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# A comprehensive analysis of Vehicle to Grid (V2G) systems and scholarly literature on the application of such systems

RESEARCH PAPER

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**Abstract**

**Without any doubt, the environmental issues are the top worries between all the nations in the current century. According to the recent studies, the researchers have shown that the transportation fleet is one of the biggest sources of emission. The penetrating the renewable energy sources (RESs) and electric vehicles (EVs) are the green solutions to decrease the current environmental issues. Due to intermittent nature of RESs and high investment costs of developing EVs' infrastructure, tendency for using them is under the predicted estimations. In this paper, by analyzing a precise and comprehensive literature review, we consider all aspects of implementing the EVs especially their supporting roles for the grid in vehicle to grid system (V2G). Moreover, we study the integration of the electrified fleet with RESs in smart grid and evaluate their possible impacts on the power network. In addition, we count the advantages and disadvantages of implementing the V2G system on the power network. The main purpose of this paper is analyzing the influences of the V2G system on the power grid in four main subjects and classifying them based on their proposed methodology for the future studies. However there are some review papers related to this topic, this field of study suffers a lack of clear direction for future studies and researchers and also a comprehensive analysis about the V2G-related articles is still missing. Finally, an analysis and survey of the last two decades of scholarly literature and projects in this field of study from 2004 to March 2019 is presented. The results show that a limited number of articles have conducted to investigate the social aspects of implementation of V2G system. In addition, however, there are many researches about integration of the V2G system with RESs and smart grid; a few of them use the real data for estimating the availability of RESs in each hour of day.**

## Introduction

Nowadays, environmental issues like increasing the average temperature of the earth, GHGs emission, melting polar ice and consequently raising the sea level and non-renewable sources depletion are the top and hot headlines in the news [1]. Every day, million tons of carbon dioxide are emitted into the atmosphere that based on the recent studies, the most pollutant sources of $CO_2$ emission are industry sectors and transportation fleet. These kind of topics give a wakeup call to all the human to find solutions for such problems. Many environmentalists, NGOs and private institutions all around the world have focused on these issues in order to rescue and preserve the earth for the next generations. According to the International Energy Agency report [2] the most proportion of the total refined petroleum is consumed in the transportation and industrial sectors and in 2040 about 56% of petroleum usage will be allocated to transportation system. It is clear that by increasing the demand for oil and gas and also

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decreasing the fuel sources, the price of petroleum products will be increased in following decades.

Basically, by burgeoning the technology and industry and consequently increasing the rate of demand, the reliance on the fossil fuel has been increased and in recent decades the energy costs have had a fast growing trend. Needless to say that the fossil fuel sources are limited and they will be depleted soon. Depletion of the non-renewable sources is the biggest threat for reliability of the current electric grid (traditional system) [3]. The energy transmission from fossil fuel to electricity is one of the newest concepts that should be taken into consideration. In this field, the introducing the electric vehicles (EVs) into the market is an efficient solution for solving the environmental and technical problems that bear by traditional internal combustion (IC) automobiles. Since the EVs emit almost zero exhaust gases without any noises, they have been become more popular among industry and scientists that means this new technology is a pure environment-friendly and they have lower oil dependency [1]. Combination of new technology and innovation introduce EVs as a new alternative but with higher quality and capacity and lower costs rather than the past decades. In developed countries like the US, tax discount and lower fuel costs are offered people for motivating them to use EVs rather than IC automobiles. As a study, in the 2022 around 35 million EVs will enter to the market [4].

However, using the EVs have many positive consequences for the environment and economy, introducing a huge amount of EVs into the market can be challenging for the grid and lead to many problems and limitations for the grid. Because these huge volume of EVs in a local area need high demand of electric power and consequently can cause fluctuation in the voltage and shortage in the supply. The mentioned problems show themselves more and more in the efficiency of the grid especially during the peak demand period when many people want to use electricity and charge their EVs more than other times. In average, the efficiency of the current grid power is not suitable due to frequent fluctuations in the voltage and frequency and also energy loss. In the peak-demand period, the ancillary power generators have to enter to the network in order to avoid fluctuation that could increase the operational and maintenance costs. On other hand, during the off-peak power when there is not sufficient demand, the unused and extra-generated power will waste in vain [5]. So, the concept of vehicle-to-grid (V2G), vehicle-to-building (V2B) and vehicle-to-vehicle (V2V) or electrification of transportation system are introduced in order to solve the current obstacles and problems in the power grid.

In recent studies there are three structures for implementing the grid connected EVs. **Home to Grid** that the EVs provides the auxiliary renewable energy for the home. **Vehicle to Vehicle,** that means charging and discharging the power between two EVs and **Vehicle to Grid** that is a bidirectional flow of energy between the EVs and the grid. In this paper, we broadly focus on the V2G technology and provide a precise and comprehensive overview of this topic. Integration of V2G technology with RESs and SG is an efficient method to deal with possible problems related to high penetration of EVs and consequently fluctuation in the power supply. However, some studies and review papers have focused on different aspects of the EVs and V2G system, there is a lack of comprehensive overview of V2G system for future studies. In some of the studies, the authors only focused on limited fields of this topic and ignored the other important contents. For instance, in many of the review papers, the authors analyzed only the environmental and feasibility of the V2G system without considering the social and technical features of this technology. We believe this study covers all fields of implementing the V2G system by considering a precise and in-detail literature review in one package. To avoid distractions, all the gathered materials are given in a proper and organized classification that let the reader to follow them easily and efficiently.

The main objective of this paper is providing a precise analysis on the V2G and its integration with RESs and SG in order to recognize the research gaps and present a clue for future studies. The superiority of this paper over than existing review papers addition to its precise and in-detail literature review is discovering sixteen distinct fields of study around V2G system by reviewing the recent articles and classifying them based on their frequency and suggested methodologies. The results of this research is gathered and provided in a unique table. This table can a great tool and direction for the researchers to conduct their future studies based on possible potential in the fields with limited numbers of published papers. In addition, we cover the last two decades of scholarly literature and offered projects and services around the V2G system and analyze them based on various categories.

This paper is organized as follows: a comprehensive overview of electric vehicles and characteristics of different models of EVs are discussed in Section ''General Overview of Electric Vehicles''. The possible problems that could cause fluctuation in the grid by penetrating the EVs into the market and the concept of V2G technology are analyzed and reviewed in Section ''Vehicle to Grid (V2G) Concept''. Moreover, Section ''Advantages of V2G technology'' and Section ''Barriers and obstacles of V2G technology'' count the possible advantages and barriers of implementing the V2G system and its integration with RESs and smart grid. The main purpose of this paper is presented in the Section ''Categorization of recent studies around V2G'' and a categorization of previous studies for discovering literature gaps are analyzed. In Section ''Statistics on V2G publications'' and Section ''The V2G projects in the world'', we try to present an analysis and survey of the last two decades of scholarly literature and projects in this field of study. Finally, in Section ''Conclusion and future studies'' concludes the review.

## General overview of electric vehicles

At first, it is better to ask ourselves a question, Why are EVs important for us and our planet? In fact, innovation and creativity are an essential part of our characteristic and personality and human always try to improve the quality of life with implementing the natural rules. We live in an era that environmental issues are the unforgettable threats for next generations and us. Future of the earth is related to our current attempts for saving it. The issues like increasing the average temperature of the earth, entering million tons of GHGs into the atmosphere and air pollution have changed the living style. According to the recent studies, the transportation sector is one of the main source of energy consumption and also air pollution [2]. De-carbonization of transportation fleet is one of the top topics in energy field in the most developed countries [6–9]. Migrating from traditional internal

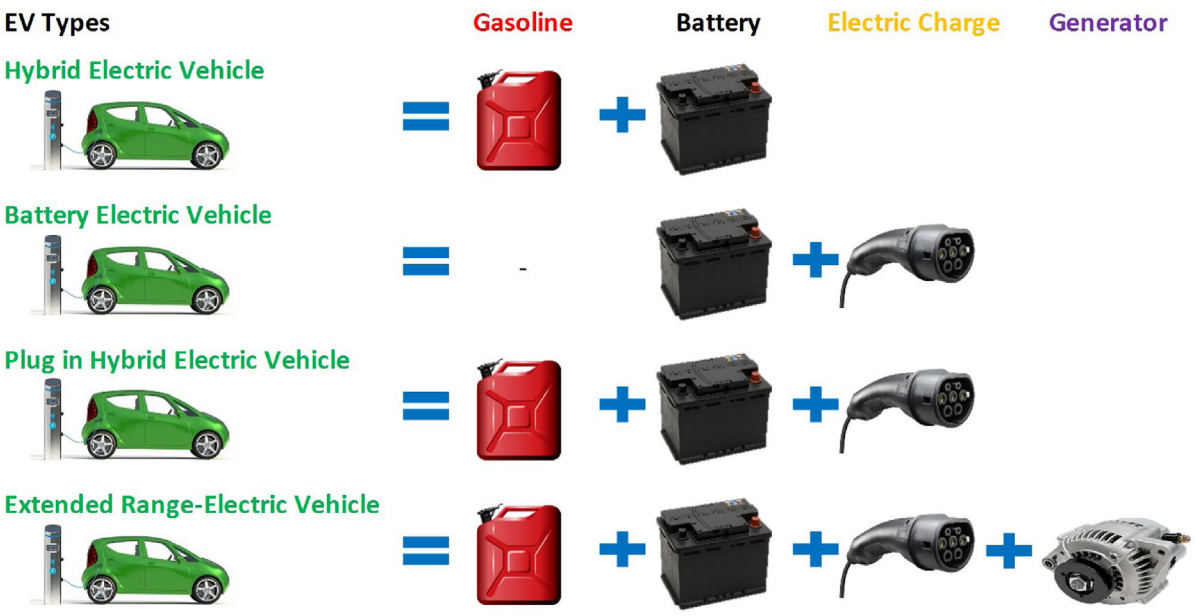


**FIG. 1**
Different types of EVs in the market.

combustion automobiles (IC) to electric vehicles is efficient action to reduce negative effects of GHGs emission on the environment.

Electric vehicles are equipped with electric motors for propulsion and energy storage system that are recharged in different ways from grid power, absorbed energy by brake energy recuperation, also from other non-grid sources like photovoltaic and wind power (renewable sources) and recharging centers [4]. In recent years, different types of EVs have been sold in the market but generally, EVs can be classified into three types: Battery Electric Vehicles (BEV), Plug-in Hybrid Electric Vehicles (PHEV) and Hybrid Electric Vehicles (HEV) [10]. However in the recent study [1], addition to these three models, another model is introduced, Extended Range Electric Vehicle (EREV). Each of them has its own characteristics and structure and in continue we focus on them in details, Fig. 1.

### *Battery electric vehicles (BEV)*

Battery electric vehicles (BEV) refers to passenger cars that totally equipped with Lithium-ion battery packs and electric motors instead of internal combustion engine [11]. The BEVs are supported by stored electric power in their batteries. The BEVs can recharge their batteries by two methods, first using the external sources like power grid or renewable source units and second, using internal sources like extracting the electric power from a process that is called regenerative braking [10]. Since most of BEVs use AC electric motors, a convertor system is needed to convert DC electric power stored in the battery to AC mode [12]. The factors like range of driving, speed, battery lifetime, price and etc. are a set of obstacles for BEVs to compete with IC automobiles. In other word, manufacturing this kind of EVs can be considered a big challenge for factories.

The reasons like clean energy without pollution and noise and decreasing fuel dependency are the key elements to introduce the BEVs as a good alternative for IC vehicles. However people know about good consequences of using BEVs, according to recent studies less than 1% of market share is allocated to EVs industry in the US and China [13]. Based on the International Energy Agency report in 2018 [14], the total stock of EVs reached to 3.1 million in 2017 that approximately two-third of this number is allocated to BEVs and also the US and China have the highest share of EVs stock compare to other countries, Fig. 2.

