Impact of electric vehicles on smart grids and future predictions: A survey

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Abstract

Mobility has modernized urban areas using an efficient transportation system. However, mobility demand growth has accelerated the expansion of the conventional transportation system, which significantly contributes to pollution. The need for a green transportation system results in the eminence of electric vehicles (EVs). Besides, green mobility minimizes pollution from transportation systems and conventional power sources when EVs are optimally integrated into the utility grid. Thus, this paper assesses different significant optimum possibilities of grid-connected EVs. A review of the critical impacts of grid-tied EVs in the smart grid environment is presented. Vehicle to the grid (V2G) is the future of electric cars. This uses a bidirectional power flow of the EV's battery charging to either charge the car or sustain the utility grid in loading conditions. However, the V2G is highly affected by diverse loading conditions that challenge the network's acceptable voltage and optimal power-sharing within the electrical network. The power electronic converters are the primary interfaces that connect the EV to the utility grid. Therefore, intelligent control coordination of power electronic converters can also mitigate the detrimental impacts of the V2G system. It is observed that the V2G perspective is based on the 5Ds (decentralisation, de-carbonization, digitalization, deregulation, and democratization) vision to overcome the overall shortcomings in the modern power grid. The 5Ds vision of V2G implementation sustains different stakeholders working on the future of electric cars. Therefore, this research would be a stronger foundation for the new perspective and vision of V2G development and applications in modern power grids.

Keywords: Battery chargers, energy storage, mobility history, power electronic converters, optimal control, renewable energy, vehicle to grid (V2G), vehicle to X (V2X), 5Ds vision.

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1. Introduction

The greenhouse effect from global warming introduces carbon dioxide, and other gases in the atmosphere [1]. The transportation system holds more than 25% of the worldwide carbon dioxide emission [2]. The internal combustion engine (ICE) car is not environmentally friendly. The Electric vehicle (EV) supports sustainable development using green energy. Most of the conventional energy resources cause pollution and will eventually be depleted [3]. These challenges create stress in the energy sectors regarding the quality of life in the future and the ensuing energy resources crisis.

The environmental policy recommends renewable energy resources (RERs) to solve diverse challenges in the energy sector [4, 5]. The energy crisis leads to different micro and independent power producer connected to the grid [6–8]. EV participates in reducing pollution in the urban sector, saving depleting fuel and improving the quality of life on the earth [9]. The EV achieves a higher level of performance compared to the ICE car. The electric machine applied in the EV eliminates diverse components of the ICE car. It significantly reduces the power and weight ratio of the vehicle, which leads to a high-speed mobility system. The electric motors used in EVs must also be competitive with the traditional electric machines with excellent fault-tolerant capability, flexible control, harsh environmental sustainability, high starting torque, less electric noise, and robust structure [10, 11].

Power electronic devices have transformed the history of EVs [12]. This allowed a new generation of EVs to participate integrally in the reliability and sustainability of the power grid. The future of EVs deals with the electricity market and various applications to assist an optimal integration of electric cars into the power grid [13]. Integrating EVs into the utility grid is the future perspective of EVs. This integration operates within a bidirectional power mode [14]. The battery life is one of the essential parameters to consider during the ancillary services from EV to the power network [15]. The degradation of the battery will be assessed theoretically, empirically and semi-empirically to design an ageing model that can increase battery lifetime[16].

The implementation of EV connected to the grid (V2G) needs more attention to ensure that it is compatible with the electrical network requirements. The electricity producers, EV industry, EV owners, aggregators, electricity grid operators, and government are the main stakeholders whose collective efforts make the sociotechnical nature of V2G adoption efficient [17]. On the other hand, the expansion of V2G challenges the distribution network, and the intermittent and stochastic integration of EVs negatively affects the power supply security [18]. Several current research studies assess various strategies that deal with grid-tied EV systems [19–23]. However, it is found that there is a chasm of assessment regarding the impact of V2G to consider a bidirectional power flow environment, which provides future perspectives that predict an implementation vision for research and development and policies and programs for innovative power grid applications. Therefore, this paper presents an overview of V2G in the smart grid application during diverse loading conditions. This consists of assessing the impact of V2G on the system voltage/power. This review contributes to the conceptual design framework for sustainable implementation to optimal control for the connection interface of V2G. It is observed that aggregation plays an essential role in connecting the battery charging-based power electronic converter to the utility grid. It also offers an opportunity for an intelligent environment of V2G operation within a dynamic bidirectional power flow scheme. A perspective vision that makes the EV the future for transportation systems and distributed power grids is also provided.

The contributions of this research work are listed as follows:

- Review a brief historical modernization of EVs to assess better different regulations for implementations and applications of electric cars in smart grid environments.
- Assess the current technologies and strategies-based V2G system to deal with different problems that impact the optimal operation of the system.
- Offer a future vision that will carry out all policies and technology development for overall implementations of electric cars to enhance green transportation systems with a fast charging process of EVs and the optimal operation of grid-tied EVs to mitigate the negative impacts.

2. Historical Overview of EVs Modernization

The history of vehicles is varied and long. The first self-propelled car was built and designed by Niclas-Josef Cugnot and M. Brezin in 1769. The first vehicle was based on a steam-power motor carriage that could speed up to 6km/hr [24]. Besides, the steam engine did not last long in the history of the car due to its low-speed constraints and fuel quality. So its history was estimated from 1770 to 1920 [25]. The need to increase the speed of cars created new possibilities to improve the performance of the vehicle. In 1807, Francois Isaac de Rivaz invented the ICE to solve the mobility issue. A mixture of hydrogen and oxygen was used in the ICE to generate propulsion. Several engineers developed ICE systems during this period, but their designs were unsuccessful. This is because of the lack of quality fuel that humanity was experiencing to satisfy internal combustion. Luckily, the advent of EV solved this issue at the beginning of the 1800s [24]. It is stated in [25] that EVs started in 1834. In 1859, the first oil was discovered. Therefore, ICEs have been successful from 1885 up until these days. This success is for how much longer than EVs, which are the future [25]. Furthermore, EVs have a long history across generations.

2.1. *Early Age of EV*

The first small-scale electrical cars were developed in 1828-1835. This was the future thinking of the community of innovators from Hungary, the Netherlands and the USA. Nevertheless, during this period, people were using horses and buggies as the principal mobility mode. In 1830-1832, Robert Anderson had an idea to design the first crude EV [26], and Thomas Davenport developed the first battery EV in 1834 [27]. This took more than three decades, and electric cars became practicable only in the 1870s or later. The story noticed that this type of EV, in 1884, was built and produced massively by an English inventor, Thomas Parker [2, 26]. During the same century, it was observed in several cities, the first EVs worldwide [28].

