Renewable and Sustainable Energy Reviews 53 (2016) 720–732

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques

Kang Miao Tan *, Vigna K. Ramachandaramurthy, Jia Ying Yong

Power Quality Research Group, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 12 June 2014
Received in revised form
2 July 2015
Accepted 13 September 2015

Keywords:
Bidirectional charger
Electric vehicle
Optimization
Renewable energy
Vehicle to grid

ABSTRACT

Energy crisis and environmental issues have encouraged the adoption of electric vehicle as an alternative transportation option to the conventional internal combustion engine vehicle. Recently, the development of smart grid concept in power grid has advanced the role of electric vehicles in the form of vehicle to grid technology. Vehicle to grid technology allows bidirectional energy exchange between electric vehicles and the power grid, which offers numerous services to the power grid, such as power grid regulation, spinning reserve, peak load shaving, load leveling and reactive power compensation. As the implementation of vehicle to grid technology is a complicated unit commitment problem with different conflicting objectives and constraints, optimization techniques are usually utilized. This paper reviews the framework, benefits and challenges of vehicle to grid technology. This paper also summarizes the main optimization techniques to achieve different vehicle to grid objectives while satisfying multiple constraints.

Contents

* Corresponding author. Tel.: +60 12 9833753; fax: +60 38 9212116.
E-mail addresses: tankangmiao@gmail.com (K.M. Tan), vigna@uniten.edu.my (V.K. Ramachandaramurthy), yongjiaying89@gmail.com (J.Y. Yong).

http://dx.doi.org/10.1016/j.rser.2015.09.012
1364-0321/

1. Introduction

The transportation sector has the largest share of total energy consumption growth in the world. Most of the energy consumption growth in transportation sector is due to the high economic and population growth [1]. The rapid increase of energy demand will result in excessive carbon dioxide emissions and energy crisis [2]. In many countries, mitigation plans have been undertaken to achieve a reduced emissions target and one of the promising solution is electrifying transportation.

Electric Vehicle (EV) is an alternative transportation option, which emits zero exhaust gases and generates minimal noises. EV uses electric motor and battery energy for propulsion, which has higher efficiency and lower operating cost compared to the conventional internal combustion engine vehicle. The continual development of lithium ion battery and fast charging technology will be the major facilitators for EV roll out in the near future [3,4]. However, the present EV industry encounters many technical limitations, such as high initial price, limited charging facilities, limited driving range and long battery recharge time [5]. Furthermore, the interconnection of EV on the power grid to receive charge has introduced negative impacts on the power grid operation.

Recently, the introduction of the smart grid concept has modernized the power system with additional communication features [6,7]. Vehicle to Grid (V2G) concept is one of the smart grid technologies, which involves the EV to improve the power system operation. V2G concept allows the energy exchange between EV and the power grid, which can provide numerous services to the power grid. Meanwhile, EV owners can also enjoy appealing revenues for their participations in the V2G services.

V2G technology can be categorized into unidirectional and bidirectional [8,9]. For unidirectional V2G, it utilizes the communication between the power grid operator and EV to throttle the charging rate of each EV. This action can prevent grid overloading, system instability and voltage drop issues [10,11]. From the perspective of the power grid, EV battery is an electric load but also can be considered as energy storage. Therefore, bidirectional V2G utilizes this idea to enable energy exchange between the EV battery and the power grid for EV charging or grid support. The bidirectional V2G provides greater flexibility for the power utility to control the EV battery energy to improve the reliability and sustainability of power system [12–14].

V2G technology is a complicated unit commitment problem associated with different conflicting objectives and constraints. Therefore, the realization of the V2G technology is achieved by using optimization techniques. There are various optimization techniques in the literature, but the main optimization techniques for V2G implementation are Genetic Algorithm and Particle Swarm Optimization. By satisfying certain constraints, these optimization techniques can achieve different objectives and services, such as peak load shaving, load leveling, voltage regulation and maximization of profit.

This paper reviews the concept, framework, advantages, challenges and optimization strategies of V2G. The key contributions of this paper are: (1) to deliberate about the overall V2G concept and framework, specifically on the unidirectional and bidirectional V2G, (2) to discuss comprehensively on the benefits, services and potential barriers of the V2G technology implementation, (3) to analyze various V2G optimization techniques with practical objective functions and constraints, and lastly (4) to provide new insights into the prospects of V2G technology. Section 1 gives an introduction on the V2G background. In Section 2, V2G framework and concept will be discussed. The comparison of unidirectional V2G and bidirectional V2G will be explained in Section 3. Section 4 presents the advantages and challenges of V2G technology. The optimization strategies for V2G are reviewed in Section 5. Section 6 concludes the paper.

2. Vehicle to grid concept and framework

EV technology has attracted the attentions of government and public due to the growing concerns on the environment and rising cost of fossil fuel. The integration of transportation sector and power grid will lead to many challenging issues to the power system. For instance, a large penetration of EVs will increase the power grid load during the EV charging process. Nevertheless, the projected penetrations of EVs have also opened up the possibility of the V2G implementation.

V2G refers to the control and management of EV loads by the power utility or aggregators via the communication between vehicles and power grid. There are three emerging concepts of grid-connected EV technologies, which are the Vehicle to Home (V2H), Vehicle to Vehicle (V2V) and Vehicle to Grid (V2G) [15]. V2H refers to the power exchange between the EV battery and home power network. In this case, EV battery can work as energy storage, which provides the backup energy to the home electric appliances and to the home renewable energy sources [16]. V2V is a local EV community that can charge or discharge EV battery energy among them. V2G utilizes the energy from the local EV community and trades them to the power grid through the control and management of local aggregator [17].