### *Plug-in hybrid electric vehicles (PHEV)*

Plug-in Hybrid Electric Vehicles (PHEV) have been entered to the market as the latest version of EVs [15]. PHEVs can be considered a mixture of BEVs and IC automobiles technology that means this kind of electric vehicles consists of one internal combustion engine that consumes fuel as base mode and a pure electric engine and consumes stored electric power in its rechargeable batteries. Based on the situation of the road and speed the PHEV's engine can be switched from electric to fuel or reverse easily. The PHEVs eliminate some operational limits of BEV and reduce the amount of emission rather than IC cars but it would be clear that two engines have higher base load and consequently higher consumption of power and fuel [16].

### *Hybrid electric vehicles (HEV)*

One of the basic differences between the HEVs and PHEVs is about the supply of electric power for these vehicles. As mentioned before, the PHEVs are equipped with IC engine, electric motor and Lithium-ion battery that are recharged by plugging into the power grid, while HEV consists of two complementary propulsion power system that works together at the same time [10]. In the first system, the HEV operates with gasoline engine that run the vehicle alone and the second system refers to supportive or complementary electric engines and electric batteries that are charged through regenerative brake process. The HEVs are not designed to recharge their batteries through the external sources like the power grid. The electric motors provide extra power to support the gasoline engine in necessary situation like accelerating or passing and also during the low speed

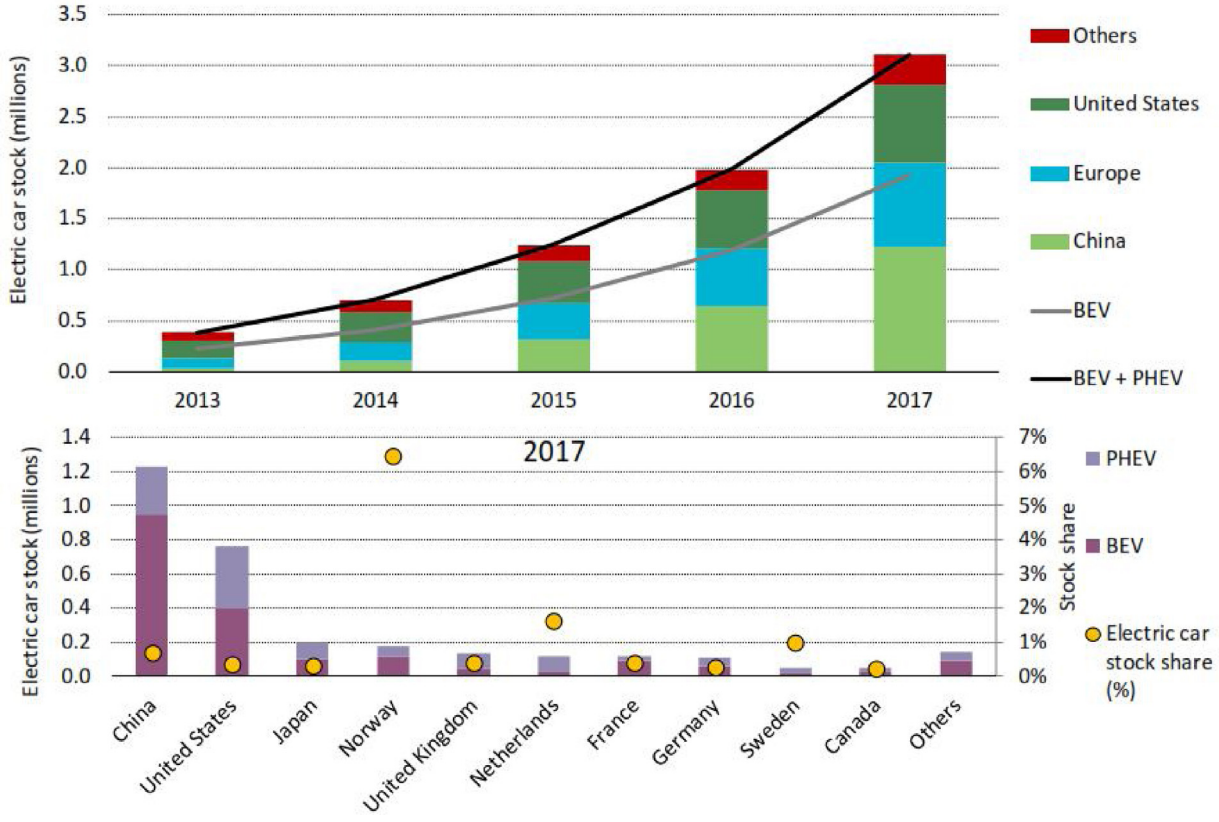


**FIG. 2**

Passenger electric car stock in major regions and the top-ten EVI countries [14].

when the gasoline engine have the least efficiency, the electric motors can operate alone and provides propulsion power for the vehicle. An automatic start/shutoff system that is called start-stop is implemented to turn the engine off when the driver is going to stop the vehicle and again restarts it when accelerator is pressed. This system avoid consuming the energy higher than required level [17].

*Extended range-electric vehicle (EREV)*

Extended Range-Electric Vehicle (EREV) or Extended Range Battery Electric Vehicle (BEVx) is new technology based on a zero emission energy storage system that equipped with backup auxiliary power unit (APU) that can enter to the circuit until the storage energy device is fully depleted [18]. The main characteristics of EREVs are the low emission and air pollution and also higher

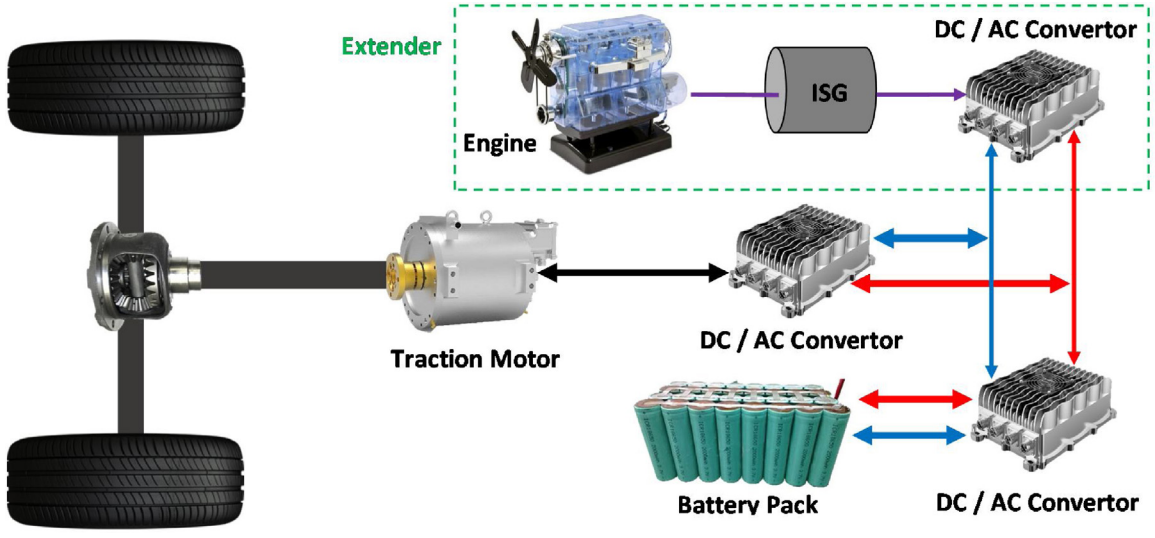


**FIG. 3**

Simple configuration of EREV system.

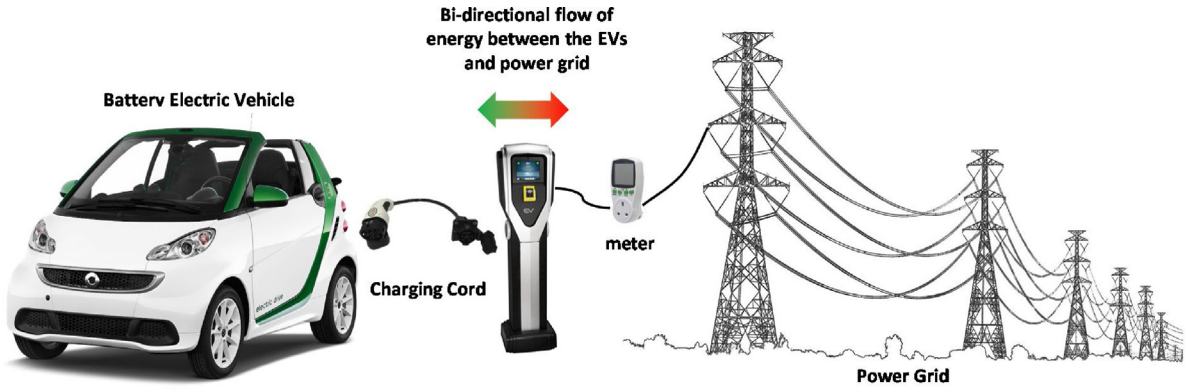


**FIG. 4**
Simplified Vehicle-to-Grid (V2G) Schematic.

durability and mileage compare to other types of EVs [19]. The ERVE consists of plug-in battery backs, electric motor and internal combustion motor. In this case, the electric motors always drive the wheels and the IC motor recharge the battery packs when they are depleted. The APU IC engine cannot drive the car directly because it is not connected to the wheels. A simple configuration of EREV system is shown in Fig. 3.

## Vehicle to Grid (V2G) Concept

In recent decades, the environmental and energy issues have been the biggest challenges for the scientists that motivated them to find solutions to rescue the earth. As recent studies, transportation industry is the major element of energy consumption and consequently air pollution, so alternative sources as fuel and new transportation systems can be considered as the methods to reduce the negative effects on the environment. The V2G technology that usually refers to ''mobile energy'', ''smart energy'' or ''virtual power plant (VPP)'' is a new term that plays an influential role in demand adjustment. A simple structure of V2G system is shown in Fig. 4.

According to a study [20], in the US, automobiles are on the road and travelling for only and only 5% of day and 90% of the automobiles are unused that are parked in the parking lots. In the future, by implementing the EVs fleet, this huge share of unused EVs can be considered as a wonderful potential for supporting the grid. The V2G technology is a flow of energy, information and money between the EVs owners, aggregators and the power grid to make a stable balance between the demand and supply. The simple structure of this system consists of three elements: ***first***, plug in connection equipment, ***second***, communication and control devices to establish a mutual relationship between the grid operator and EV's battery condition and ***third***, metering device for measuring the input and output flow of power [21,22].

The V2G system provides an incentive-pricing plan for the EVs owners to motivate them to participate in this charging/discharging system. According to this plan, during the off-peak demand, when there is extra and unused power in the grid, the EVs' owners can charge their vehicles with cheaper fees and in contrast, during the on-peak demand, when there is shortage in the grid system, they can discharge the extra stored power in their batteries to the grid with higher fees. Therefore, EVs owners can make profit only by participating in this plan [23].

In the US, almost seventy percent of fuel is imported and most of it consumes in the transportation sector [24]. Energy dependency or energy addiction is the controversial and political issues that need to be considered as a top priority. Battery Vehicles (BVs) are a good policy to decrease the dependency on fuels especially gasoline. BVs can regulate the grid by discharging their storage energy in peak demand, adjust the frequency and voltage of the electric power in the grid, and make it reliable. In a study, scientists found that if they implement 4 million BVs in California, the grid does not need to setup the new power plant to support it because of charging and discharging technology in the V2G system [25].

Due to unpredictable and unstable nature of the RESs, especially wind and solar power that are function of wind speed and sunshine, they generate an intermittent power supply and in this case ancillary power generators should be run to make a balance between the supply and demand. By increasing the share of the RESs in the grid, the role of natural gas power plants is increased in order to avoid fluctuation in the grid but the working hours of these kind of power plants is decreased and due to their high maintenance costs, they become less profitable. So in order to solve this problem implementing EVs fleet and V2G concept are valuable and efficient.