In April 1881, Gustave Trouve´, a French inventor, developed the first human-carry EV. This electric car was successfully evaluated in central Paris [2]. On the other side of the North Atlantic Ocean in Moines-Iowa, William Morrison invented the first triumphant EV in the USA. Morrison's vehicle was slightly more than an electrical wagon [2, 29]. Therefore, their interest in William's invention sparked EV. This leads to an interesting observation made in 1896 that most early EVs were advertised exactly as carriages. Baker EVs were first produced in 1899 [27]. Therefore, EVs gained popularity due to their usage and being environmentally friendly compared to other automobiles.

2.2. *Heyday and Challenges of EVs Historic*

Mobility development has a long journey throughout humanity. The motor vehicle was made available in electric, gasoline and steam version at the end of the 1800s. The story of direct current (DC) cars and the extension of electricity revolutionized the transport system. These cars had several advantages compared to gasoline and steam cars, such as no-vibration-less, no-smell, no-noise, no-smell, no-vibration and easy and fast to start and drive because they did not have gear changes [25, 30]. The heyday of EVs was between 1900-1912. Following the advent of electric cars, this new century introduced all the rage in the USA about electrical mobility with several range options. In 1901, the increased demand for friendly transportation led to the technological improvement of electric cars. This superior electrical mobility inspired Thomas Edison to design an excellent battery. Ferdinand Porsche invented the world's first hybrid electric car in the same year, 1901. This was named the Lohner-Porsche mixte, powered by a gas engine and electricity stored in a battery [24, 29].

Between 1908 and 1912, a model T based on gas-powered cars was massively produced. This was widely affordable and available and dealt a blow to EVs. Henry Ford first created the model T. The electric starter was developed in 1912 to accelerate the sale of gas-powered cars [26, 27]. This also plays a significant role in the decline of EVs. One of the most critical factors that affected the fall of the EVs market environment was based on innovation that fulfilled the needs of consumers. For instance, in the 1910s, model T was innovative, but this model was outdated clunker in the 1920s [25]. Besides, the discovery of fuel for ICE in several regions, such as Texas, also plays a significant role in the decline of EV [30]. Political and economic factors also institute a major across-generation in the fall of EVs [31], and electric cars were also expensive [25, 30]. Furthermore, the downfall of EVs was caused by their lack of horsepower, the desire of people to travel long distances, and the availability of gasoline [32].

The decline in EVs was observed from 1920 to 1935. This was caused by excellent roads and the discovery of cheap crude oil in Texas. In 1935, all-electric cars disappeared and made room for gas-powered vehicles because the gasoline filling stations were extensively expended, even in remote sectors in the USA. The gas prices soared through the roof after three decades of gas-powered cars during 1968-1973. The need for alternative fuel for vehicles started in the 1960s-1970s. This ushered in a strong interest in EVs again[27]. In 1971, the first human-crewed vehicle to drive on the moon was an EV, which raised the profile of electric cars. The next generation of EVs was introduced in 1973. This was a prototype developed by General Motors and presented at the First Symposium on Low Power Systems Development [2]. Sebring-Vanguard was the first leader in EV sales, with more than 2000 sales of their CitiCar. In 1975, the company was the sixth-largest US automaker. EVs faded again in 1979. While the mobility requirements and demand were increasing, electric cars suffered several drawbacks and failed to satisfy the transportation market.

2.3. Electrical Cars Regulations and Modernization

The new regulations of the transportation markets in 1990-1992 reasserted EV interest [26]. The automakers started redesigning the popular cars into EVs to meet the system performance much closer to gasoline-powered vehicles. It is important to note that the modern EV era culminated in the 1980s, but it was released in the 1990s [2]. In 1996, from the ground up, General Motors devised and developed a cult following EV1 that enticed the transportation markets [29]. The Prius was the first hybrid car massively produced by Toyota. The Prius attracted the transportation market and was released worldwide by increasing the EV's profile. The improvement of EVs and their batteries were a concern among scientists and engineering communities in 1999. A startup in silicon valley, Tesla Motors, declared in 2006 their capacity to produce luxury sport EVs with a range of more than 200 miles. This announcement challenged other automakers who worked on EVs all over the world. From 2009-2013, US energy department investments developed nationwide charging infrastructure for EVs.

General Motors introduced the first plug-in hybrid for sale in 2010, commercially called Chevy Volt. In December of the same year, Nissan introduced an all-electric zero tailpipe emissions car named LEAF. Based on a loan from the Energy Department, the LEAF was assembled in January 2013 for the North American market. The most expensive component of EVs is the battery [2]. The Energy Department's investment led to a drop of 50% in battery costs within four years observed in 2013. Furthermore, diversity on EVs was launched in 2014. Various choices have been introduced, including hybrids, plug-in hybrids, and all-electric cars.

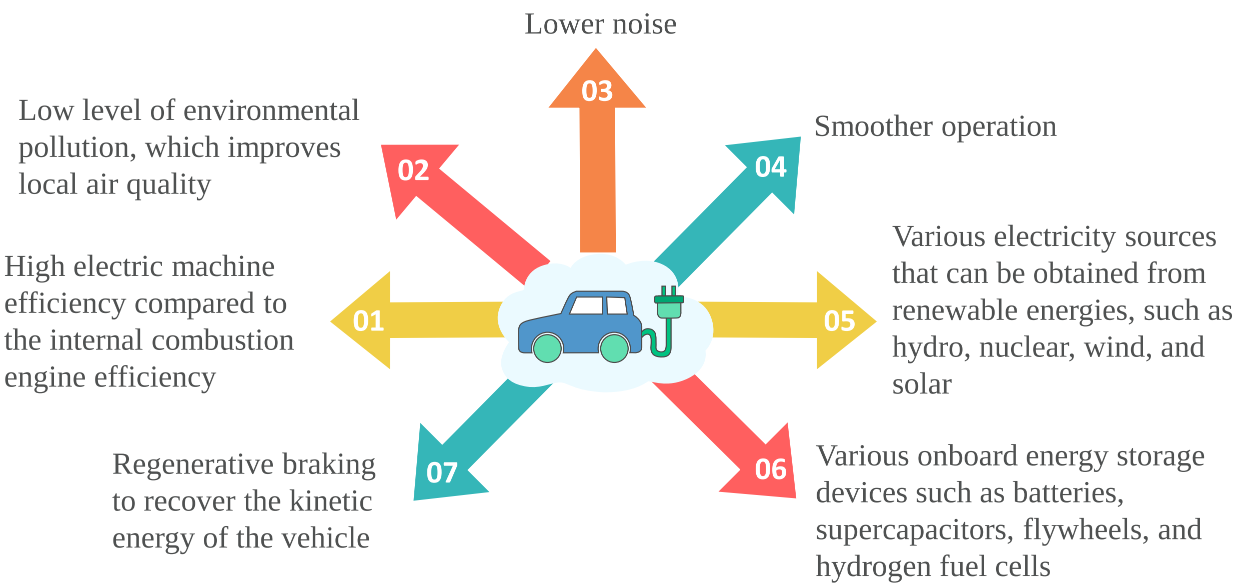
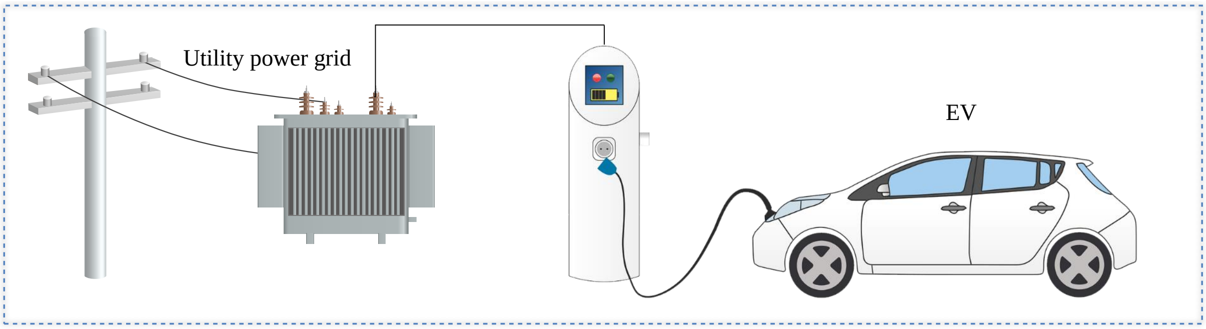


