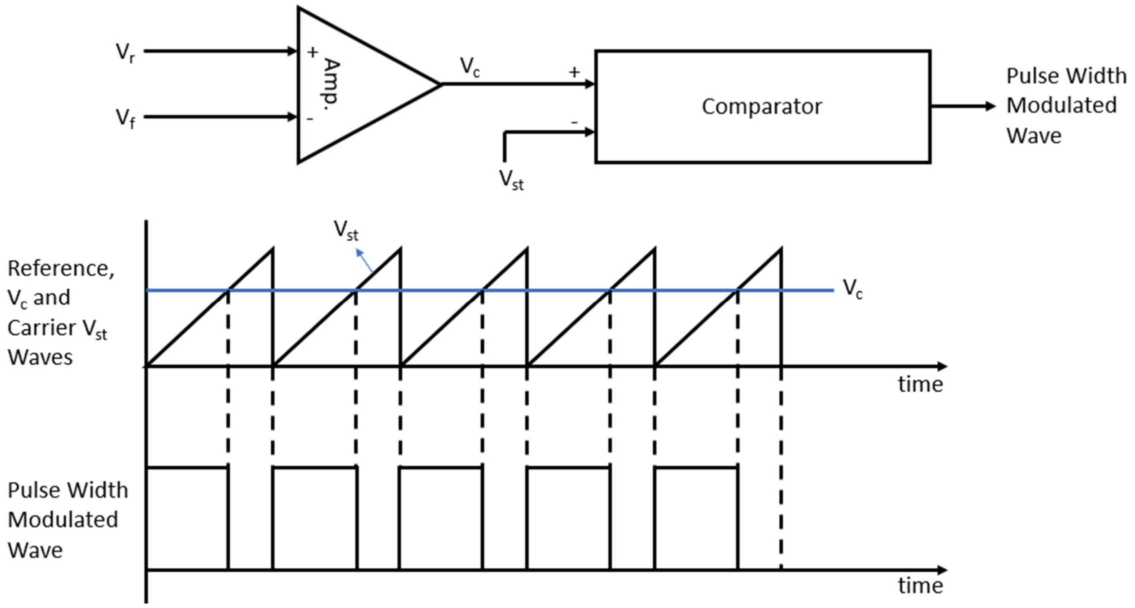

Figure 10. Pulse width modulation technique: a pulse width modulated wave is found by comparing a reference signal, Vc, and a carrier signal, Vst.

3.1.2. Bi-Directional Half-Bridge and Full-Bridge Controlled Converter

In Figure 11, the circuit diagram of a bi-directional half-bridge and full-bridge controlled converter is given. In the bidirectional half-bridge-controlled converter, the AC energy received from the electricity grid is converted into DC energy in half-bridge with the switching elements and is reduced to the voltage level of the battery by using the converter (buck converter). At the same time, the DC received from the battery is amplified by the boost converter circuit, which increases the voltage and then gives it to the grid by converting it from DC to AC through diodes [78]. In the bidirectional full-bridge-controlled converter, the conversion process from AC to DC is done through a full-bridge converter circuit. The other parts are the same as the bidirectional half-bridge-controlled converter [78,79].

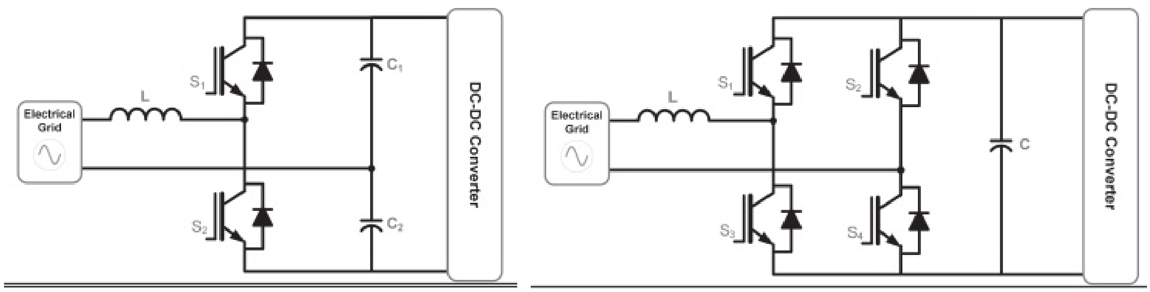

Figure 11. Bi-directional half-bridge and full-bridge controlled converter.