Based on the grid demand and location of charging stations, EVs coordinate in this process and release their energy into the grid, so it will be clear that uncoordinated vehicles can cause turbulent for the grid because they charge fully when plug into the grid regardless of peak time and leave charging process earlier. The coordinated EVs can be defined in the smart grid in three ways: sending signal to the all vehicles one by one, sending signal to the central controller that could manage EVs in a facility (like parking lot) and a third-party aggregator manages the located vehicles [21].

Another important concept in V2G technology is aggregators as servant energy accumulators. The effects and role of single and distinct EV is negligible, so aggregators are central units to make a chain of EVs to monitor, control and support the grid by providing the ancillary services. The Aggregators should follow a set a dispatching strategies for satisfying the driving demand, frequency regulation and making profit.

The V2G as a new system has several limitations like battery wearing, limited charging stations and related equipment, high needed investment and so on. This system can be implemented in two ways unidirectional and bidirectional. In unidirectional

system, there is a one-sided flow of energy from the grid to the EVs and the grid operator can monitor and control the rate and duration of the charging in order to avoid overloading and fluctuation. While bidirectional system consists of a mutual flow of information and energy between the EVs and grid operator that the EV's battery as an energy load could charge itself during the off-peak and discharge its power during the on-peak to provide auxiliary power to the grid. In this case, flexibility and efficiency of the bidirectional is more than the other one but this system needs higher investment with more complicated infrastructures.

## Advantages of V2G technology

The migration from fossil fuel to electric power especially in the transportation fleet has countless advantages that we can divide them into three main groups, environmental, technical and economic. These benefits provide the privileges for both sides, the grid system and EVs' owners. In continue the advantages and positive effects of V2G system will be discussed in details.

### *Environmental aspects*

In these years, the dominant share of automobiles has belonged to IC automobiles and EVs fleet has not be implemented broadly especially in the developing countries. IC engines do not operate efficiently and they waste a huge amount of energy, also the rate of GHGs emission in this traditional type of automobiles is high. As mentioned before, transportation sector has one of the biggest sources of air pollution and GHGs emission and everyday million tone of $CO_2$ and other harmful gases enter into the atmosphere, so migrating from traditional fleet to EVs and consequently implementing V2G system is an influential step for eliminating negative effects of GHGs on the earth. Moreover, EVs operate almost without any noise and this helps to increase the health criteria in big cities.

### *Technical aspects*

Generally, penetrating a huge volume of EVs into the market can be considered a big challenge for the grid and cause fluctuation in the voltage and frequency. Moreover, replacing the traditional power plants by RESs like wind, PV, and electric batteries with no large spinning masses can affect the reliability of the system and make deviation from standard frequency [60−50 Hz]. The rising or falling the frequencies can be result of imbalance between the supply of power demand [26]. One way to avoid such problem is running the enormous spinning bulk of turbines in the power plants until more sources of energy are added to the system. The problem of this method is high maintenance costs of backup system and pollutions. Another and more efficient way is using the potential of stored energy in the EVs especially V2G system. Applying V2G system is an efficient solution for shaving and leveling of the peak demand and providing the ancillary services to avoid shortage. The goal of implementing V2G system is providing an ancillary service to establish balance between the demand and supply that can be used in three methods: regulation down and up, spinning reserve and non-spinning reserve. These methods have their own characteristics but mainly the regulation up and down provides the fastest response, shortest service availability and duration and also the highest operational costs to maintain balance in the grid. The characteristics of the EVs' batteries are more suitable for quick response so this system should be more efficient to provide regulation up and down and spinning reserve. The EVs are not suitable for the non-spinning reserve due to long duration and lower prices.

As mentioned before, there is universal trend for applying the RESs like photovoltaic and wind power to produce electricity because fossil fuels are going to be depleted and bear so many negative consequences on the earth. An important and influential concept here is, these kind of energies are unpredictable and their performance and efficiency is a function of weather and geographic location. For example, during the summer when the rate of sunshine is higher than the winter and days are mostly sunny, the solar power system operates with higher efficiency and produce higher electricity or the speed of the wind is not same in different seasons. So in this situation, by integrating V2G technology with RESs and providing necessary fundamentals and techniques, the system can make ancillary energy and support the RESs and deliver uniform and uninterruptible power to the grid. The authors in Ref. [27] suggest a detailed model of V2G system with a hybrid energy storage system (HESS) to provide primary frequency control (PFC) and dynamic grid support (DGS) simultaneously without disturbing the schedule of charging/discharging. The V2G technology can be considered as a backup system for renewable energies like solar and wind by accumulating the extra power during the off peak and support it in needed times.

### *Economic aspects*

The economic benefits of V2G system also is not deniable. In the traditional regulation system, there are big generators that in emergency and shortage start to operate and enter into the circuit to satisfy the demand; the operational and maintenance costs of this system are high and are not profitable. While EVs, in V2G system, can store the unused energy during the off peak demand and release it into the grid. In other words, the V2G system decrease the dependency to the central power plants in peak periods. Pricing module is another motivating and beneficial plan for V2G system, in this plan EVs owners can buy the electricity for their driving demand during the off peak with lower price and then sell the extra and remained power in the batteries during the on peak demand with higher price and make profit.

## Barriers and obstacles of V2G technology

Migrating from IC automobiles to EVs and implementing V2G system like other new technologies provides so many privileges and positive consequences but it is not correct to ignore its possible challenges and obstacles. Substituting the traditional transportation fleet with V2G system represents new challenges to the grid system that are mostly related to control, scheduling and operation of the current grid system. In continue some of the possible obstacles that can make difficulties for implementing V2G system are counted.

### *High investment*

One of the biggest obstacles and risks for implementing this system is high-required investment. As a matter of fact, V2G system is founded base on a mutual flow of information, power and money between the EVs owners, aggregators and grid operators that needs a well-organized and smart infrastructure. For

example, an efficient telecommunication system is needed to establish a bridge between the players in this system. The EVs have to equipped with the plug in connectors and metering equipment to measure the input and output power and sending the level of battery charging to the operators. Totally, all of these factors need a high level of investment and time to implement V2G system efficiently.

### *Stochastic nature of EVs and RESs' features*

Stochastic and uncertain nature of the EVs, such as departure/arrival times to charging centers, daily driven distances, battery sizes charger/discharger types and so on are influential parameters that can decrease the reliability of the power grid. In addition, stochasticity in generated electricity by the RESs like solar and wind power is another parameter that can influence the network negatively. In Ref. [28], the authors present an innovative GAT (general analytical technique) for assessing the stochastic behaviors of EVs and PV power (photovoltaic) and their influences on overall system. The authors in Ref. [29] offer an analytical technique for evaluating the impacts of stochasticity of Feeding biomass-fueled gas engines (BFGEs) as a renewable energy source and EVs on the radial distribution systems (RDSs). Due to stochastic nature of these sources, a probabilistic approach is used to do this assessment. In Ref. [30], the authors by applying a proposed probabilistic method (PPM) assess accurately the combined technical influence of the EVs and PV uncertainties on RDSs.

### *Battery degradation*

The capacity and efficiency of the EVs' batteries are the key factors to evaluate the performance and quality of an electric vehicle and mainly the quality of the battery is a valuable criterion for the customers' choice. According to an analysis [31], the price of high capacity battery for an EV can be approximately USD 500/kwh that totally about USD 35,000 to 40,000 of total EVs' price is for a pack of battery. So factories have to equip EVs with lower capacity batteries to be more affordable. Improvement of technologies have had a great influence on quality and capacity of EVs' batteries and average cost of them has a decreasing trend. Life cycle of electric batteries is another important factor that can be affected by charging/discharging rate, voltage and temperature. In the V2G system, the coordinated EVs need to charge and discharge frequently during the day to receive travelling demand power and also send the extra power to support the grid. This process of charging and discharging can increase the internal residence of battery and consequently decrease the battery usable capacity. The battery degradation costs due to frequent charging and discharging have influential effects on the feasibility of the V2G technology on other hand trading with wholesale market has the highest income rather than other opportunities.

### *Social issues*

Generally, the penetration of EVs into the market have had a positive trend and in the close future, the IC automobiles will be substituted by EVs. In V2G system, by increasing the number of coordinated EVs in this plan, the total performance of the system will be increased but there is an anxiety between the EVs owners to participate in the V2G system. The level of charge in the battery, charging stations and charging facilities in local areas and also the initial high investment costs are the main worries among the public to coordinated in this plan. As a result, the rate of participants in the V2G system can be affected that this problem could be managed by implementing a well-organized and encouraging plan to make sure the public about the efficiency of this system.

According to the V2G system, the EVs can provide and distribute ancillary power into the grid by communicating with the central aggregators. Central aggregators play an important role for efficiency of the system because they connect a huge group of EVs into the grid (the effects of small cooperative EVs on the grid is negligible). In this between, one of the biggest concerns of the EVs' owners is the privacy and security of this system. Because, there is a continuous and mutual communication between the EVs' owners and the grid operators that may all the owners' information like home and work address, identity, schedule, health status, religion (by analyzing the pattern of visited places) and so on accessible to them [32].

Different aspects of V2G system have been analyzed until now but rarely the scientists have focused on privacy of the system. In Ref. [33], a new privacy policy that is called Privacy via Randomized Anonymous Credentials (PRAC) is suggested. This policy could be compared with P2 (Privacy-Preserving) that suggested before. According to the P2, for preserving privacy of EVs, there is an online system that EVs can sign an anonymous permit for cooperating in the V2G system [34]. The collected information signed blindly and aggregators cannot access to identities. The high telecommunication costs of P2 system is one of its disadvantages. In the suggested protocol, PRAC, there are three players: EVs, aggregators and a trusted third party (TTP). In PRAC, in contrast with P2, the third party (TTP offline) is responsible for collecting credentials and central aggregators do not have any role for this case. In this system, each EV after registration is equipped with a device that can be trusted platform module with high security for storing the private information.

## Categorization of recent studies around V2G

Since the current environmental and energy issues, there is a tremendous trend in introducing the EVs into the market. In one hand, the technologies that are used in the recent EVs convert them to green vehicles with almost zero emissions but in another hand, entering the huge number of EVs can be considered as a big threat for the grid and that is fluctuation in demand. As mentioned before, in average about 90–95% of EVs' daily time is idle and free that usually parked in parking lots. The rechargeable electric batteries support the mobility of the EVs and also can be considered as a storage system that could support the grid in emergency.