Figure 1: Key advantages of EVs.

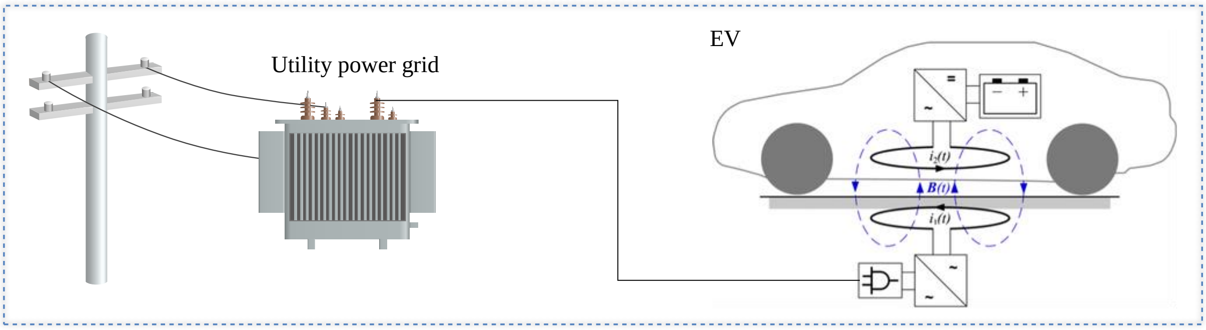
The future of EVs creates a sustainable vision to reduce oil dependency and minimize carbon pollution from the transportation system. Several countries, including China, Germany, Italy, Japan, Norway, South Korea and the US, have developed a new generation of electric cars. Figure 1 presents the most notable advantages of EVs in comparison with ICE cars [28]. EV is also a cost-efficient and nice driving car with greater torque than an ICE. On the other hand, three principal disadvantages of EVs are the high cost of the energy storage system, constraint car range on a single charge, and long battery charging time [26]. The gridable EV (GEV) is the present and future electric car that can charge and discharge power to the utility grid [27]. GEV was introduced under the concept of the vehicle to grid (V2G) in 1997 by Kempton and Letendre [13, 33]. Therefore, V2G is a well-known concept to describe the novel generation of EVs. Figure 2 presents the two connections of GEV currently implemented to support the optimal operation of the system [34]. The efficient process of future EVs requires applying renewable energy resources, such as solar photovoltaic [35], with several intelligent applications for enhancing mobility and reducing atmospheric pollution.

3. Development and Implementation of EVs

Figure 3 presents various benefits that can be used to justify the development and implementation of EVs [28]. The efficient operation of an EV requires intense coordination of different components to produce a mechanical movement. Apart from the main advantages of EVs, as detailed in Fig. 1, high- performance is the principal advantage of EVs that can make the ICE counterparts obsolete shortly. The drawbacks of the electric car can be resolved effectively by the improved technology, which makes the EV the future vehicle. Some relevant advantages of electric cars are high driving response, lower driving and maintenance cost, high torque and power, highly safe, single-speed transmission, and effective traction control.



(a) Wired Charging system of V2G (updated from [36]).



(b) Wireless charging system of V2G (updated from [37]).

Figure 2: Types of GEV applied in the current regulation and modernization of electric cars.

3.1. *Electric Motor*

The electric motor is the engine of the propulsion system of EVs. Several types of electric motors are used for this purpose. Table 1 classifies different motors used to guarantee the propulsion system of EVs' fallibility. The propulsion system can be based on a single motor or multi-motor drive that can operate with or without gears. The propulsion system design of EV motors, as detailed in Table 1 and specified in Fig. 3, requires an acceptable characteristics relationship between torque and speed, cost-effectiveness, excellent reliability, high efficiency over broad torque

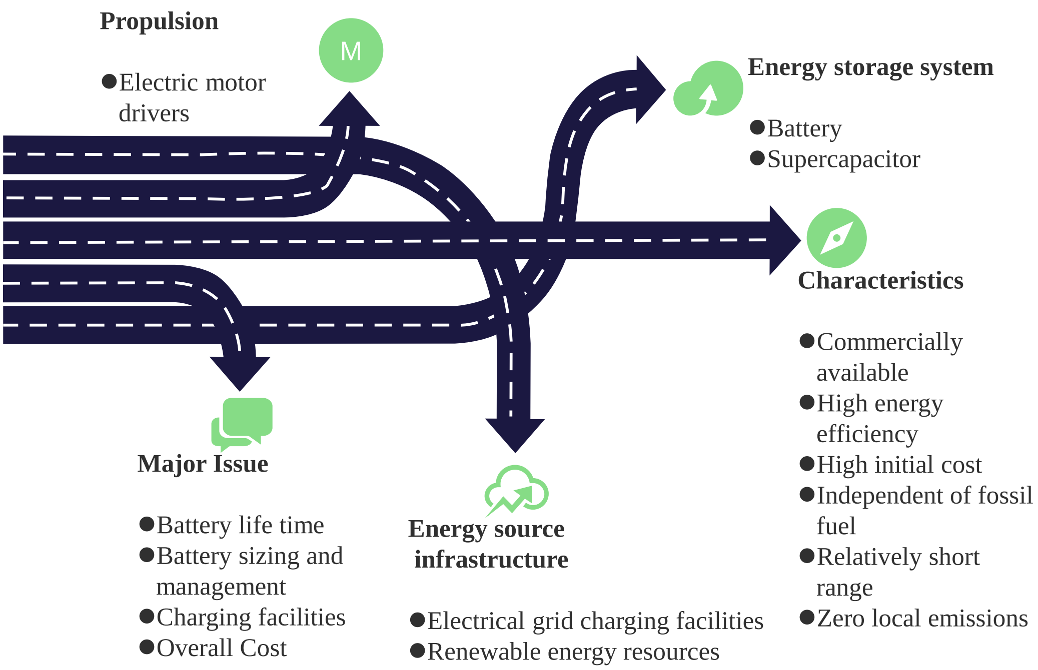


Figure 3: Features of EVs [38].

and speed ranges and power ratings. In addition, the EV electric motor needs a higher current density electric machine with the highest standard operation requirements compared to the traditional motor operating at the same power rating [10, 28].