3.1.3. Bi-Directional Buck–Boost Isolated Converter

The charge level of the battery is required to be equal or more than the voltage converted from AC to DC. Similarly, it is necessary that the current level drawn from the battery is adequate in the conversion process. If these conditions do not exist, voltage collapse and similar negative situations occur. For this reason, the bi-directional buck–boost converter topology is needed in power electronics. In Figure 12, a bi-directional buck–boost converter and bi-directional isolated converter circuits are depicted. In the conversion process, the S1 switch is used in buck operation, and the S2 switch is used in boost operation [80]. Thus, the desired voltage level for the battery charge and the voltage levels needed in the battery to convert the energy to AC are obtained. In the bidirectional isolated converter, the DC voltage converted from the AC is transferred to the other side through an AC voltage and isolated transformer; then, it is converted into DC to charge the battery. The same processes also apply in transferring from the battery to the grid. Firstly, the voltage that is obtained from the battery is converted into AC and then transferred from the isolated transformer to the other side, thereby being converted into an alternating current through the AC voltage corrector circuit. Here, the grid and the battery part of the circuit are isolated with the isolated transformer circuit to ensure circuit protection [80,81].

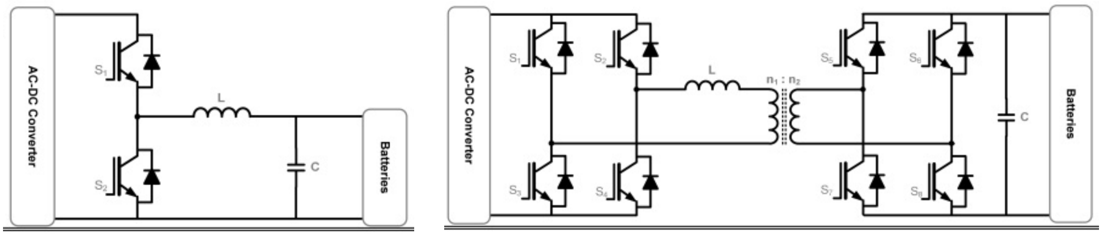

Figure 12. Bi-directional buck–boost converter and bi-directional isolated converter circuits.

3.1.4. Non-Isolated Charging Topology with PWM and Bi-Directional Buck–Boost DC/DC Converter

In Figure 13, the non-isolated charging topology, which consists of PWM (pulse width modulation) and bidirectional buck–boost DC/DC converter are shown [82]. Firstly, the AC grid signal is converted into DC voltage by the converter circuit and is filtered by the capacitor; then the battery is charged by using the S5 switch (reducing converter). Similarly, the DC voltage obtained from the battery is increased by the switch S6 (increasing converter), and converted into AC by the inverter circuit and given to the grid [83–85].

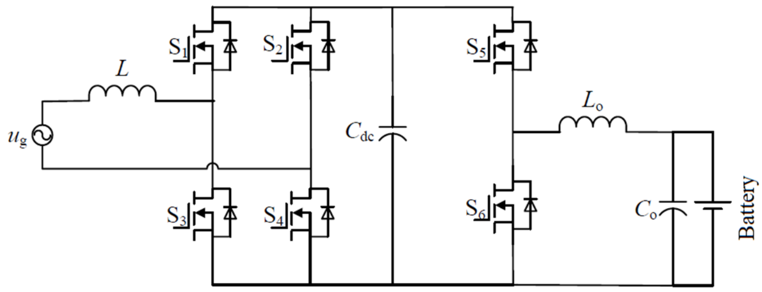

Figure 13. Non-isolated charging topology with PWM (pulse width modulation) and bidirectional buck–boost DC/DC converter.

3.1.5. The Non-Isolated Charging Topology with PWM and Bi-Directional Cascade DC/DC Buck–Boost Converter

Figure 14 illustrates the non-isolated topology, which consists of PWM (pulse width modulation) and the bidirectional cascade DC/DC buck–boost converter. Firstly, the grid signal is converted into DC voltage by the rectifying circuit and is then filtered by the capacitor and the coil. Then, the battery is charged by using the buck–boost converter circuit. Similarly, the DC energy obtained from the battery is increased with a converter circuit, which increases or decreases the voltage to the grid, and is then converted into AC voltage by the inverter circuit [86].

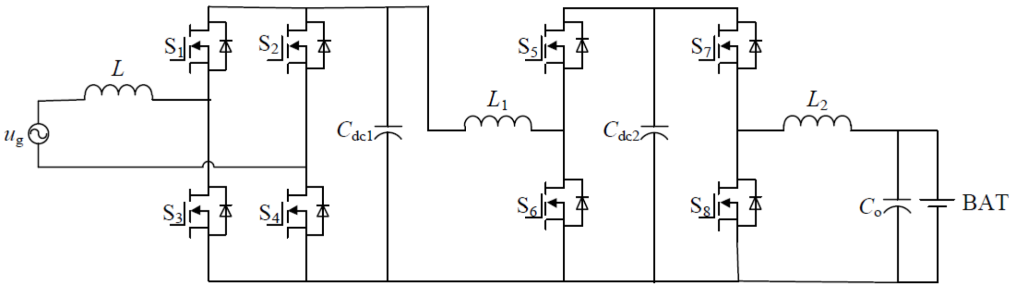

Figure 14. The non-isolated charging topology with PWM and bidirectional cascade DC/DC buck–boost converter.