During the recent decades, many studies have done around this technology and each of them focused on different aspects of this topic. In the most of these studies, the environmental issues like negative effects of traditional transportation system have been the most popular points of view. Many studies have counted the possible advantages and barriers of implementing the EVs fleet and V2G system in the society and some others by applying the innovative algorithms tried to find the optimality in different fields like income, battery life time, stability in supply, scheduling, emissions and etc. Many review papers have analyzed the previous studies and brought the general framework of V2G system. In this

**TABLE 1**

**Categorization of recent studies based on their methodologies and problem solving.**

| Ref. | Optimization | Simulation | Intelligent Dispatch and RES integration | Degradation | CS and its placement | Line Loading | GA & Integer | Scheduling | Social and Behavior | Aggregation | Tax | Battery costs and charging rhythm | Encouraging system | Environmental Issues | Feasibility of Implementing V2G | Regulation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [21] | ✓ | ✓ | ✓ | | | | | ✓ | | | | | | ✓ | | ✓ |
| [5] | | | ✓ | ✓ | | | | | | | | ✓ | | ✓ | | |
| [15] | ✓ | ✓ | | | ✓ | ✓ | | | | | | | | ✓ | | |
| [35] | ✓ | | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | ✓ | | ✓ |
| [20] | | | | ✓ | | | | | ✓ | | | | | ✓ | ✓ | |
| [24] | | | ✓ | ✓ | | | | ✓ | | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| [36] | ✓ | | ✓ | ✓ | | | | ✓ | | | ✓ | ✓ | | ✓ | | |
| [37] | | ✓ | | ✓ | | | | | | | | | ✓ | ✓ | ✓ | |
| [38] | | ✓ | | ✓ | | | | | | | | ✓ | | ✓ | ✓ | |
| [39] | | ✓ | ✓ | | | | | | | ✓ | | ✓ | | ✓ | | ✓ |
| [40] | | | ✓ | ✓ | | | | | ✓ | | | ✓ | | ✓ | ✓ | ✓ |
| [41] | | ✓ | | ✓ | | | | | | | | ✓ | | ✓ | | ✓ |
| [42] | ✓ | ✓ | | ✓ | | | | | | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| [43] | ✓ | ✓ | ✓ | | | | | | | ✓ | | | | ✓ | | ✓ |
| [44] | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | | ✓ | ✓ | ✓ | | ✓ | | |
| [45] | ✓ | ✓ | ✓ | | ✓ | | | | | ✓ | | ✓ | | ✓ | ✓ | |
| [46] | ✓ | ✓ | ✓ | | ✓ | | | | | ✓ | | ✓ | | ✓ | | |
| [47] | ✓ | ✓ | ✓ | | ✓ | | ✓ | | ✓ | ✓ | | | | ✓ | | ✓ |
| [48] | | ✓ | ✓ | | | | | | | ✓ | | | | ✓ | | ✓ |
| [49] | | ✓ | | | ✓ | | | ✓ | | | ✓ | | | ✓ | | |
| [33] | | ✓ | ✓ | | | | | | | | | | | ✓ | | |
| [50] | ✓ | ✓ | | ✓ | | | | | | | | ✓ | | ✓ | | ✓ |
| [51] | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| [52] | | ✓ | ✓ | ✓ | | | | | | | | ✓ | | ✓ | | |
| [53] | ✓ | ✓ | | | | | | ✓ | | ✓ | | | | ✓ | | |
| [54] | ✓ | ✓ | ✓ | | ✓ | | ✓ | | | | | | | ✓ | ✓ | ✓ |
| [55] | ✓ | | ✓ | | | | | | ✓ | | | | | ✓ | | |
| [56] | | | | | | ✓ | | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| [57] | ✓ | ✓ | | | | | | ✓ | | | | | | ✓ | ✓ | |
| [58] | ✓ | ✓ | ✓ | | | | | ✓ | | | | | | ✓ | ✓ | ✓ |
| [12] | ✓ | | ✓ | | | | | | | | | | | ✓ | ✓ | |
| [59] | | ✓ | ✓ | | | | | ✓ | | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| [1] | | | ✓ | ✓ | | | | | ✓ | ✓ | | ✓ | | ✓ | | |
| [60] | ✓ | ✓ | ✓ | | ✓ | | | | | ✓ | | ✓ | | | | |

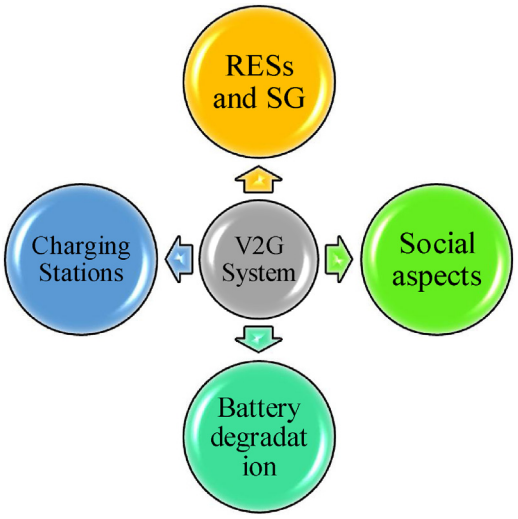


**FIG. 5**
The main categorization of recent studies.

between, this field of study suffers from a lack of clear map to conduct the future studies and show the possible gap in literature.

In this study, we are going to bridge this knowledge gap and propose a complementary direction for the future studies and explore the shortages in this field of study. Therefore, we propose a framework for the future studies that consists of a scientific categorization of previous studies based on their methodologies as given in Table 1. According to the gathered data, it is revealed that most of authors focused on the environmental issues that could be summarized in GHGs emission, air pollution, oil and gas resource depletion, petroleum dependency, increasing the temperature of the earth, and so on. In some of the studies, the authors by using the innovative algorithms like the genetic algorithm or Monte Carlo cycle have tried to reach an optimal solution for their suggested models. These models are usually around optimality of the total income of the aggregators and EVs' owners, efficiency of the grid, GHGs emission, fluctuation and so on. Based on the Table 1, there is a gap in literature for topics like social aspects, finding the placement of charging stations, line loading and the scheduling for charging and discharging the EVs. Based on our paper that mostly encompasses the recent relevant studies, the most common fields of research around the V2G system could be classified into four basic groups that cover all aspects of V2G technology, Fig. 5. In each field, we are looking for the clues and structure of their research to reach a general overview of them and focus on the possible gaps.

### *Integration of the V2G with RESs and smart grid*

Generally, the environmental issues as a result of human activities are big threats for the future of the earth. In each day, million tons of GHGs enter to the atmosphere that bear negative consequences on the health of human and animals. Based on the recent analysis, the transportation system and industrial activities are the main source of air pollution. In recent decades, many attempts from governmental institutes or NGOs have focused on these issues to find solutions in order to preserve the earth for the next generations. One of the suggested solution for solving environmental problems was migrating from using the petroleum fuels and power plant to establishing the RESs for generating electric power. The RESs especially photovoltaic and wind power can be used for generating electric power without any air pollution and avoid GHGs emission. But one the biggest weakness of this system is the wind and solar energy are unpredictable and intermittent in nature. For example during the summer when the level of sunshine is high or in some days when speed of wind is faster than other days, the solar or wind power plant can generate electric power higher than demand. In reverse, after sunset, the solar cells are out of service and their outputs reach to near zero [61]. So, the RESs need a complementary system to support it in different situations and convert the intermittent current of power to uniform and continuous current. One of the possible alternatives is using huge electric storage batteries with high capacity and high quantity to store the electricity when the system has surplus power and release it in emergency. Another alternative is applying the V2G concept. The recent studies around integration of V2G system and RESs in smart grid could be divided as follows:

### Storage systems and scheduling

Due to variability of the RESs like wind and solar energy, supportive energy storage systems are needed to save the excess load and release it in necessary. The stationary energy storage system (SES) is a collection of electric batteries, hydrogen energy storage, air compressors and flywheels are designed based on the demand and installed to correct capacity to support the grid in necessary and integrate with RESs. However, PHEVs and V2G are another complementary technology that are being deployed for many purposes like decreasing emissions, mobility, integration with RESs and so on. Implementation of PHEVs as integrating system with RESs is fundamentally different with SES for the same purpose.

In the SES, the charging and discharging mode is a function of system's capacity and the only constraint for this system is its energy storage capacity, but in the V2G system many other factors must be satisfied to integrate with RESs. For example, the EVs in the V2G system with different states of charge are plugged into the grid and the number of EVs differs from one time to other times, or each EV has its own pattern of driving that remained charge has to satisfy the demand for mobility. Therefore, the flexibility of V2G system is less than SES but the benefits of V2G system is not equivalent with benefits of SES. In Ref. [60], the authors analyze the equivalent characteristics of electric storage systems in both V2G and SES system to evaluate their effects on the grid in different topics like the amount of emission, renewable energy utilization and balancing power plant operation. The results of this study can be summarized as follows:

1 The storage systems based on the V2G are more efficient than SES for utilizing the available renewable generated energy.
2 The storage system based on the V2G are less capable for balancing the power plant facilities rather than SES due to various driving pattern of EVs.
3 The discharging ability of storage system based on V2G provide a wide range of benefits like emissions and balancing the grid system over than traditional charging mode.
4 The V2G-based storage system can show its own benefits when there are sufficient and proper facilities and workplace for EVs to connect to the grid and absorb the peak energy generated by the solar during the day otherwise this system is not efficient rather than SES.

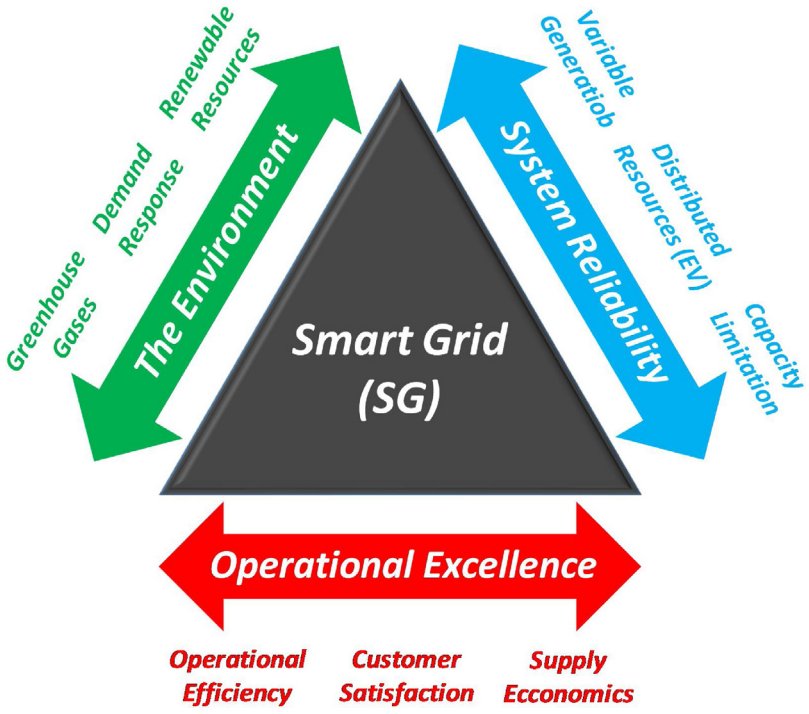


**FIG. 6**

EVs in relation to the new emerging smart grids.

In recent years, many studies [62–65] have analyzed performance and durability of hydrogen fuel cells and their effects on the V2G system. The authors provide a technical feasibility of EVs that equipped with hydrogen fuel cells and their relationship with a residential building for reaching to a ZEB. This system is tested in a small sample (one house and EV with hydrogen fuel cell) and all the possibilities are analyzed. In a simulation that conducted by 10 houses and 5 EVs through a year, all the relationships between the main players in this system are analyzed; in this simulation the people who live in this house could receive a constant current of power between 0–10 KW from the V2G system. During the day, all the electrical activities like cooking, cooling and heating systems are supported by PV and in availability of EVs, they can plug into the grid. In this case, if the generated power by the EVs is sufficient, the extra power could feed the power grid, but in other sider when the stored power in the EVs could not support the demand of the houses so the required power is drawn from the grid.

According to a study [66], the buildings are the major consumer of energy that use about 40% of total produced energy. So, energy management in buildings can be a good target for reducing the emissions and eliminating carbon footprint and making the energy-usage efficient. In this case, many new technologies are implemented in these buildings to meet all the predicted benefits and bear good consequences that this type of buildings called smart buildings. An important concept in this field is demand response (DR) that focuses on planning, implementing and monitoring all the relevant activities to influence on the habits of end-users consumptions and bear beneficial outputs [67]. The smart buildings let the end-energy-users to play an act as energy producers and support the grid in emergencies.

In fuel cell, reaction of hydrogen and oxygen can produce electricity, heat and water, so by applying these type of fuels in industry and other consuming sectors, the GHGs emission can be reduced and eliminated. Therefore, they are applicable for short period of time to support the grid and avoid the fluctuation because of intermittent nature of RESs.