The electric machines of the EV propulsion system can operate either in alternative current (AC) or direct current (DC) based on specified design requirements. Among the AC motors detailed in Table 1, the induction motor, despite being the workhorse of modern industry [39], is challenging to control the speed of induction motor; thus, it is classified to be the last in the list of matching the requirement of EV's propulsion system[10]. Therefore, a vector-controlled induction motor is used. However, this system presents a lower efficiency at light loads, which is not acceptable for EV propulsion requirements. Therefore, the permanent magnet (PM) brushless DC motors type is the first. These motors have the best power density and torque vs speed characteristics, less maintenance, long life, low electromagnetic interference and quiet operation. Therefore, the AC PM synchronous motor and switched reluctance motor are classified as the second and the third [11]. However, DC motors possess several drawbacks, especially regarding electric noise, speed range, power density and operating life. This makes the DC motors less competitive than the induction motor [10, 40].

3.2. Energy Storage System

The energy storage system (ESS) of EVs holds a significant part of electric car performance. The ESS requirements for an excellent rendition of system mobility must be safe in all operating conditions with an incredible life cycle, calendar life or self-discharge, high energy and power den-

Table 1: Various classified motor applications in EV.

Current type	Model	Technology	Reference
Sinusoidal fed AC	Induction Motor	1. Wound	[41]
		2. Squirrel cage	[42]
	Synchronous (PMSM)	1. Surface	[43]
		2. Interior	[44]
Rectangular fed AC	PM Brushless DC	1. Surface	[45]
		2. Interior	[46]
	Reluctance motor		[47]
DC fed	Self-excited	1. Shunt	[48]
		2. Series	[49]
	Separately excited	1. PM excited	[50]
		2. Field excited	[51]

sity, adequate charging acceptance capacity, and be cost-effective [28, 52]. Some critical features are nominal voltage and operating temperature [10]. The power sources of electric cars are based on electrochemical energy storage, well known as batteries [3]. The energy storage system (ESS) of EVs also uses electric energy storage. This ESS is called a supercapacitor or ultracapacitor with electrical double-layer capacitors [3, 10]. The battery pack plays a significant role in the design and performance of EVs. About 11 types of batteries can be used in electric car applications, and any battery can be used as a power supply for EV [10]. This has been observed in several EVs developed wide-world. Nevertheless, a battery must meet all requirements for EVs [28].

Table 2 presents the most popular energy storage (ES) technologies in EVs and hybrid electric vehicles (HEV). It also describes their advantages, drawbacks, and essential features for the V2G system. These ES are lead-acid, lithium-ion, nickel-metal hybrid, and ultracapacitors. The lithium-ion batteries are used in different applications and possess several types, including lithium cobalt oxide, lithium iron phosphate, lithium manganese oxide, lithium nickel cobalt aluminium oxide and lithium nickel manganese cobalt oxide [53].

Table 2: Types of ESS for EV applications: pros, cons and features.

Type	Advantages	Drawbacks	Features
Lead-Acid Batteries	Affordable; Designed and developed for high power; Reliable; Safe; Technical maturity [54]	Low energy and power densities; High maintenance requirements; Material consumption; Poor cold-temperature performance; Short life cycle due to sulfation issues; Short response time; Toxicity [54, 55].	High-performance; The most mature electronically ESS; Operation in a broader range of EVs; Advanced high-power BESS are developed for available commercial EVs with ancillary loads [55, 56].
Lithium-Ion Batteries	Excellent life cycle; high-temperature performance; fast charging capabilities; High energy efficiency; High energy and power densities compared to other batteries; Long internal resistance and lifespan; Low maintenance; Low self-discharge; Short response time [53, 54, 57].	High manufacturing cost; Life cycle dependent on discharge levels; Low usage; Overheating that creates safety problems and can lead to an explosion [53, 54, 58]	Applications for high target velocity curve; Attractive ES technologies; Battery recycling; Suitable for HEV; [56, 59].
Nickel-Metal Hydride Batteries	Excellent safety and abuse tolerance; Long life cycle; Technical maturity [60].	High cost; High maintenance requirements; Low energy density; Low power density; Short response time; Required hydrogen loss control; Toxicity; Overheating and self-discharge problem at high temperatures [61].	Most common used batteries in different applications (e.g. HEVs, utility ESS, etc.) due to their excellent specific energy and power capabilities [62].

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Type	Advantages	Drawbacks	Features
Ultracapacitors	Fast charge and discharge; Excellent safety performance (no pollution and memory effect); High power density; Long-life cycle [63].	Required protection over both charging and discharging process and line control; Unable to discharge large current [64].	Supported several applications of other BESS to mitigate the overcharge and dry conditions; Assisted in the acceleration and hill-climbing with fast recover braking energy of EVs [65, 66].

3.3. Power Electronic Devices

Table 1 presents different motors that can be implemented for the mobility of EVs. The fed AC motors offer several advantages that suit the performance requirements of the electric car. The power electronic devices invert the DC power supply from the battery to AC to supply the motor. The converter DC to DC can also be used for DC motor-based electric cars. Several types of power electronic devices are used for electric drivers [11]. The brain of EVs is based on the power electronic devices for the electric driver. This controls the speed of the car by varying the supplier frequency and coordinating motor power output by varying the amplitude of the AC power [28].

For the efficient operation of EVs, there are four operating modes of an electric motor: speed (positive and negative) and torque (positive and negative). These are forward (motoring and braking) and reverse (motoring and braking) [67]. In addition, it is necessary to specify that the regenerative braking system of the electric car also makes the vehicle's driving system efficient by using only one pedal. During the regenerative braking mode, the electric motor needs to be controlled as a generator [39]. This powerful system avoids overheating the car due to the tremendous kinetic energy that is saved and converted to electricity. The power electronic interface adjusts the input power frequency and keeps the rotating magnetic field speed in generator mode. This operation is also based on a freewheeling process where all passive components (inductor and capacitor) will transfer their energy to the battery [39, 68].