3.1.6. The Two-Stage Topology with PWM Convertor—Active Double Bridge and Series Resonance Convertor

In Figure 15, the bidirectional topology is highlighted, consisting of a PWM converter and active double-bridge. In Figure 16, a two-stage topology is given, consisting of a PWM converter and series resonance converter. In both topologies, the grid and battery sides are isolated by using an isolated transformer [87,88]. In Figure 16, a capacitor is used in the topology, which consists of a series resonance converter, to increase the output voltage and efficiency [20,89]. Full-bridge AC/DC converter with PWM controllers are also widely used in different switching power converters [90,91].

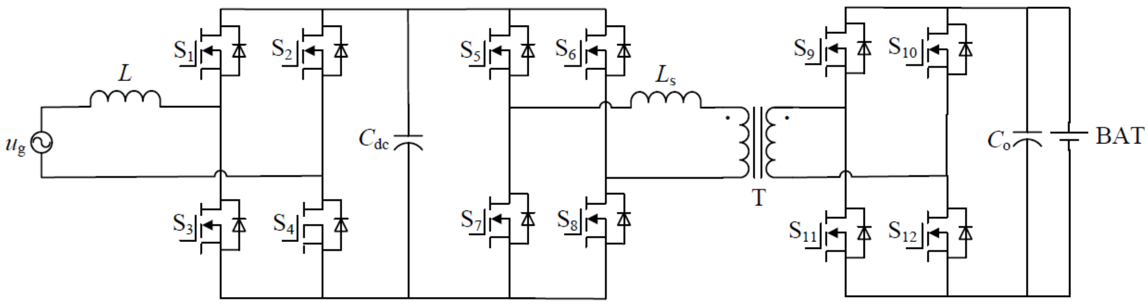

Figure 15. The two-stage topology with PWM convertor and active double bridge converter.

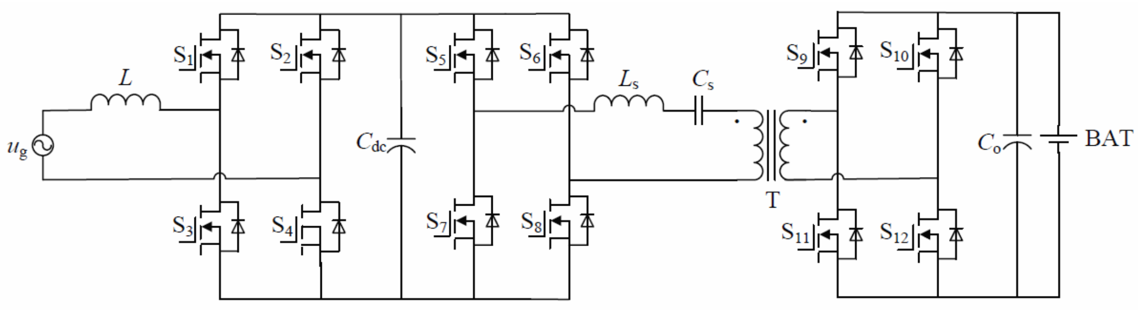

Figure 16. The two-stage topology with PWM converter and series resonance convertor.

3.1.7. Buck–Boost DC/DC Convertors

Buck–boost converters essentially consist of non-isolated type power converters, which consist of a functional combination of a buck converter and a boost converter. The factor, which determines whether such convertors work as buck or boost convertors, is determined by the duty rate (D), which is the rate of the pulse width to the total period [92]. When the semiconductor switching element in its structure is in the transfer position, it is fed only by the inductance, and in this way, the current passing through the inductance increases in a linear way, and the energy level of the inductance is increased [93]. The feeding of the load is provided by a capacitor. When the semiconductor switching element is in the cut-off position, the power diode starts transmission, and the output is fed by the energy that is accumulated in the inductance [94]. After this point, the inductance current decreases in a linear way, and the energy level of the inductance is reduced. Here, the power elements are exposed to the total of the input and output voltages [95]. In addition, since the direction of the output voltage is reverse to the input voltage direction, these converters are also known as inverted convertors [10]. The circuit structures, which show the basic circuits of the semiconductor switching element and the transmission and cutting status of the semiconductor switching element and basic waveforms, are given in Figure 17.