The participated EVs in V2G system can affect the patterns of power demand and supply. For having positive and more efficient impacts on the power network, existing an effective management of the EVs based on the communications, information and technologies will be a major function of SG [68]. In Ref. [69], the authors suggest an information models for vehicle-to-grid (V2G) and vehicle-to-infrastructure (V2I) communication according to the International Electro-technical Commission (IEC) 61850 and IEEE 1609 WAVE standards for managing EVs load in distribution networks. In Ref. [70], based on the IEC 61850-90-8 and IEC 61850 Standard information models for all the scenarios in V2G and also communication models for EVs are established. Moreover, coordination scheme for the EVs under SG operation a list of terms is demonstrated. In Ref. [71], the authors provide an IEC 61850 communication-based EM for the EVs in micro grids and propose a standardized communication for micro grids under a high penetration of the EVs based energy management. Especially in this study, future insight for developing IEC 61850 communication model is provided and an XMPP based service mappings for micro grid communication network is presented. In Ref. [72], the authors establish a scheme for providing uninterruptible energy supply by available assets and distribution lines in a local power network. In addition, a communication technique for managing the power energy in emergency cases based on IEC 61850 standard is developed.

Many studied try to find the optimal schedule and dispatch for the current generation resources to make sure that provide sufficient PFR (primary frequency response) all times for the grid but none of them focused on the storage technology for efficiency of system by providing PFR during long times. The values of the provided services by the storage systems are affected by two elements, their size and location that should be optimized to give us the highest benefits. The article [51] suggests a mathematical formulation by considering the generation and storage system. In this model, the PFR with its probabilistic nature is defined as constraint. Then this model tries to optimize the sizing and siting of the storage system to find the best schedule for them to provide PFR services under condition that high level of RESs operate in the system. Then the results of this system are compared with the conventional expansion model that is lack of PFR as constraint.

The implementation of smart grid bear positive consequences in three dimensions, as shown in Fig. 6. First, this system by integration of EVs and using renewable energies like wind and solar can decrease the air pollution and greenhouse gas emission. Second, this system can increase the performance and efficiency of the grid by distribution of the power based on V2G and G2V technology and finally all in all this system can increase the final customers' satisfaction and operational efficiency [73].

For having such positive consequences, an integrated system to manage the demand and supply is required. ANN and ANFIS are smart controller that by using fuzzy techniques are designed to control the system in two modes G2V and V2G technology. The precise measurement of SOC (state of charge) is important to determine the capacity and stored energy in the battery and avoid possible damages like excessive depth of discharge and also overcharging. In Ref. [54], the inputs for smart controller consist of two types of information direct and indirect data for both grid and batteries. The previous charging controllers have limited functions but in the proposed controller, all of requirements are satisfied. The main objective functions of this study is analyzing the suitable place of smart parking lots and also defining the size of RESs in order to reduce total energy loss and also introducing a smart and intelligent operational controller for optimizing the process of V2G and G2V system.

In many studies, the authors focused on the RESs in smart grid and its integration with EVs to reduce the peak load rather than peak demand. There is a lack of realistic samples of smart grid and EVs, their relationships and possible effects to realize the efficiency of this system that many of studies analyzed one deterministic approach with one possible scenario at a time. In Ref. [58], a small sample of smart micro grid is considered that consists of an office building and connected DER elements like photovoltaic panels, storage systems and some EVs for charging and discharging. In this simulation, the moving patterns of EVs is analyzed as stochastic model and PV production is formulized under uncertainty. Also a mixed integer linear programing is suggested to analyze the energy management system structure under connected elements like V2G, G2V, V2B, PV and metering system and in different scenarios to find the optimality of the system and make a balance between them. In addition, conditions when there is extra power and system could sell it back to the grid is examined.

Uncoordinated charging can bear serious problems for the power grid by increasing the energy loss, peak demand and overloading. A solution for balancing the level of demand and supply is developing the grid system that is expensive and needs a huge amount of budget. Another efficient way is establishing a suitable schedule for EVs coordinated charging that divided into two approaches: EV day-ahead charging scheduling and EV real-time charging scheduling [66,74]. In the day-ahead charging schedule, the aggregators play an important role for making bidding decisions. The gathered and confirmed bidding decisions are sent to the distribution system operator (DSO) for final approval and then DSO negotiates with the aggregators for reaching a bidding agreement. In this approach, the information like availability and consumption of the EVs can be obtained but these information are uncertain because of uncertainty of EVs mobility.

For having a practical energy management, EV real time scheduling can be more efficient by considering a stochastic EVs' driving scheduling. In this approach, the aggregators collect the EVs information, optimize the charging schedule, and then send the

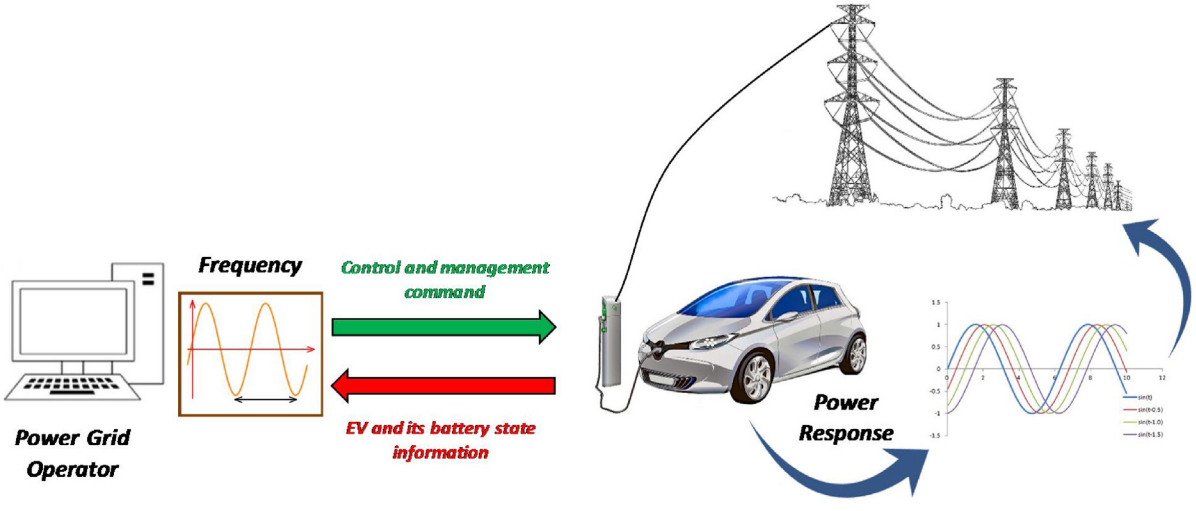


**FIG. 7**
A simple scheme of distributed dispatch system.

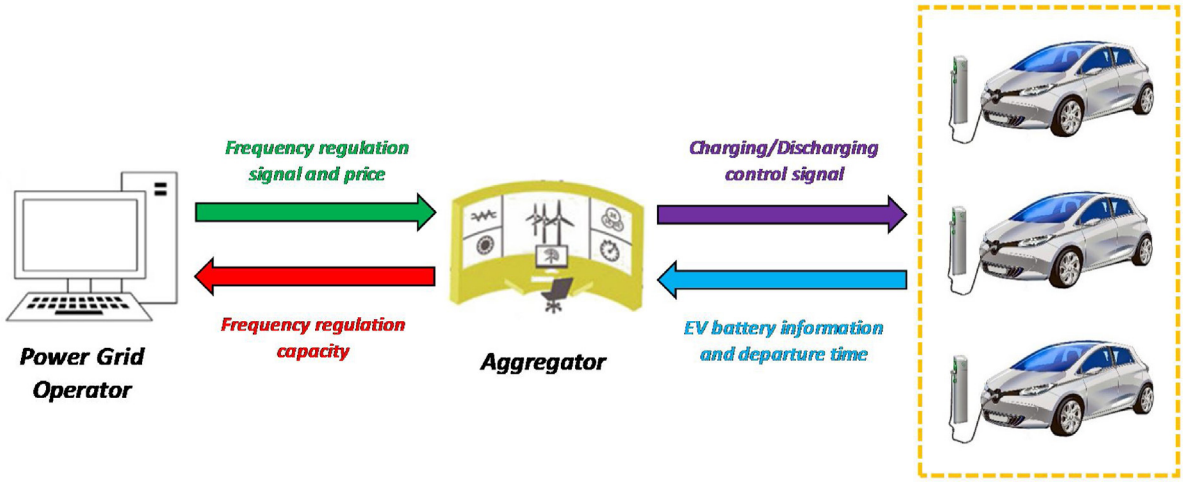


**FIG. 8**

A simple scheme of centralized dispatch system.

proper scheduling to the charging posts. In this case, high-speed telecommunication between the aggregators and charging posts is crucial. Totally, there are two challenges, first one is uncertainty of charging behaviors of EVs and second one is overlong solving time for finding the optimality of solutions in the charging scheduling problem of large-scale electric vehicles [53]. Based on the day-ahead approach, the aggregators have sufficient time for establishing bidding solution, although these solutions are based on uncertainties and are not precise. Therefore, a linear program in real time charging schedule is developed in order to connect a huge amount of EVs into the smart grid.

In Ref. [49], the effect of charging schedule on the $CO_2$ emission is analyzed in order to find the optimal scheduling for having less rate of $CO_2$, also the environmental aspects of implementing V2G system is evaluated. The suggested methodology is based on the real samples in different regions of the US that each of them has its own regional driving pattern and marginal energy generation in order to minimize the $CO_2$ emission. All the measurements of $CO_2$ emission are conducted in three periods of time (day, evening, night) by two types of EVs (Nissan Leaf and Chevrolet Volt)

## Aggregation modules and regulation

All in all, for implementing the V2G system some basic and necessary requirements are needed like electronic devices, communication network and especially smart grid [75,76] system has many advantages for the grid like increasing the efficiency [77], continuous monitoring, integrating with RESs, reliability, flexibility and so on. Because of some possible mistakes in forecasting and intermittent features of RESs, there is not a balance between the power generation and demand, so in this situation charging and discharging the EVs should happen on the correct scheduling and right moment based on the adjusting plan [21]. In the V2G system, EVs by discharging during peak demand can reduce the total demand from central power plants and reduce the fix and operational costs of the grid.

One of the most controversial topics for supporting services of V2G technology is frequency regulation. Dispatching strategies define the efficiency and feasibility of EVs that participate in frequency regulation [40]. The aim of dispatching strategies follow two main problems: first stability of frequency and second economic aspects that refers to increasing the EVs' owners or aggregators profit in order to encourage them to participate in this

**TABLE 2**

**Classification of dispatching strategies in V2G system.**

| Dispatching strategy for | Based on | Aim |
|---|---|---|
| Stability Problems | Grid Frequency | Grid frequency as objective function and aggregated power is dispatched based on grid demand (backup system for renewable energy resource, signal analysis, reduction of peak load) |
| | Participating Capacity | EVs capacity as objective function for optimization |
| Economy Problems | Benefits of EVs' owners and aggregators | Maximization of their profit to motivate them to participate |
| Demand of the EV's Owners | – | Maximizing the SOC |
| Mobility Behavior of EVs | – | Satisfying the travel demand for EVs' owners as objective function |
| Response of EVs to Frequency Regulation Signal | – | Aggregators or grid operators send message to the EVs' owners and inform them about the grid demand and then owners make a response |
| Fair Allocation Between EVs | – | Priority for participating in frequency regulation based on SOC, so high level of charge means higher priority |
| Other Economic Factors | – | Elements like battery degradation, unpredictable costs, environmental effects |

supporting system. So, in order to optimize the objective function under these two problems, different strategies are discussed. Participants can provide their services for frequency regulation in two modes [78]; **Distributed dispatch system** and **centralized dispatch system.** In distributed dispatch system, integration points are distributed in public and private sectors and grid operators manage the individual EVs to support the grid. In centralized dispatch system, integration points are focused on charging stations, parking lots and defined locations and aggregator operators control the individual EVs and grid operator manage aggregator operators as shown in Fig. 7 and Fig. 8.

In Ref. [43], a new optimal dispatching strategy is suggested that simultaneously focuses on satisfying required driving demand and maximizing the participating EVs owners' profit and also increasing the efficiency and performance of the system to regulate frequency properly. The body of the suggested dispatching strategy contains four modules:

- Driving demand calculation module
- Electric vehicles participating frequency and voltage regulation judge module
- Optimality in regulation power participating in frequency regulation calculation module
- Regulation power allocation module

Generally, all the possibilities for dispatching strategies are divided into seven groups that can be summarized in Table 2.