3.4. Charging System for ESS

The battery charger of EVs maintains the state of charge of electric cars. The charger-based-power electronic converters connect the ESS of the EVs to an external electrical network to charge/discharge the battery. The charging system of electric vehicles requires several standardizations to avoid unexpected voltage and power-sharing disturbances between the grid and the charger. Fig. 4 presents various converter topologies that can be used for the EVs battery charger

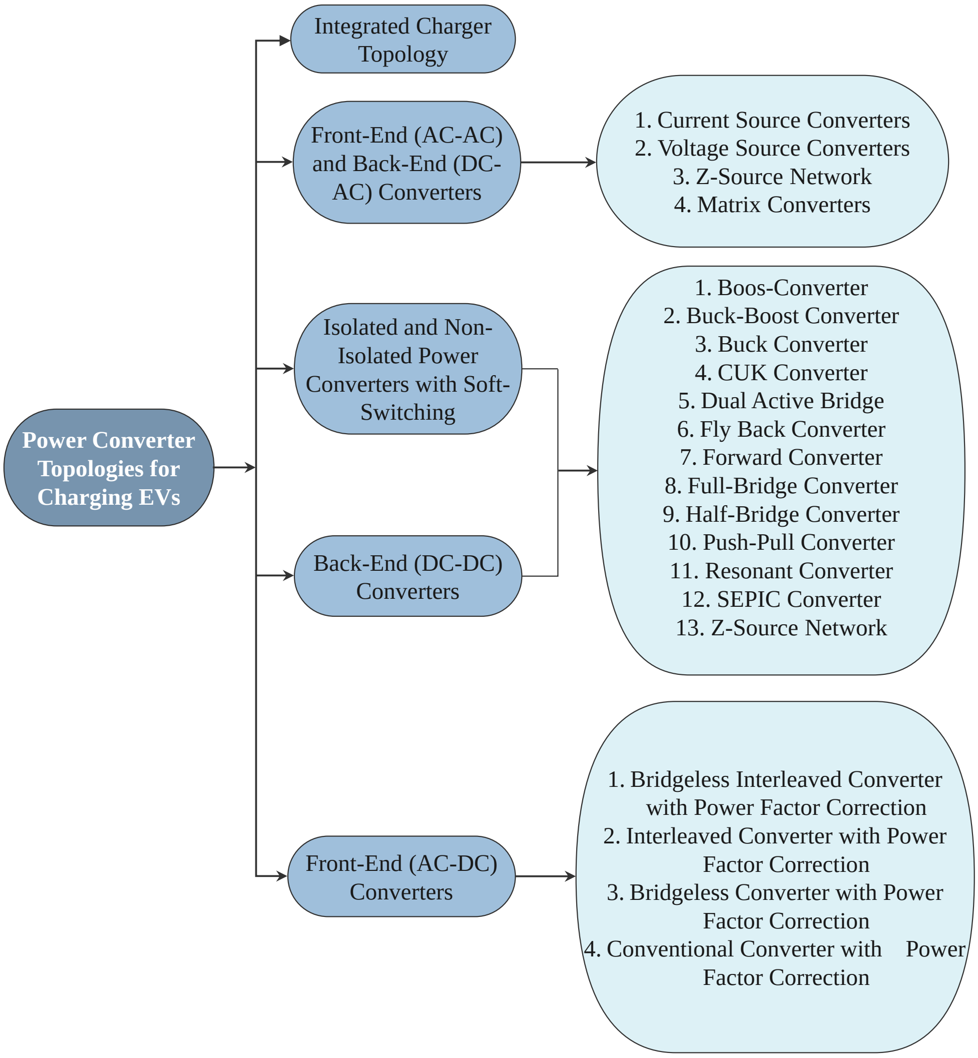

Figure 4: Power electronic converters for EVs' charging system.

[69]. The structure details different converter typologies used in EVs. It should also be necessary to notice that the power electronic converters for EVs can also contain a multi-input system [12]. The charging system offers diverse opportunities to connect EVs [70]. This can be from vehicle to vehicle (V2V), vehicle to home (V2H) and vehicle to grid (V2G) [27]. The weight of power electronic interfaces negatively affects the performance of EVs. Eliminating some switching components from the charger and propulsion system can increase the overall efficiency of the EVs [68]. As detailed in Figs. 2a and 2b, the battery chargers of the EVs have two types of charging stations, namely wired (AC and DC) and wireless (using magnetic induction) configurations [34]. It is necessary to specify that the inductive wireless power transfer (WPT) system for EVs does not eliminate the power electronic devices of the charging system [71]. This is because the WPT is based on the power transformer component [67]; therefore, the need for power electronic converters is critical for an efficient dynamic operation of EVs.

4. Vehicle to Grid

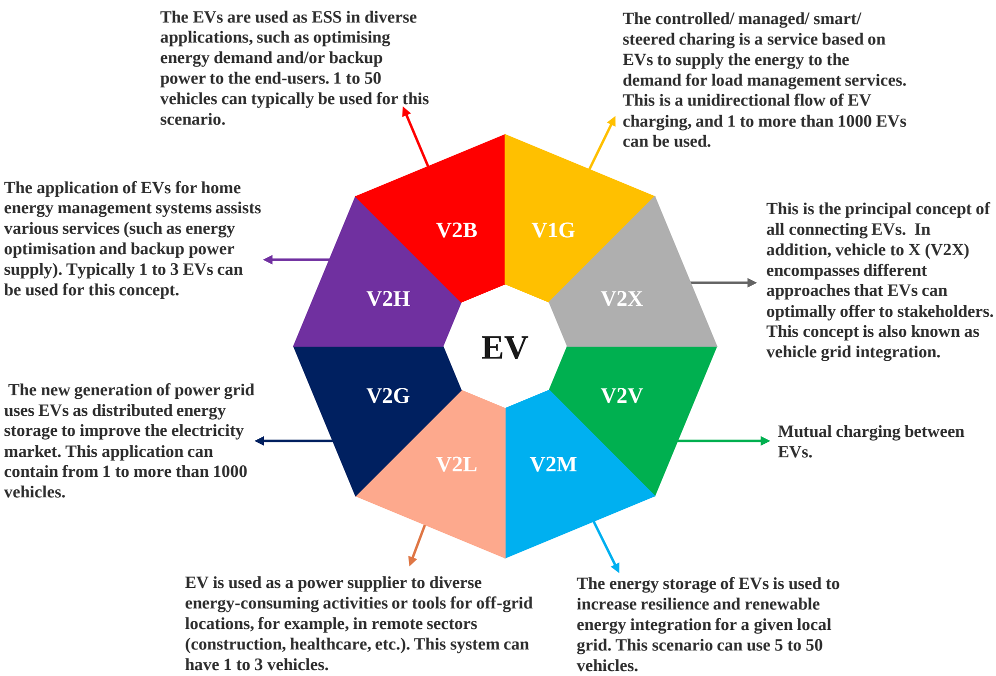

Figure 5: Different concepts of V2G [38].