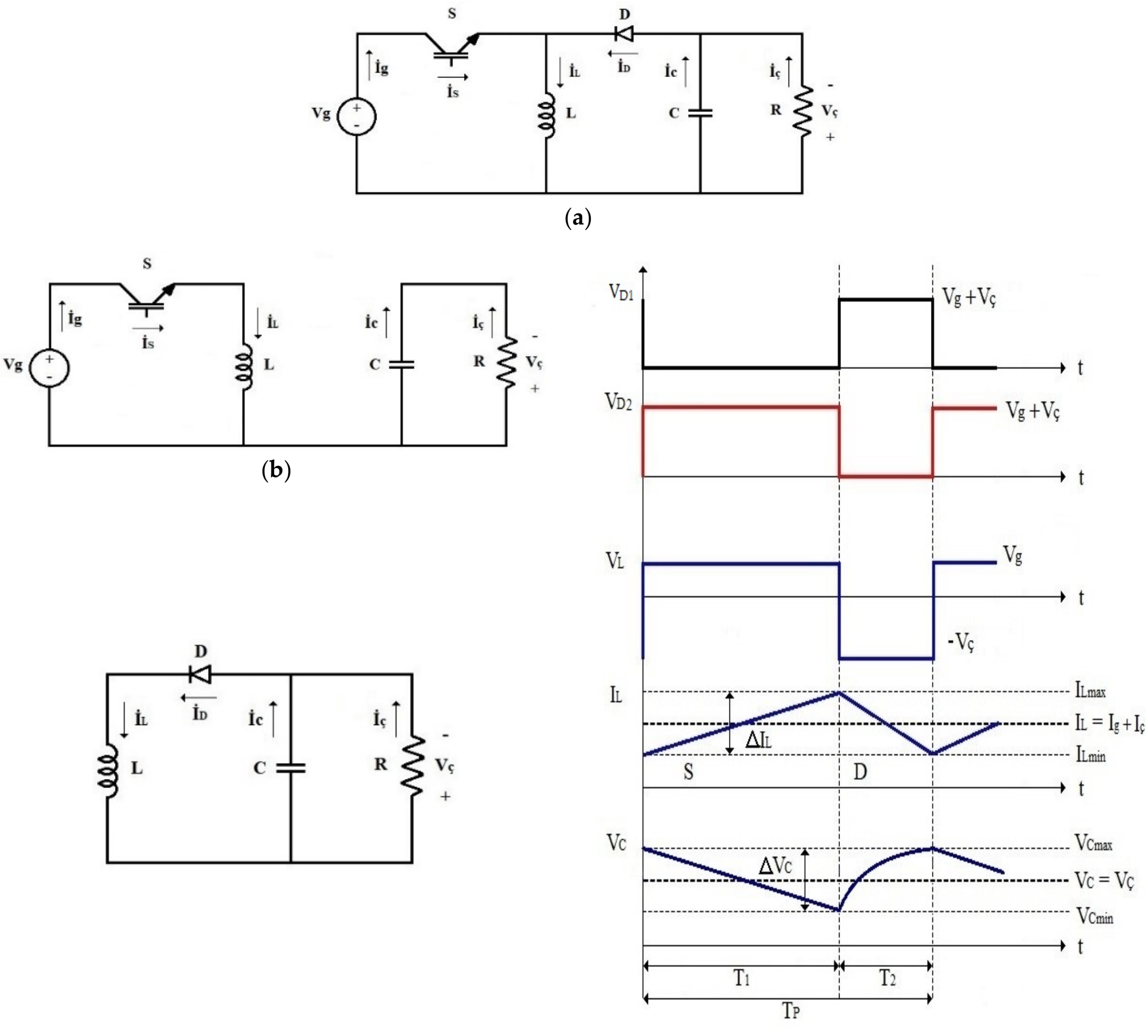

Figure 17. (**a**) Basic circuit, (**b**) status with turned-on IGBT, (**c**) status with turned-off IGBT, and (**d**) waveforms of the circuit of the buck–boost convertor.

4. Communication Standards in Electrical Vehicles

Interactive operation with the grid of electric vehicles and the communication methods used in the charging mode of electric vehicles cause a complex structure [96]. Seamless communication is required to design charging stations with sharing networks. To effectively schedule charging operation for the users, improved and resilient communications are imperative [97]. Various internet-based communication schemes [33,98–100] have been proposed to avoid the compatibility issues among charging stations. Furthermore, to prevent this negative situation, communication standards have been established, and it has become compulsory for the production companies to comply with these standards. There are four sets of standards considered for EVs: (1) plug, (2) communication, (3) charging topology, and (4) safety. All these standards are maintained in the V2G technology. These standards that apply to the charging of electrical vehicles are illustrated in Figure 18. The connector structures, the communication methods, the charging topologies, and the safety and the interoperability standards are given separately [101].