Penetration a huge amount of EVs into the market could bear serious challenges for the grid. In this case many studies [79] have asserted that there should be defined a limit range for extracting the power from the grid by the EVs for charging their batteries in order to avoid fluctuation in power. In Ref. [59], the authors analyze the influence of implementing EVs fleet on the power electric generation system in Portugal by using real data existing electrical installations and equipment. In addition, the integration of this system into the household without need for additional fund or and concerns are considered.

Ramp up or ramp down is a backup system when the output of power plant suddenly changed [46]. Due to intermittent nature of RESs, they cannot provide a continuous power supply and for avoiding the power shortage, natural gas power plants provide some ramp up and ramp down to make balance in the system in other word, the wind power and gas power plant are implement of each other. Individual EV cannot have a tangible effect on the grid but if a huge group of EVs are managed and aggregated by the central transmission operator, it can balance the system and avoid interrupt.

## Feasibility and economic aspects of V2G

In Ref. [37], there is an analysis of predicted income through the generating the power in three different scenarios: building self-consumption, STOR (Short Term Operating Reserve) and the Wholesale market. In this study, authors suggest a Mont Carlo-based simulation to evaluate the potential of implementing the V2G technology. The outputs of this simulation are encompassed the battery degradation costs, generated income and costs related to energy saving. According to the results of this simulation, the V2G system has a noticeable benefits and revenue for both the grid and EVs' owners. But the battery degradation costs due to frequent charging and discharging have an influential effects on the feasibility of the V2G technology, on other hand trading with wholesale market has the highest income rather than other opportunities.

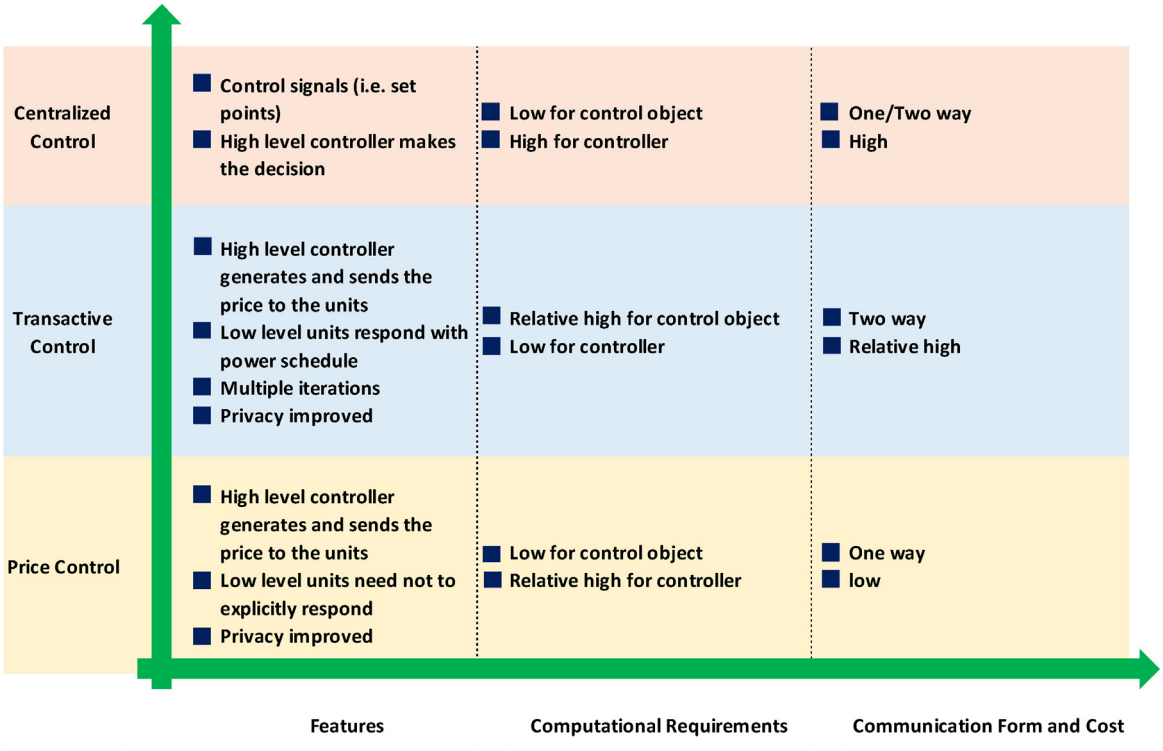


**FIG. 9**

Comparison of control strategies.

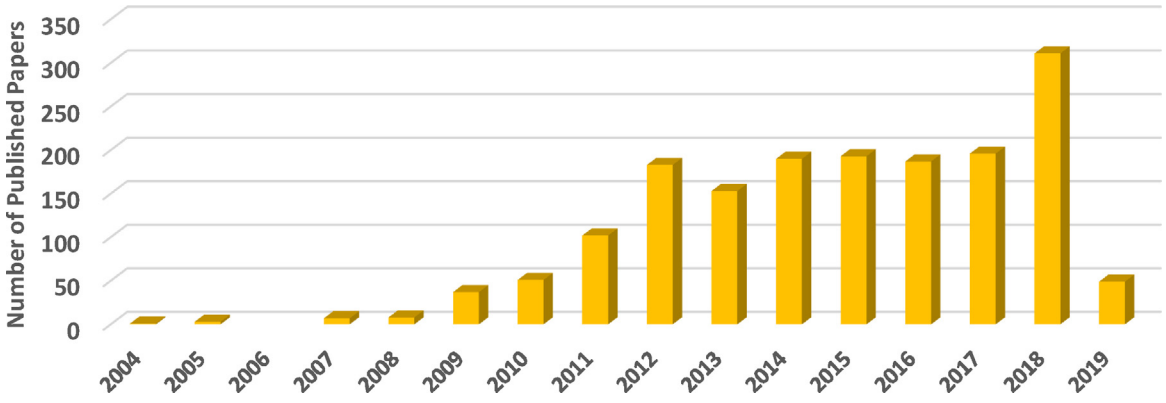


**FIG. 10**

Distribution of the V2G-related published articles by year.

The main topic in Ref. [55] is analyzing the financial aspects of V2G system as a supportive alternative for RESs and analyzing the smart and intelligent methods for increasing the time life of EVs batteries. For applying the V2G system as ancillary services, two factors play important role, SOC that show us the rate of charged capacity and probability of participation (POP) that is a results of many other elements. Both of them have an uncertain concept that a stochastic model needed for analyzing the effects of V2G system on the grid.

In Ref. [47], the authors try to find an optimal relationship between the type of the building and EVs owners' behaviors for increasing the efficiency of the system by using a novel mixed integer linear programming. In this study, the flow of energy between each building (that has its own power generators and thermal and electric storage facilities) with charging stations (provide power through renewable energy sources) is analyzed. In this model, three parameters are introduced: the initial SOC, desired charging level after departure and availability of EVs. The general purpose of simulating this model is maximizing the feasibility of implementing V2G and V2B and maximizing cost saving.

In Ref. [42], a real tested V2G system in Los Angeles Air Force with 30 different EVs is evaluated to minimize the operation costs of the fleet and maximize total revenue from wholesale market participation. Finding the optimal size of ancillary services or efficient schedule is based on some uncertain variables and constraints like time which EV plug into the grid, regulation costs and rate of demand for mobility and grid services. Therefore, to handle these kind of uncertain variables, aggregators need to use stochastic models to meet all the requirements.

**TABLE 3**

**The 24 journals that have published the greatest number of the V2G articles.**

| No. | Journal | Number of Published Papers | % of Papers |
|---|---|---|---|
| 1 | IEEE Transactions On Smart Grid | 67 | 14.0% |
| 2 | IEEE Power And Energy Society General Meeting | 45 | 9.4% |
| 3 | Applied Energy | 35 | 7.3% |
| 4 | Energies | 32 | 6.7% |
| 5 | IEEE Transactions On Vehicular Technology | 19 | 4.0% |
| 6 | World Electric Vehicle Journal | 19 | 4.0% |
| 7 | Dianli Xitong Zidonghua Automation Of Electric Power Systems | 18 | 3.8% |
| 8 | IEEE Transactions On Sustainable Energy | 18 | 3.8% |
| 9 | Electric Power Systems Research | 17 | 3.5% |
| 10 | IECON Proceedings Industrial Electronics Conference | 17 | 3.5% |
| 11 | Journal Of Power Sources | 17 | 3.5% |
| 12 | Advanced Materials Research | 16 | 3.3% |
| 13 | Energy | 16 | 3.3% |
| 14 | Energy Policy | 16 | 3.3% |
| 15 | IEEE Transactions On Power Systems | 16 | 3.3% |
| 16 | IEEE Transactions On Industrial Electronics | 14 | 2.9% |
| 17 | IEEE Applied Power Electronics Conference And Exposition APEC | 13 | 2.7% |
| 18 | Dianli Zidonghua Shebei Electric Power Automation Equipment | 12 | 2.5% |
| 19 | Dianwang Jishu Power System Technology | 12 | 2.5% |
| 20 | Energy Procedia | 12 | 2.5% |
| 21 | IEEE Transactions On Industrial Informatics | 12 | 2.5% |
| 22 | IEEE Transactions On Power Electronics | 12 | 2.5% |
| 23 | International Journal Of Electrical Power And Energy Systems | 12 | 2.5% |
| 24 | Renewable And Sustainable Energy Reviews | 12 | 2.5% |
| | Total | 479 | |

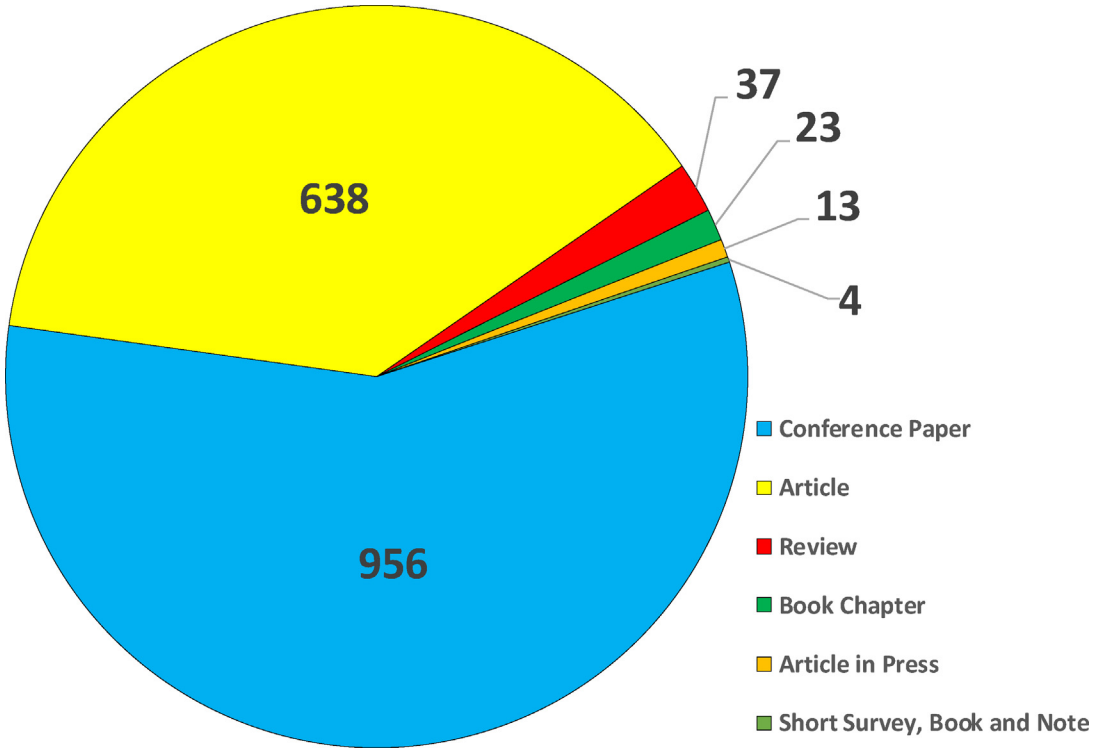


**FIG. 11**
Number of publications based on document types.

In Ref. [45], the authors suggest an optimization model to evaluate and simulate electric buses (15 buses) in real life and analyze their function and performance for analyzing the influence of type and size of the RESs. Four cases are proposed that are compared with the basic case that is case without renewable energy. In this study, the suggested two-level optimization model, the energy, capacities, reserve and regulation up and down **first** for the parking lot operator (PLO) and then in the **second** level for the distribution system operator (DSO) are analyzed and developed. The objective function of the first level is maximizing the PLO profit and in the second level minimizing the DSO costs.