The new generation of EVs offers several opportunities for the discharging process. Fig. 5 summarizes different charging/discharging processes of the new EV generation. The GEV system derives from vehicles to X (V2X) concept [13, 27, 33]. The V2X contains seventh vehicle connection systems. These are controlled vehicle (V1G), vehicle to building (V2B), V2H, V2G, vehicle to load (V2L), vehicles to microgrid (V2M) and V2V. The GEV contains two types of V2Xs, V1G and V2G [33].

V2G participates in the power grid's reliability by using EV batteries to guarantee the optimal power-sharing of the electrical network. Many principal factors must be considered to sustain the efficient operation of EVs on the grid. These factors are an aggregator or any specialized charger to control the charging and discharging process of ESS, a bidirectional power flow connection between the grid and EV, and an efficient communication strategy to monitor different services [13, 33]. Based on V2G, deviated concepts presented in Fig. 5, V2B, V2H, and V2M (or vehicles to the community (V2C) [13]) can be the low-scale strategy of the V2G. Apart from the overall layout of smart grids presented in [72], V2G operates as distributed power generation at the distribution system operators (DSO) level and possesses its particularity system set up to deal with bidirectional communication and electricity. On a low and large scale, the system consists of V2G as prosumers to efficiently coordinate with electricity services (power generation, transmission system operators (TSO) and DSO) and data transfer (money and information). The control technique-based-aggregation strategy of V2G balances the responsible party, electricity market and retailer and transfers diverse information into the different levels of the system [33].

4.1. System and Technologies

The implementation system of V2G is related to the fundamental model of the grid-connected battery storage system [16], where the dynamic of energy storage significantly enacts [73]. The bidirectional EV charger can operate in three different modes: charging the car, discharging the vehicle to the grid, and the local load [14, 74]. The charging devices ensure the connection in different level integration, such as commercial/office sectors for V2B, residential sectors for V2H, and public sector for large-scale V2Gs [75]. Figure 4 presents different power converter typologies used for the V2G system. The overview scenario of EV power consists of charging by either AC or DC through power electronic converters [16].

The technologies for implementing EVs charger to guarantee a bidirectional power flow reside on communication standards and battery technology [33]. V2G technologies contain four standards: charging topology, communication, plug and safety [14, 74]. The efficient operation of V2G is based on a smart grid environment to coordinate bidirectional data and energy flow on the system [14, 72]. The impact of V2G battery degradation on delivering V2G services has been assessed in [15]. The energy throughput plays an essential role in the degradation of the battery, which is most sensitive to the depth of discharge. Therefore, the vehicle lifetime requires optimal replacements of multiple battery packs. The technology and standard of V2G are ultimately enhanced through intelligent grid applications to improve the performance of the power grid [75, 76].

4.2. Control Strategies

The control strategy of V2G depends on the charging typologies of the system. There are several control strategies to handle the connection of the bidirectional power flow of V2G. An overview of control schemes for V2G is presented in [76]. Four control strategies, i.e., aggregated control, load-frequency control of EV connections, multi-agent control and virtual synchronous machine-based control, are assessed in the framework of smart grids. The aggregated control strategies autonomously provide an optimal scheduled charging centralised control scheme to globally manage power flow. The system model also coordinates aggregated storage-based-scheduled charging for V2V with centralized V2G integrated into the power grid through the aggregator. The aggregator scheme plays an essential role in the interface of the electric car fleet and grid operator. The coordination of DSO, electricity market regulation, scheduled power of EVs, and TSO is ensured through the application of aggregators [77]. The battery state of charge (SOC) plays a major role in the control modelling of EVs.

Ota et al. [78] have developed an independently distributed control strategy for V2G. The system also deals with centralized V2G as a secondary control scheme combined with the primary control. The load frequency control scheme based-SOC is designed to handle the scheduled charging of plug-out and plug-in idle time of the vehicle. In [79], an adaptive droop control scheme to deal with charging frequency regulation by applying innovative grid technologies is developed. This strategy aims to coordinate the charging schedule's improvement and regulate the V2G frequency in real time. Notably, effective coordination of the vehicle charging system also improves the integration of DEG [80]. Therefore, the designed model in [79] is under the decentralized V2G strategy to participate in primary frequency control. A power generation scheduling model based on a novel fuzzy logic control is presented in [81]. The performance index of the control strategy uses the SOC model to minimize the power from the utility grid. This strategy was developed for a plug-in hybrid EV connected to the electrical network. However, the model is not advanced enough to deal with peak shaving on the consumer side. A peak-shaving and valley-filling control scheme based-V2G system are designed in [82]. The objection function is developed to optimally handle connected EVs and target curve values system constraints.

4.3. Electricity Market

The electricity market is one of the principal designs of V2G aggregations and implementations. This incorporates different actors operating under specific electricity policies [83–86]. Two inter-dependent group stakeholders guarantee the interconnection of EVs to the utility grid. The first stakeholder group comprises three principal actors (aggregators, electricity grid and EV owners). The second group coordinates the electricity producers, EV industry, and government [13]. The energy market policies aim to create a platform where all V2G stakeholders can optimally benefit from the system implementation and set a bench of techno-economical and social benefits.

5. Impact of Electrical Car on the Grid

Battery degradation has various consequences that affect EV's capacity and power fades. The top contributory factors that generate degradation mechanisms and models are high temperature, high SOC, large cycle number and current, considerable depth of discharge (DOD), low SOC and temperature when cycling, and lifespan time [16]. As a result, there is a critical need to control V2G in terms of system efficiency, improving battery life, and guaranteeing the interconnection between vehicles and the power grid [78].

Figure 6 presents a bidirectional power flow of V2G connection which results from Fig. 2, respectively wired and wireless V2G system. An optimal bidirectional V2G operation with a fleet of EVs- connected to the distributed power system is developed to deal with frequency and voltage regulation services [77]. The battery degradation cost and charging requirements [87],

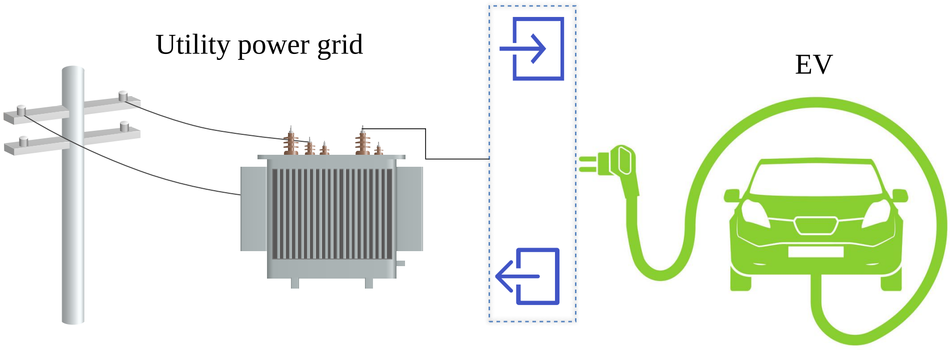

Figure 6: Schematic of the bidirectional charging system of V2G.

initial SOC of ESS challenge, EV plug-in time and desired departure and regulation prices are optimally addressed by formulating V2G day-ahead scheduling strategies. The developed model in [77] uses the V2G technology-based smart grid to minimize the EV charging cost during the on-peak time. This model also considers the critical need for active and reactive power and ensures the bidirectional power flow in the system.