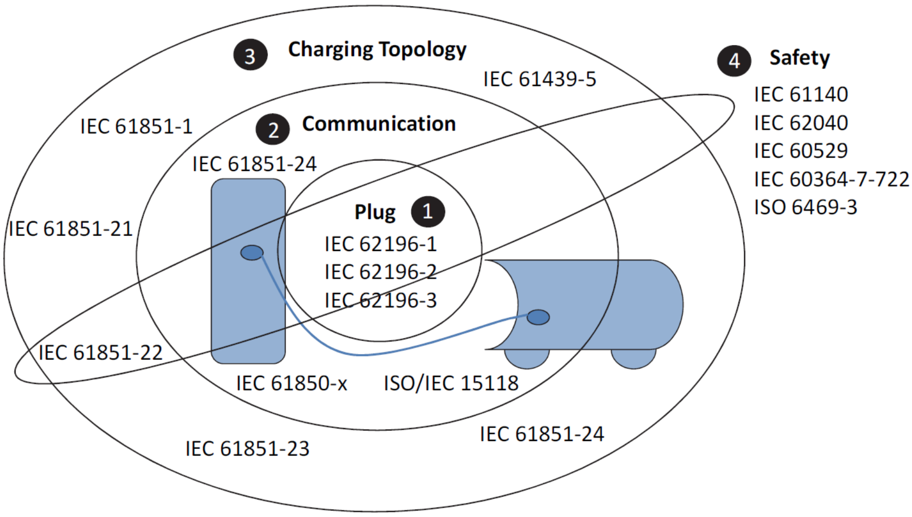

Figure 18. Standards on charging processes of electric vehicles.

In Figure 19, the sample communication standards of the vehicles using V2G technology are given [102–108].

- IEC 62196-1: Plugs, socket-outlets, vehicle couplers and vehicle inlets—conductive charging of electric vehicles, charging of electric vehicles up to 250 A AC and 400 A DC.
- IEC 62196-2: Plugs, socket-outlets, vehicle connectors and vehicle inlets—conductive charging of electrical vehicles, dimensional compatibility, and interchangeability requirements for AC pin and contact-tube accessories.
- IEC 62196-3: Plugs, socket-outlets, and vehicle couplers—conductive charging of electric vehicles, dimensional interchangeability requirements for pin, and contact-tube coupler with rated operating voltage up to 1000 V DC and rated current up to 400 A for dedicated DC charging.
- IEC 61850-x: Communication networks and systems in substations.
- ISO/IEC 15118: Vehicle-to-grid communication interface.
- IEC 61439-5: Low-voltage switchgear and control gear assemblies, and assemblies for power distribution in public networks.
- IEC 61851-1: Electrical vehicle conductive charging system—general requirements.
- IEC 61851-21: Electrical vehicle conductive charging system—electric vehicle requirements for conductive connection to an AC/DC supply.
- IEC 61851-22: Electrical vehicle conductive charging system—AC electric vehicle charging station.
- IEC 61851-23: Electrical vehicle conductive charging system—DC electric vehicle charging station.
- IEC 61851-24: Electrical vehicle conductive charging system—control communication protocol between off-board DC charger and electrical vehicles.
- IEC 61140: Protection against electric shock—common aspects for installation and equipment
- IEC 62040: Uninterruptible power systems (UPS).
- IEC 60529: Degrees of protection provided by enclosures (IP code).
- IEC 60364-7-722: Low voltage electrical installations, requirements for special installations, or locations—supply of electric vehicle.
- ISO 6469-3: Electrically propelled road vehicles, safety specification, and protection of persons against electric shock.

Both data and energy flow are bidirectional among the vehicles, charging stations, and the grid. The ISO/IEC 15110 standard is used for communication between the EV and the charging station, whereas the IEC 61850 standard is used for communication between the charging station and the grid. In addition, the communication among the charging stations and the smart grids are carried out to facilitate charging and supply tariffs dynamically [109–111]. EV fleeting operators (FO) are being highly recommended by researchers to utilize the new business opportunities by giving varying services to system operators [112,113].

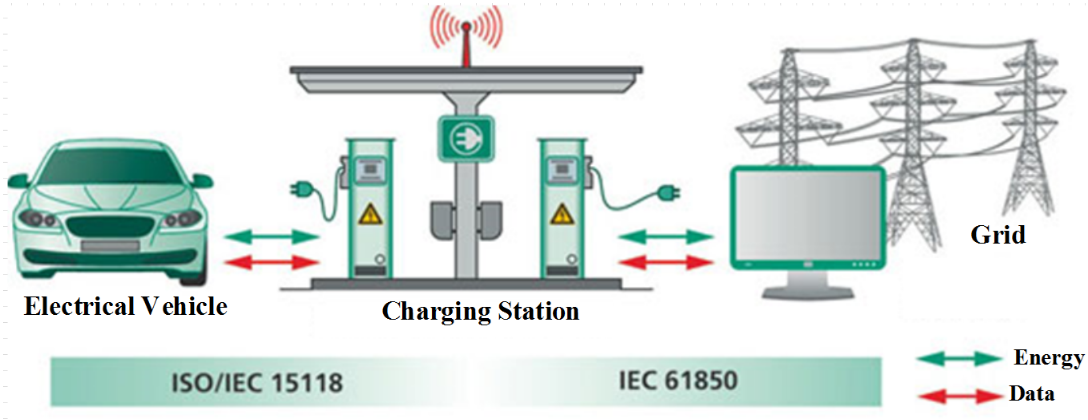

Figure 19. Sample communication standard of the vehicles using V2G technology.