### *Battery degradation*

Implementing the V2G system can bear four main consequences: increasing reliability of the grid, decreasing the operating costs, offering lower prices for storage devices and reserving for renewable energy integration. Overall, behind these kind of benefits, battery degradation and battery wearing is one the most concerns of cooperating in the V2G system as a result of frequent charging and discharging. As a study, the battery of EVs should be replaced with the new one when it reaches its end of life (EOL) and losses 20% of its storage capacities. The battery wearing is a result of many elements like temperature, depth of discharging, rate of charging and time. In fact, battery degradation is a result of many factors that make it hard to be evaluated. For example, temperature of the EVs battery is affected by solar radiation, heat the generated by charging and discharging, ventilation system, temperature of the environment and so on. In Ref. [50], the authors mainly focus on the quantifying the battery degradation in two modes driving vs. driving and providing ancillary services in V2G

**TABLE 4**

**The 30 most used keywords by number of the V2G-related articles.**

| No. | KEYWORD | Number of Publications |
|---|---|---|
| 1 | Electric Vehicles | 982 |
| 2 | Charging (batteries) | 665 |
| 3 | Vehicle To Grid (V2G) | 645 |
| 4 | Electric Power Transmission Networks | 630 |
| 5 | Vehicles | 592 |
| 6 | Vehicle-to-grid | 526 |
| 7 | Vehicle To Grids | 519 |
| 8 | Smart Power Grids | 326 |
| 9 | Smart Grid | 315 |
| 10 | Electric Vehicle | 293 |
| 11 | Electric Vehicles (EVs) | 287 |
| 12 | Secondary Batteries | 277 |
| 13 | V2G | 248 |
| 14 | Vehicle-to-grid (V2G) | 206 |
| 15 | Plug-in Electric Vehicles | 175 |
| 16 | Electric Batteries | 168 |
| 17 | Optimization | 168 |
| 18 | Renewable Energy Resources | 158 |
| 19 | Costs | 155 |
| 20 | Electric Power Distribution | 151 |
| 21 | Electric Machine Control | 143 |
| 22 | Electric Utilities | 136 |
| 23 | Vehicleto-Grid (V2G) | 134 |
| 24 | Electric Power System Control | 118 |
| 25 | Vehicle To Grid | 113 |
| 26 | Electric Automobiles | 109 |
| 27 | Scheduling | 108 |
| 28 | Frequency Regulations | 105 |
| 29 | Hybrid Vehicles | 105 |
| 30 | Battery Management Systems | 104 |

**TABLE 5**

**The distribution of the V2G-related articles in different countries.**

| No. | COUNTRY | Number of Publications | % of Papers |
|---|---|---|---|
| 1 | China | 361 | 17.2% |
| 2 | United States | 356 | 16.9% |
| 3 | India | 118 | 5.6% |
| 4 | Iran | 88 | 4.2% |
| 5 | United Kingdom | 85 | 4.0% |
| 6 | Germany | 83 | 4.0% |
| 7 | Canada | 80 | 3.8% |
| 8 | Australia | 74 | 3.5% |
| 9 | Italy | 61 | 2.9% |
| 10 | Japan | 61 | 2.9% |
| 11 | Portugal | 59 | 2.8% |
| 12 | South Korea | 58 | 2.8% |
| 13 | Denmark | 56 | 2.7% |
| 14 | Hong Kong | 47 | 2.2% |
| 15 | Singapore | 47 | 2.2% |
| 16 | France | 45 | 2.1% |
| 17 | Spain | 41 | 2.0% |
| 18 | Greece | 24 | 1.1% |
| 19 | Netherlands | 24 | 1.1% |
| 20 | Brazil | 22 | 1.0% |
| 21 | New Zealand | 22 | 1.0% |
| 22 | Norway | 21 | 1.0% |
| 23 | Switzerland | 21 | 1.0% |
| 24 | Turkey | 18 | 0.9% |
| 25 | Saudi Arabia | 17 | 0.8% |
| 26 | Sweden | 16 | 0.8% |
| 27 | Taiwan | 16 | 0.8% |
| 28 | Belgium | 14 | 0.7% |
| 29 | Pakistan | 14 | 0.7% |
| 30 | Egypt | 13 | 0.6% |
| 31 | Malaysia | 12 | 0.6% |
| 32 | Other Countries | 127 | 6.0% |
| | Total | 2101 | 100.0% |

**TABLE 6**

**Top 5 most popular research keywords in 2018 and 2019.**

| No. | KEYWORD |
|---|---|
| 1 | Vehicle-to-grid |
| 2 | Vehicle To Grid (V2G) |
| 3 | Electric Power Transmission Networks |
| 4 | Charging (batteries) |
| 5 | Electric Vehicles |

**TABLE 7**

**Application fields of the V2G methodology in 2018 and 2019.**

| No. | Field of Research |
|---|---|
| 1 | Engineering |
| 2 | Energy |
| 3 | Computer Science |
| 4 | Mathematics |
| 5 | Environmental Science |

system by using thermal model, pattern of driving and powertrain model. There are two methods for measuring the lifetime of EVs battery. First one is calendar life that is the amount of years that the batteries are be expected to operate and the second one is cycle life that is the number of charging ad discharging cycles.

There are many studies around managing strategy for optimizing the performance of the grid and also operating cost. In Ref. [5], the situation of battery in frequent charging and discharging during the day (battery wearing) and charging stations are analyzed via three strategies: centralized control, autonomous or transactive control and battery management strategies [44]. Centralized control that is some defined stations based on demand and location and coordinated EVs can be charged and discharged and support the grid. In autonomous control, EVs are scattered everywhere but they need intelligent charger to collect information about grid and price policy automatically and then by a defined schedule they support the grid. Another strategy is battery pack replacement that is defined as some full charged and ready to use battery in charging stations that provide services for the EVs and can decrease the charging time and improve the reliability of the grid. A general comparison of aforementioned control strategies are provided in Fig. 9 based on the features, computational and communication requirements.

Basically there are three types of battery molding in the recent studies: first and the most used model is about state of charge (SOC), second, voltage model and relevant calculation for energy losses in the batter and third molding for the life time of the battery [44]. In Ref. [39], effects and obstacles of implementing the V2G system like required costs, battery degradation, effects of penetration level are discussed and this study compares the effects of coordinated and uncoordinated EVs on the efficiency of the grid.

In Ref. [59], the energy efficiency of the EVs is defined in two ways. First, the power efficiency is a ratio between the total extracted power from the rechargeable battery to the supplied power by the grid (E out/E in) and second, the efficiency is defined as a product of charger efficiency and battery efficiency (*n charger * n battery*). Charger efficiency refers to the energy losses as a result of converting the power from AC to DC mode that shows itself as heat. The efficiency of the charger of Opel Ampere EV is estimated around 94% while based on another study [80], in the USA is revealed that efficiency of this EV is around 86.4%. Totally, the charger efficiency is related to the temperature that means by increasing the temperature, the efficiency can be dropped. Also according to this study, the efficiency of charges less than 2 KWh is 83.5% and above the 2 KWh is around 86.5%. In average, the battery efficiency is approximately 86.4%.

In Ref. [35], the possible challenges for V2G system is discussed like battery wearing, high initial money, and social issues for accepting this system and so on. Moreover, two common techniques (Genetic Algorithm and Particle Swarm Optimization) and their characteristics are reviewed.

### *Social aspects of V2G implementation*

The demand response (DR) is an encouraging system to motivate the end-users of electricity manage the demand during the peak time when the grid faces with high risks. The DR program can be divided into two groups. First one is **time-based** that consists of time of use (TOU), real time pricing, and critical peak pricing. In this system, the price of electricity is higher during the peak-demand and is lower in off-peak demand. The goal of this system is shaving the peak demand and reducing the possible risks of fluctuation in power supply. Moreover, the participated EVs in this

program are in the G2V mode. The second one is **incentive-based** that consists of frequency regulation and spinning reserve that both of them provide ancillary power for the grid and support it in necessary. The EVs can participate in this plan as V2G and G2V system and distribute the power.

In Ref. [51], the authors mainly suggest a new stochastic model that consider both time-based and incentive-based program simultaneously and analyze the interaction of independent system operator and aggregators for their own profits. The possible risks like uncertainties of renewable energies (wind and solar), parking patterns and loading patterns are studied. The effectiveness of the model is evaluated in different environment (commercial, residential and industrial sectors) and according to the EV penetration, the level of risks are discussed.

In Ref. [36], three scenarios of V2G are discussed: **workhour price-taker scenario**, an **arbitrage-guided scenario with perfect information**, and a **user-defined electricity selling price scenario** that each of them has its own procedure for the vehicles to charge and discharge themselves according to the power demand. In the second part of this article, the effects of $CO_2$ Tax on the participants is analyzed. The aim of this plan is encouraging method to attract the participants in the V2G system. So, during the charging the EVs owners based on the consumed power pay the tax and in reverse during discharging capture the $CO_2$ tax as benefits.

### *Charging stations*

The PHEVs as the latest upgraded version of EVs is considered an auxiliary power for the grid to support it in the peak demand if it is integrated into a chain of supply and demand that is called V2G system [81]. One of the prerequisite for implementing this system is charging stations in order to charge and discharge the EVs. The optimal location of CSs is crucial for the efficiency and performance of the system. Actually the finding the optimal placement of charging stations means how the EVs could coordinate in V2G system as a renewable energy resource to support the grid during peak demand.

There are limited number of studies around this topic and rarely we can find a general analysis for charging station and its placement. Totally, these studies have focused on two policies. First one is finding the optimal location of charging stations and second one is focusing on the power grid concepts. In Ref. [82], the objective is placing the charging station in urban areas and maximizing the total number of reachable households and minimizing the energy costs between the CSs and home. In Ref. [83], the objective is determining the charging stations in city of Vienna and Austria in order to satisfy the demand of electric taxi vehicles. In Ref. [15], the authors by applying an algorithm (quantum binary lightning search algorithm) try to find the optimal placement of CSs in order to improve the quality of the grid and regulate the power and decrease the loading time. Genetic algorithm and particle swarm optimization are popular methods to determine the optimal location and size of CS but these methods have some limitations in premature convergence. Therefore, the authors propose a new algorithm that is called quantum binary lightning search algorithm that is derived from original binary LSA, in order to find the optimal placement of the CSs and increase the power quality in the system [15]. The authors in Ref. [84] consider the social and economic aspects of charging stations and employ a genetic algorithm to define the optimal placement of CSs and minimize the transportation costs. Also in [85,86] a hybrid genetic algorithm is applied for minimizing the investment and travelling costs.

## Statistics on V2G publications

There has been rapid and continuous growth in the field of the EVs and the V2G-related studies. In this section, we explored related articles on SCOPUS (http://www.scopus.com/) and combined them into our dataset that is mainly collected from the website of www.sciencedirect.com. We considered publications until end of March 2019.