The TSO ensures the impact of the regulation capacity forecast of the aggregator and signal of active power. In contrast, DSO guarantees the reactive energy capacity forecast of the aggregator and signal [77, 88]. Therefore, the power system operators can see the impact assessment of voltage and reactive power for V2G operating in the fleet using an aggregation system.

5.1. Energy Management

The energy management of V2G develops a dynamic system to strategically handle the power-sharing within the system [19, 89, 90], as presented in Fig. 6. This is a schematic for one EV, and the need for green transportation and DER contains several charging systems where multiple EVs are integrated into the power grid. Therefore, the EV fleet integrally improves the energy management strategy of a power network. In [91], a knapsack problem is introduced to formulate an energy management model of EVs and then consider the possible assessment of an electrical car fleet. This system applies a wavelet packet decomposition strategy to determine the performance index for the grid connected to the required EV, wind power and supercapacitor. It is observed that dynamic programming plays a significant role in designing the optimal control model that can handle the system behavior.

The development of a control scheme and/or management strategy for EVs abides through the aggregation. The aggregators handle the developed algorithms to minimize technical impacts and maximize the privacy of V2G [17]. The smart grid provides several features to coordinate both the generation and the consumption of energy. The demand response (DR) scheme introduces various energy management applications for V2G.

The efficiency of the energy management strategy is its ability to operate in different loading conditions [92, 93], which depend on the load factor of the electrical network. These can be classified as heavy load, average load, medium load and light load. The standard load is a system where the load factor equals unity. In practice, the average load is assimilated to a medium load with a load factor less than unity. In addition, the optimal operation of V2G in an intelligent grid environment must guarantee the power grid's stability and acceptable voltage and frequency [72].

5.2. Impact of Voltage

The power converter is essential in connecting the EV to the utility grid through voltage conversion, as detailed in Fig. 4. In [94], an adaptive zero voltage switching (ZVS) converter is presented to optimize the reactive current for the battery charger. This is assessed under various load/line conditions. The model uses a full-bridge voltage converter for different load impacts where an impact improvement is observed for heavy loading conditions. A ZVS based on a multiple-phase-shift modulation approach is developed in [95]. This strategy resolves the light-load grid current distortion using variable switching frequency based on dual-phase shift control. Finally, a hybrid phase-frequency control scheme for a robust wireless EV charger-based-novel voltage inverter topology is presented in [96]. As a result, high efficiency is achieved between the power grid and the battery. The model regulates charging EVs requirements based on battery voltage, dramatically varying in the comprehensive range function and coupling between coils. Better voltage harmonic performance is observed on multilevel converters with lower switching losses and voltage stress on power electronic devices [74]. V2G technology supports regulating both frequency and voltage at different loading conditions to guarantee power-sharing and compensate for the reactive power within the network [77].

Two inductances and a capacitor (LLC) converter possess more advantages in terms of voltage regulation for V2G compared to ZVS. The LLC converter operates efficiently over a wide range of applications of the battery SOC to work in a wide load range. The DC-link control scheme is used, and the proposed system improves the system efficiency during the lightest and heaviest load conditions [97]. A voltage source converter-based dynamic power balance system on creating a transfer from the unbalanced heavily loaded feeder to the lightly loaded feeder in the vicinity is presented in [18]. This voltage sources converter stabilizes the system voltage of the DSO with the integration of several EVs. A Monte-Carlo strategy is developed to coordinate the stochastic variations of EV charging loads. The approach integrates EVs and PV to fast balance power flowing without constraining the EV owners and minimize the overloading risk of the DSO's equipment. The power losses, increased faults and voltage deviations are also observed during the increasing numbers of EVs at peak time [98]. In [99], a novel charging management system is developed to regulate the charging activities of EVs connected to the DSO. This strategy reduces the unexpected impacts of EV integration and raises the voltage effectively. Only two control cycles permit acceptable voltage during the voltage drops caused by a grid-heavy loading condition.

5.3. Impact of Power

The transient stability of the power grid with both distribution and wide-area levels is based on its optimal coordination of the control scheme [76, 100]. The grid load supply capability is also improved using the developed strategies to coordinate the EVs connected to the power grid [99]. The charging with frequency regulation control for V2G developed in [79] improves the bidirectional power flow and coordinates the scheduled charging demand of the system. The smart grid technologies guarantee an optimal bidirectional energy flow for V2G to avoid diverse detrimental power variations. Smart grid-oriented EV charging introduces frequency regulation, load flattering, intelligent grid-oriented uncertainty and voltage regulation [101]. V2G technology can also compensate for the reactive power of the network while providing active power in the main grid. [14]. Besides, the control of the EV charging scenarios is more focused on active power rather than reactive power. Thus, the reactive power output is assumed to be zero in the steady-state operation. This optimises the voltage source converters by managing the unbalanced output power flows from the EVs [18].

A fixed-switching frequency triple-phase shift control is applied at the light-load conditions to guarantee power quality and limit the current stress. The strategy also coordinates a smooth transition between the heavy and light loads and smooth sinusoidal current without affecting the zero-crossing points from all load ranges. As a result, the efficiency was well improved for heavy load [95]. Furthermore, efficiency for all loading conditions with a smooth output regulation in all ranges of coupling coefficient between the coils, power and voltage is also observed in [96].

In [102], a multiple-phase-shift control that can improve the grid power quality at the light load is developed. This system uses the dual active bridge that guarantees the power factor and power delivery of the system. A smooth transition between various load conditions and charging effectiveness is assured. This control scheme provides the performance for both light and heavy loads. The switching of power electronic converters, mainly based on semiconductors elements, negatively impacts the power quality by introducing harmonic currents [103]. High-frequency switching-based PMW can effectively control the power converters and cancel the harmonics into the system. Innovative grid technologies provide a better platform to handle the dynamic behavior of the power electronic converter control.

5.4. Impact of Harmonic

A significant increase in power quality, reality and sustainability by managing frequency regulation and minimizing harmonic distortion in output current is observed by V2G technologies [14, 17, 74]. This requires robust and real-time control and mentoring schemes to coordinate the system and deal with the fast charging requirement of EVs with a high-power rating and injecting harmonics into the grid [74]. An excellent strategy to reduce the negative impact of V2G is also based on hybrid three-phase rectifies [104]. This hybrid approach improves the power factor (PF) with a lower total harmonic distortion (THD) in the current waveform suitable at the standard level. PF and THD of this type of EV battery charging are 97.73% to 99.89% from the second to the thirteenth harmonic. Vadi et al. [14] establish a classification scheme of the THD for bidirectional inverter applications for V2G. For example, the system operates with a lower THD for the third harmonic of less than 3%. On the other hand, the system will have a higher THD when the third harmonic is more than 3%. In the WPT system, the THD increase with the charging power level. As a result, the vehicle wireless charging system pollutes the power grid [105]. Compensation topologies minimize the harmonic pollution of the WPT for the V2G system for capacitive power transfer converters. The advantage of this strategy is to stabilize the system voltage and ensure the current sharing of V2G [106].