As seen in Figure 20, when the connection socket is attached between the grid and the electrical vehicle, the identification, the authorization, and the verification procedures are done to ensure a secure connection.

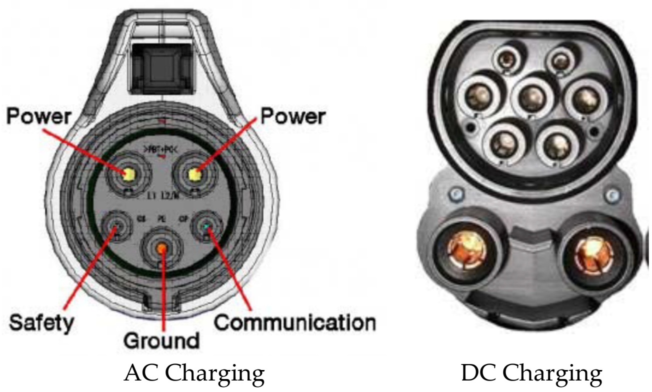

Figure 20. AC and DC charging socket structure. These sockets are attached with the vehicle and the grid for the transfer of energy between them.

5. Discussion

The bidirectional AC/DC converter topologies that are employed for V2G and V2H technologies and their features, advantages, and disadvantages are given in Table 2. In general, full-bridge topology is preferred in AC/DC conversion. As the power of the system increases, the number of the semiconductor switches that are employed in the switching process increases also, which, in return, increases the total harmonic distortion (THD) of the system while decreasing its efficiency. The output voltage of the converter varies depending on the battery voltage level or DC bus voltage (G2V or H2V). LC or LCL filters are preferred for connection to the grid in the V2G direction. These filters reduce ripples in the current and voltage.

Table 2. Comparison of bi-directional AC/DC inverter topologies for V2G applications in the literature.

Bi-Directional AC/DC Inverter Topology	Power	DC Bus Battery Voltage	Number of Switching Devices	Filter	Power Factor	Total Harmonic Distortion (THD)	Advantages/ Disadvantages	Ref. Number
Full bridge	500 W	60–120 V	4 IGBTs 4 MOSFETS	LC	1	not known	Low efficiency Hard switched	[114]
Full bridge	500 W	60–120 V	4 IGBTs	LC	0.99	4.3%	No DC bus capacitor	[114]
Full bridge	3.5 kW	300–340 V	4 IGBTs	RLC	1	not known	No isolation	[115]
Full bridge	3.6 kW	270–360 V	4 IGBTs	L	0.99	<3%	Low THD	[116]
Full bridge	3 kW	120 V	4 MOSFETS	-	1	4.5%	High THD	[1]
Full bridge	3.3 kW	400–450 V	4 IGBTs	LCL	variable	not known	Fast response, compensation	[117]
Full bridge	400 W	120 V	4 MOSFETS	LC	variable	6.15%	High THD, compensation	[118]
Three phase full bridge	20 kW	800 V	6 IGBTs	LCL	not known	3 %	99% efficiency (due to SIC devices)	[20]
Three level	18 kW	350 V	8 MOSFETS	-	1	2.3%	Low THD, more number of switches,	[119]
Single state isolation	3.3 kW	280–350 V	8 MOSFETS	3 LC	0.98	<5%	97% efficiency, complex control	[120]

The bidirectional DC/DC converter topologies used for V2G and V2H technologies and their properties, advantages, and disadvantages are given in Table 3. When the studies given in Table 3 are considered, for the increase of the voltage level for V2G or V2H transfer, or for the reduction of the voltage level for G2V transfer, the bidirectional buck–boost inverter is preferred. In the comparison table, the system feedback of the closed-cycle control system is employed with a current-controlled setting, voltage-controlled setting, or both together. As the battery voltage level increases, high-frequency switching is needed to control the system, and the efficiency of the system reduces. As the magnetic isolation between the inverter and the converter reduces the current and voltage ripples that are caused by the high-switching frequency, it increases the whole system efficiency.

Table 3. Comparison of bi-directional DC/DC converter topologies for V2G applications in the literature.