### *Statistics based on year of publication*

Based on Fig. 10 that indicates the number of published papers around the V2G system between 2004 until March 2019, the rapid increase of V2G-related articles by years is clear. In recent two decades (2004–2019), there are approximately 1671 the V2G-related articles in the literature. Since 2012, a tremendous growth in published papers in journals shows the importance of this topic. In addition, based on the recent environmental issues there is a huge tendency among the scientists, institutions and government sector for implementing the electrified transportation fleet and especially the V2G system and in average in each year, about 200 articles have been published.

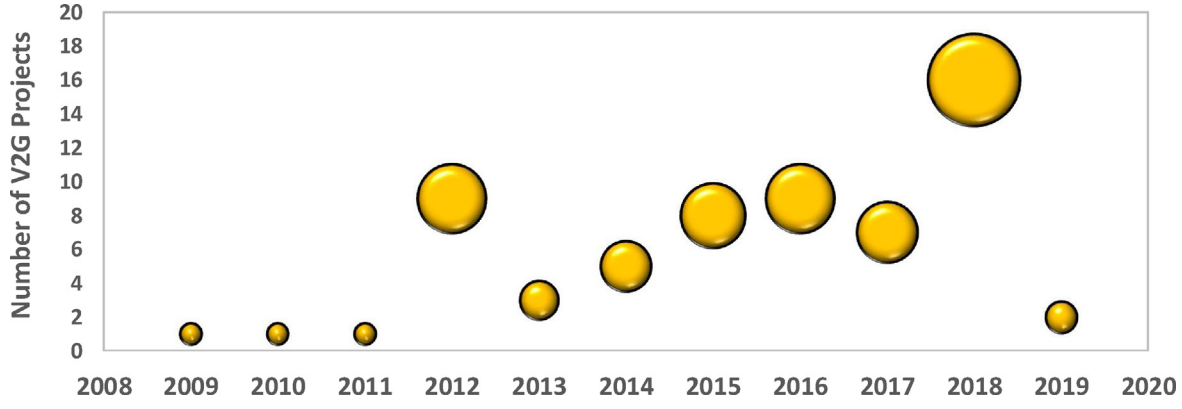


**FIG. 12**

Number of V2G Projects.

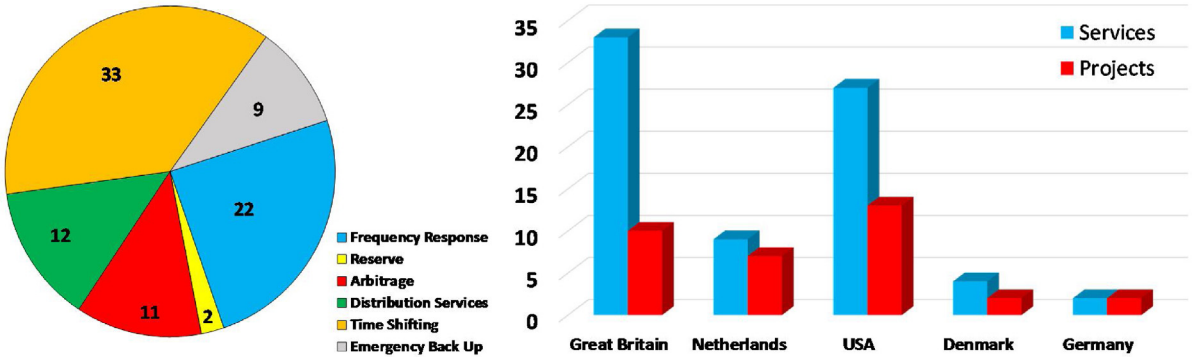


**FIG. 13**
Offered V2G services in top countries.

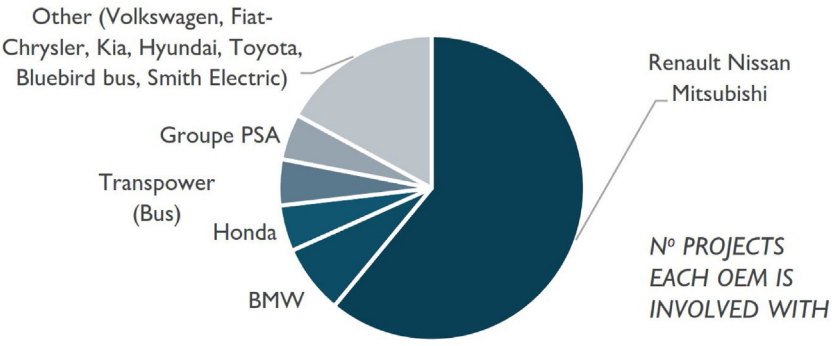


**FIG. 14**
Contribution of vehicle manufacturers in V2G projects [88].

In general, we can roughly classify the development status of the V2G-related articles into three stages. 2004 to 2008: In this stage, the growth of the V2G-related articles is relatively slow in the sense of the article numbers. 2009 to 2017: In the second stage, the growth of the V2G-related articles is relatively stable and the average number of published articles is less than 200 per year. 2018 to March 2019: In the third stage, the number of the V2G-related articles shows the high growth and the average number reaches about 300 per year.

### *Statistics based on different journals*

Table 3 intends to indicate the top 24 journals that have published the greatest number of the V2G-related articles in the last 15 years. According to the following table, IEEE Transactions On Smart Grid, IEEE Power And Energy Society General Meeting, Applied Energy, and Energies are the most utilized journals in this field of study. Based on the sciencedirect database most of the publications are review articles and research articles. The scopus website has an in-detail classification for the publications about the V2G system based on the document types, as shown in the Fig. 11. As show in the figure, conference paper, article and review papers have the highest values rather than the other types.

### *Statistics based on keywords used*

According to our dataset and scopus database, most the V2G-related journal papers have identified keywords, and so approximately 14,924 distinct keywords were used. The Table 4 shows the first 30 most used keywords. There is no doubt that Electric Vehicles is the most used keywords with number of article of 982. Moreover, Charging (batteries), Vehicle to Grid (V2G) and Electric Power Transmission Networks are also most popular keywords in the existing the V2G-related articles.

### *Statistics based on country*

Studying publication volumes at the country level is key to understanding and improving a country's research system. The impact of research can be measured on national or regional scales and in this case, another classification for the published papers around the V2G system is given in the Table 5. Researchers in China by publishing around 361 articles have the highest rate in our raking. The researchers in the U.S., India and Iran have shown more interests to this field of study rather than other countries. Distribution of published papers in diverse countries either developed countries or developing countries have indicated the importance of the electrified transportation fleet and the V2G system in current decade.

### *Current studies and future trends*

In order to discover the current field of studies and future trends in the V2G research, we further investigated the keywords of articles that published in the last two years (2018 and 2019). To indicate the current fields of studies we list, in Table 6, the top 5 most popular research keywords that used in the V2G-related articles published in the last two years.

Next, we further list, in Table 7, the top 5 latest application fields of the V2G with the greatest numbers of journal articles, including Engineering, Energy, Computer Science, Mathematics and Environmental Science.

## The V2G projects in the world

The crisis of energy and air pollution are two of the main reasons for developing the green energies and transferring from the old and pollutant technologies to the new ones. Introducing the electrified transportation system and its sub-systems like V2G system have influenced the industry and society positively. Scientists and researchers around the world have realized the importance of the EVs and V2G system and nowadays the number of published papers in this field is rapidly increasing. In the previous section, we considered the statistics on the V2G publications around the world and shown its positive trend in number of publications in the recent decades. In this section, we focus on the V2G system's projects in different countries and analyze related aspects of developing these projects.

Based on [87], there have been 67 projects about the V2G systems in 17 countries since 2009 that approximately 20 of them are still ongoing and active. The Fig. 12 indicates the number of V2G projects that started in a certain year that is clear there is increasing growth in total number of V2G projects in the recent years.

In projects, based on their concepts and applications some services are offered that mainly we can classify them in six main fields. In 89 offered services, about 37% of them considers time shifting and charging schedules for shaving the peak demand and 25% of them focus on frequency response. The reserve, arbitrage, distribution services and emergency back u pare the other offered services in these projects. Great Britain with 33 and the United States with 27 offered services are top two countries in terms of offered V2G services, Fig. 13.

Based on report [88], in average about 98% of the V2G projects there are technical elements and 40% of them consider the commercial and economical aspects. The interesting point is only 27% of projects focus on the social aspects of implementing the V2G system and it is another proof about overlooking this topic (it indicates the precision of our literature review and also connection between the numbers of publications and projects). Among top 12 vehicle manufacturers that have participated in the V2G projects, Renault Nissan Mitsubishi has the biggest share of these projects, about more than 60% of the total projects (Fig. 14).

## Conclusion and future studies

Nowadays, one of the most controversial issues that has absorbed many attention to itself is air pollution. Every day million tons of GHGs enter to the atmosphere that bear many bad and negative consequences on the environment. According to the recent studies, the transportation fleet is the major source of $CO_2$ emissions and has a highest dependency to the petroleum products. The oil and gas sources are limited and depletion of them will be a big threat for different aspects of life. Many of the NGOs and environmental institutes have tried to offer new alternatives for decreasing the negative influences of consuming oil and gas. In this case the introducing the EVs as a substitute for traditional automobiles (ICA) has been the most efficient way to reduce the dependency to the oil and gas and simultaneously eliminate the GHGs emissions. As mentioned before, there is positive and tremendous trend in migrating to electrified transportation fleet but the problem is, penetrating huge amount of EVs into the market can cause fluctuation in the grid because of their high demand for charging especially during the peak periods. The RESs as complementary system can solve a part of this problem but due to their intermittent and unpredictable nature, they cannot be efficient to support the grid in emergency. The introducing the vehicle to grid (V2G) technology as mobile energy and its integration with the RESs and smart grid are the most efficient system to eliminate the possible problems in the demand and supply. In recent decades, many studies have focused on this technology and different aspects of this system have been analyzed. In these such studies, the environmental issues are the common concerns between the authors and most of them by using the mathematical models have tried to minimize the negative influences of emissions. There are some review papers around the V2G system and its integration with RESs and SG, but there is not a general categorization of previous studies on this topic. In this paper, we present a general categorization of the recent studies based on their field of the study and their suggested methodologies in order to discover the possible existed gaps and show the direction for future studies to the scientists and who enter to this field of study recently. As shown in the Table 1, the most of the studies consider the environmental issues as the most important point for introducing the V2G system and the topics like battery degradation, integration of V2G with RESs and SG, aggregation, feasibility studies and economic aspects are analyzed in the recent studies. It is interesting to say, a limited number of articles and offered V2G projects are conducted to investigate the social aspects of implementation of V2G system and also topics like encouraging plans, placement of charging stations and line loading that can play substantial role to attract the EVs' owners to participate in this system. Although the economic and technical aspects of implementing new technologies are important, the motivating and encouraging plan and accessibility of these kind of services can be more influential.

In this case, to bridge these research gaps we suggest the authors considering the social aspects of implementing the electrified transportation system and especially V2G system and focusing on the ways for motivating the EVs' drivers to participate in the V2G system. One of most important motivation plans for participation in the V2G system is offering tax reduction and electricity fee discounts based on aggregators' policies for the participated EVs in the V2G system that mostly ignored in the previous studies. Another social aspect of implementing the V2G system is analyzing the security and efficiency of the communication system. One of the most common worries among the people about joining in the V2G system is sharing the data and information around their location, driving patterns, charging locations etc. with aggregators and central power units. Analyzing the communication standards, protocols, laws and related issues are worth of attention in future studies. Another interesting topic for future studies is optimization model for placement of the charging stations and accessibility of this service for charging and discharging that can cover social, feasibility and efficiency of the system. In addition, however, there are many researches about integration of the V2G system with RESs and smart grid, a few of them use the real data for estimating the availability of RESs in each hour of day. We suggest that the best way to analyze the availability and behavior of RESs is studying the real data from these kind of sources and their behaviors in a long term and extracting their pattern of generation and their supporting level for the grid in each hour of day. Then based on these data, the implementation and integration of the V2G system

with the RESs and smart grid can be considered in the more efficient and valuable way.

## Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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