6. FUTURE PREDICTION

Since V2G only started in 1997, its future vision, e.g. 2030, in the smart grid environment, is based on high-capacity energy storage and battery charging and aggregations coordination. Therefore, the prediction of the effective implementation of V2G in the smart grid during diverse loading conditions can be summarized within the 5Ds, as detailed in Fig. 7. This is the perspective vision regarding improving V2G activities to guarantee the efficient operation of the power network.

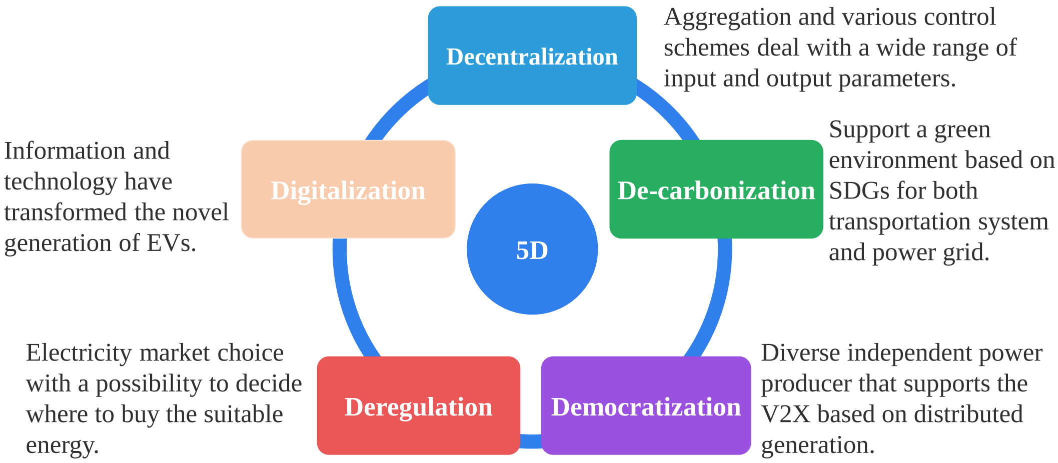

Figure 7: 5D vision of electric vehicle integration to the utility grid in the smart grid environment.

Direct integration of renewable energy into the power grid can harm the electrical network when it is not well coordinated. The curtailment of variable renewable energy is a challenge that decreases the economic benefits of the system. The bootable behavior, elastic, intelligent and predictable energy storage device power consumption effectively solve this problem [91]. The battery charging of EVs with its bidirectional power flow solves power quality problems when their integration is optimally coordinated and synchronized with the power grid.

Energy storage is one of the most critical features of EVs, as shown in Figure 3. This depends on a propulsion system and power electronic converter to create an efficient EV operation. Evs' future perspective consists of developing a novel generation of an affordable battery that does not overheat. The battery technology perspective from the EV owners to the EV industry is one aspect that needs several investments. First, the battery degradation should be at an acceptable range to the consumer side [17]. Second, the power electronic converter is an interface that links the battery charging to the power grid. The highly reliable and low-cost converters are in considerable need of the improved charging process of EVs. Some power electronic converter typologies have been proposed to create the novel charging feature of EVs [69], increase battery life and avoid harming the DSO.

The effective control of power electronic converters assists in mitigating the detrimental impacts of EVs connected to the power grid [103]. The smart grid environment applies novel technologies to support the bidirectional power flow between the vehicles and the utility grid. Figure 5 shows that the V2G system is a large-scale system that requires several suitable control schemes to protect the distribution network equipment. The 5D vision, detailed in Fig. 7, provides a conceptual design framework for V2Gs. This vision utilizes power electronic converters using intelligent control schemes to support the optimal operation of EVs and DSO.

The future perspectives of this research work can be outlined as follows:

- As the battery is the essential component of V2G, develop ping the ESS that can have all advantages of lithium-ion batteries, as detailed in Table 2, which are affordable and safe (without overheating issues), is one of the perspective visions of the EV market. This novel generation of ES technologies will transform the future of both transportation and power systems.
- Fast power transfer without a loss for the V2G is required. Therefore, the high-efficiency and robust battery chargers with a bidirectional power flow option are one of the future prediction aspects for V2G that need more investigation to handle the complexity of the modern power grid and minimize the detrimental impacts from the integration of EVs.
- WPT uses the magnetic resonance technology that leads to harmonic pollution to the power grid. Thus, the WPT converter of the V2G system should be designed and implemented with a compensation topology to mitigate harmonic pollution and ensure the quality of the power within the network.
- The energy storage management effectiveness for grid-tied EVs requires robust and dynamic modelling strategies for accurate operation. Moreover, optimal control technologies support the coordination of such a system. Besides, the smart grid technologies possess various platforms and applications to enhance the G2V schemes and mitigate different adverse impacts of grid-integrating EVs. The designed aggregation under the innovation technologies also requires several philosophical investigations and designs for the fast-charging process of EVs.
- The application of 5Ds vision, detailed in Fig. 7, offers various perspectives to deal with new knowledge and policies about the future of electric vehicles. The advantage of the 5Ds vision covers the overall applications of EVs to satisfy multiple stakeholders. For instance, the perspective vision of deregulation and democratization of grid-tied EVs considers the universalizing of battery chargers. This adaptive charging system is one of the essential aspects to develop for the effective operation of Grid-tied EVs carefully. Moreover, the 5D vision also provides a digital platform for future EV applications and implementations to achieve sustainable development goals [1]. This platform can effectively be developed throughout the internet of energy within an innovative coordination of several distributed energy resources [107].

7. CONCLUSION

The advent of novel technologies resolves several operation problems of EVs and makes electric cars suitable for the future transportation system. The EVs battery provides a bidirectional power flow opportunity to be connected to the DSO. The bidirectional connection opportunity of V2G is constrained by the charging and discharging operation boundaries of the battery. This is the future of EVs. Nevertheless, the V2G has several challenging situations that detrimentally affect the voltage/power of the utility grid during any loading condition. Battery charging devices based-power electronic converters guarantee optimal operation of grid-connected EVs with some negative impacts when they are not suitably controlled. It is observed that the smart grid environment offers a 5D vision for V2G implementation to optimal control the operation of grid-tied EVs and protect both vehicles and grid equipment. This vision is based on the future projection of EVs to guarantee an optimal battery life, sustain the synchronization of V2G and create a conceptual design framework for an intelligent control scheme of V2G in different loading conditions.

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