Bi-Directional DC/DC Convertor Topology	Type of Feed	Power	DC Bus Battery Voltage	Number of Switching Devices	Filter	Isolation	Switching Frequency	Efficiency	Advantages/ Disadvantages	Ref. Number
Buck–boost converter	Current–voltage feed	500 W	60–120 V	2 IGBTs	C	No	20 kHz	83%	Low efficiency, high current ripple	[121]
Buck–boost converter	Dual current feed	500 W	60–120 V	2 IGBTs	LC	No	10 kHz	<85%	Low efficiency, high current ripple	[122]
Buck–boost converter	Dual current feed	3.5 kW	270–360 V	2 IGBTs	LC	No	20 kHz	>90%	Fewer components	[123]
Buck–boost converter	Current–voltage feed	1.2 kW	100–130 V	2 IGBTs	LC	No	50 kHz	Not known	Fewer components	[124]
Interleaved buck–boost converter	Current–voltage feed	30 kW	170–200 V	4 IGBTs	C	No	20 kHz	Not known	High power transfer	[125]
Interleaved buck–boost converter	Current–voltage feed	400 W	120 V	4 IGBTs	C	No	20 kHz	>94%	Low power output	[117]
Cascaded buck–boost converter	Dual current feed	9 kW	350 V	4 IGBTs	LC	No	20 kHz	91%	High transient stability	[126]
Dual full bridge converter	Dual voltage feed	3.3 kW	230–430 V	8 IGBTs	CLC	Yes	250 kHz	Not known	High frequency	[96]
Dual full bridge converter	Dual voltage feed	30 kW	360 V	8 IGBTs	C	Yes	20 kHz	Not known	Compensation	[120]
Half full bridge converter	Current–voltage feed	1 kW	250–450 V	6 IGBTs	C	Yes	100 kHz	95%	High efficiency, control flexibility	[127]

Strengths of V2G and V2H technologies

- V2G and V2H technology ensures that the reactive power is compensated by providing active power or renewable energy sources in the existing grid.
- The advantages of V2G and V2H technology are not only possible for the grid, but also for the owners of electrical vehicles. These systems provide vehicle owners with continuous power support at home or at work.
- Increasing the capacities of the existing energy sources or preparing new energy sources necessitates high costs; therefore, it is less costly to have support from V2G or V2H technologies in periods when the demands are high.
- These technologies increase the energy quality, reliability, and sustainability by reducing frequency regulation and harmonic distortion.
- The technologies are compatible with micro grid and smart grid applications.
- Electrical vehicles provide more stable, safer, and more continuous energy backup or emergency energy support compared with solar wind and other renewable energy sources, which depend on charging.
- While electrical vehicle owners charge their vehicles at low-cost rates at night, they sell energy to the grid during peak hours when energy is expensive within the day, and, thus, obtain financial gains.

Weaknesses of V2G and V2H technologies

- The life cycle of the batteries will shorten as the charge–discharge process will increase the internal resistance considerably. This negative situation is considered as the disadvantage of these technologies.
- As the fast charging method also shortens the life cycle of batteries, the use of such technologies is not recommended because they cause the breakdown of batteries.
- Purchase of electric vehicles that have V2G or V2H technologies requires high initial costs.
- Coordination and standardization with the grid operators are difficult at initial steps.

Opportunities of V2G and V2H technologies

- The battery management system can be formed by using optimization and control algorithms to extend the service life of the battery.
- Software and hardware may be developed to measure battery health status to estimate the service life of batteries. In this way, the owner of the battery can be informed before the battery life ends, and thus measures can be taken in terms of contributing to the continuity of the energy.

Threats of V2G and V2H technologies

- As cyber-attacks are becoming increasingly complex, providing necessary measures to deal with current cyber threats will not provide adequate protection. The power system may also become vulnerable to new attacks in the future. For this reason, it is necessary that the basic components of the power system are defined and protected as a whole.
- Wired or wireless communication methods are employed to ensure the security between the energy systems, grids, electric vehicles, and charging station, which are among the critical infrastructures. For this reason, a possible cyber-attack to these critical communication methods may damage the whole system. Necessary preventions must be taken in this respect.
- All batteries lose their capacity over time. Therefore, the amount of energy to be transferred to the grid and the energy to be sold to the grid will decrease with time.

6. Outcomes

The purpose of this paper is to summarize and arrange all necessary information about V2G and V2H technologies, along with their communication standards and charging topologies, such that it provides a substantial knowledge to a beginner in this field. The key findings of this paper are listed below:

- The world's concern for the environment is on the rise, as traditionally-used non-renewable fuels are harmful and expensive. In order to ensure green transportation technologies, the concept of electric vehicles (EV) has come into the limelight. EVs run on electricity, posing no threats to the environment. They can also be developed on the basis of existing electricity infrastructures, making them less costly. Their additional advantage is that they can store electrical energy and can act as a source when not in use. This feature of EVs has ushered the dawn of V2X technologies.
- V2X is a general term where X is a variable representing either grid (G), home (H), device (D), building (B), or vehicle (V). These are technologies wherein electric energy is supplied from vehicles to the grid, a home, a device, a building, or to another vehicle.
- Vehicle to grid (V2G) technology is a bidirectional energy transfer between a vehicle and the electricity grid. The energy transfer also includes necessary AC/DC or DC/AC conversion, along with magnitude changing. The vehicle charges itself from the grid when the electricity demand is low, or when the electricity prices are less. On the other hand, the vehicle discharges or supplies energy to the grid during the peak demand hours when the electricity prices are high. Thus, the vehicle owner obtains a financial profit through this technology.
- Vehicle to home (V2H) technology is similar to the V2G technology, except that the energy transfer is between a home and the vehicle. If a vehicle supplies a house with energy during the peak hours, the demand on the grid reduces, making the electricity distribution smoother. Again, the vehicle can get charged from the off-peak hours.
- The charging systems of the batteries of the EVs depend on multiple factors, such as the design of the batteries, their charge status, temperature, former cycle history, and usage. There are two main charging systems, namely constant current charging, and constant current–constant voltage charging. The constant current charging often results in overcharging the battery, thereby overheating it and damages it. On the other hand, the constant current–constant voltage method eliminates the risk of overcharging but increases the charging time of the battery. As an optimization, the battery is charged at a constant current until a preset voltage is reached, and then charged at a constant voltage. A battery management system (BMS) is employed in the system to act as an overall controller of the battery health by monitoring its charge status, temperature, battery cycles, and other such parameters, providing data to and communication with other modules.
- The bidirectional AC/DC power converter topologies used in the charging–discharging systems of batteries in V2G and V2H technology are classified into isolated and non-isolated converters on the basis of the presence or absence of a transformer between input and output to provide isolation. The converters use either pulse width modulation (PWM) or frequency modulation (FM) to control the output voltage.
- The bidirectional AC/DC converters can be either half-bridge or full-bridge. In both cases, buck and boost converters are employed to reduce or enhance the voltage level.
- The voltage level of the receiver must be less than that of the supplier. Hence a definite voltage level must be maintained in the vehicle's battery in order to supply energy to or extract energy from the grid. Otherwise, a definite current level must be maintained to protect the battery, along with ensuring fast charging. These conditions are met using a bidirectional buck–boost isolated converter, which can alter the voltage levels as and when required.
- A non-isolated charging topology with PWM control can also be employed with bidirectional DC/DC buck–boost converters to raise or lower the voltage levels.

- Multiple units of DC/DC buck–boost converters can also be cascaded to perform multi-step reduction or amplification of voltage in case of the non-isolated charging topology with PWM control.
- The charging topology can also be composed of two-stages isolated by a transformer. The two stages can be formed either with a PWM converter and an active double bride converter, or with a PWM converter and a series resonance converter.
- Buck–boost converters are extensively employed in the V2G operation to obtain the desired voltage level in various stages of the energy transfer process.
- For a successful and organized transfer of energy in the V2G technology, a good communication is required between the vehicle and the grid operator. There are predefined communication standards set for this purpose. The standards vary according to the connector structures, the communication methods, the charging topologies, and the safety and the interoperability standards.
- In the V2G technology, both AC/DC and DC/DC converters are indispensable. There can be numerous topologies of these converters. For each type of AC/DC converter, the power consumption, power factor, number of switches, type of filter, merits and demerits, and THD are explored. Similarly, for the various types of DC/DC converters, the type of input, power consumption, efficiency, switching frequency, and merits and demerits are examined.
- Finally, an extensive SWOT analysis of the V2G technology is made, wherein it is evident that, despite the few weaknesses and threats, this emerging technology has a promising future and can contribute towards building a greener and much more efficient energy infrastructure.

The charging topologies and the communication standards of V2G and V2H technologies can be enriched further with more study, research, and development in this sector. There can be better charging topologies that will be efficient as well as inexpensive. The communication standards can be made more reliable and versatile so that the need for so many individual standards for individual purposes is quenched. Future research work in this field can be directed towards this motive.

7. Conclusions

This study is an assisting document for those who want to work in this field. With the help of the technology developed in recent years, electrical vehicles now have access to V2X technology. Electrical vehicles are useful for preventing greenhouse gas emissions and global energy and climate changes, and promoting the efficient use of energy and energy saving. V2G, V2H, or V2X technologies provide an efficient use of existing energy resources and also reduce the infrastructure costs of the planned energy sector. The continuity of the existing energy in the grid is ensured with V2G or V2H technologies, together with an efficient and reliable source formation, a stable operation, and a high quality of power. In the future, the problem of emission from vehicles will be eliminated completely by bringing the grid power connection standard in the electrical vehicles. Companies will form universal charging stations to charge their own electrical vehicles or to charge the vehicles of other companies, thus minimizing the charging time that is spent on battery charging by installing battery exchange units or battery rental stations. Thus, the world can shift to an era of smarter transportation and wiser energy management.

In the present study, V2G and V2H technologies were introduced, and information on their structures and components was given. The charging system of the batteries in the vehicles was narrated with brief talks about battery life, its health indicators, how different factors affect its health, and battery management systems. In addition, the topic was enhanced by including the power electronics topologies that are widely used in this sector. The basic idea and circuit structure were assessed for each converter topology. The communication standards used in this technology were indicated. A comparative assessment of the overall performance of different types of AC/DC and DC/DC converters was made that includes several parameters. Finally, a SWOT analysis of the V2G technology was made to elucidate that this technology will eventually bring in good results for the energy sector.

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