Generally, V2H, V2V and V2G involve elements such as power sources, power loads, power grid aggregator, power transmission system, communication system, electric vehicles, and vehicle to grid chargers. The framework of a typical V2G system is shown in Fig. 1.

3. Power flow from vehicle to grid

V2G refers to the interaction between electric vehicle and power grid with the assistance of the communication system. Power grid operator utilizes the communication facility to control and manage the power flow between the EV battery and the

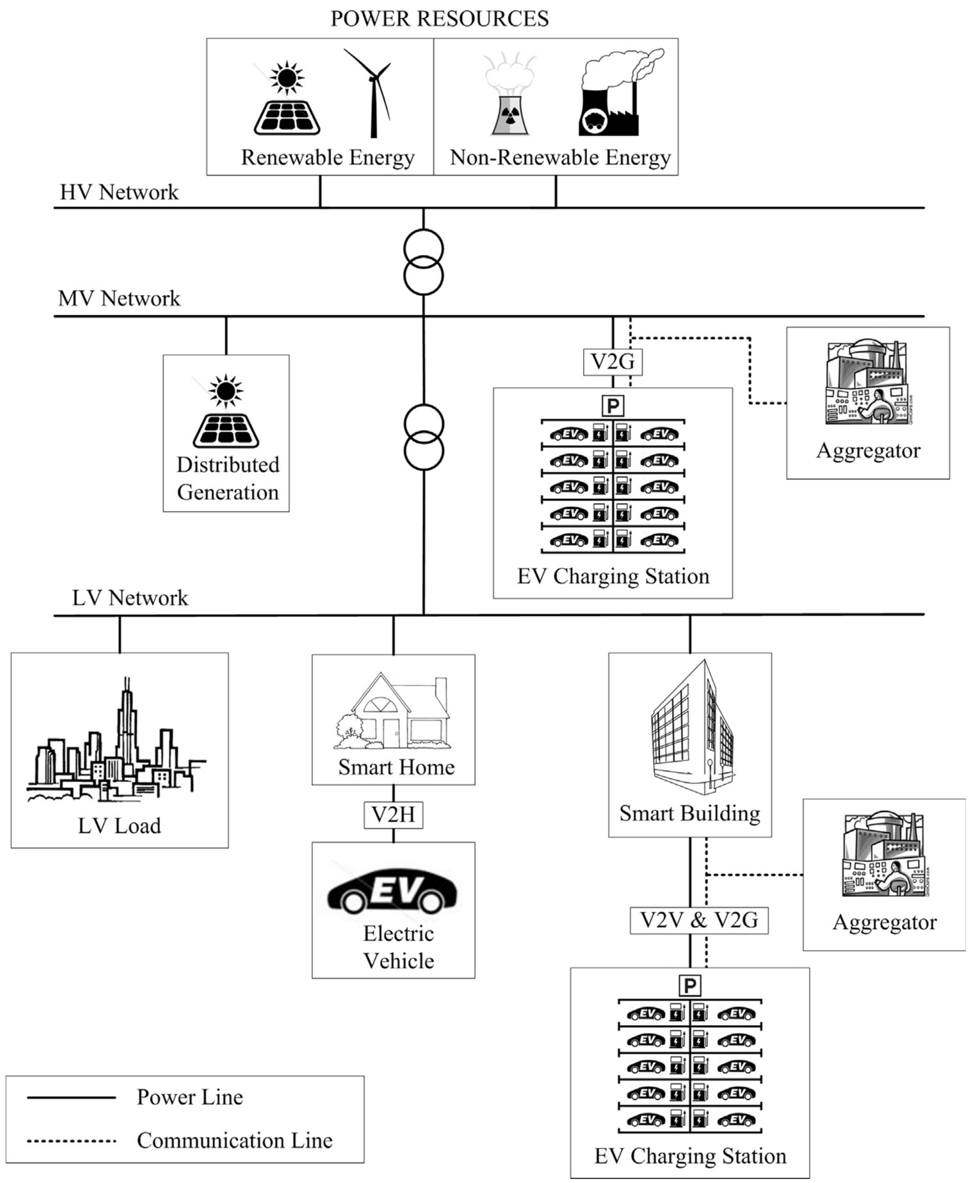

Fig. 1. V2H, V2V, and V2G framework [15].

power grid in order to achieve desired benefits. In most cases, the objectives of the V2G management are to maximize profit, reduce emissions and improve power quality of the grid [18,19].

3.1. Unidirectional V2G

Unidirectional V2G is a technology that controls the charging rate of EV battery in a single power flow direction between the EV and grid [8,20]. The realization of the unidirectional V2G is inexpensive by adding the simple controller to manage the charge rate.

Unidirectional V2G can provide ancillary services to the power grid, such as power grid regulation and spinning reserve [21,22]. This can enhance the flexibility of the power grid operations. The implementation of unidirectional V2G needs the existence of an attractive energy trading policy between the EV owners and the power utility [23,24]. In order to encourage the participation of EV owners, this energy trading policy must guarantee revenues to the EV owners if they charge their EVs during off peak hours and limit the EV charging during on peak periods [25–27]. At the same time, the power utility can avoid overloading during on peak hours. In addition, unidirectional V2G can achieve maximization of profit and minimization of emission by using optimization technique [18,28].

However, unidirectional V2G services are limited by the ability to provide ancillary services to the power grid. Functions such as peak load shaving, reactive power support, voltage regulation and frequency regulation are the premium services which can only be achieved with bidirectional V2G.

3.2. Bidirectional V2G

Bidirectional V2G refers to the dual direction power flow between EV and the power grid to achieve numerous benefits [29]. A typical bidirectional EV battery charger consists of AC/DC converter and DC/DC converter as depicted in Fig. 2 [13,30]. The AC/DC converter is used to rectify the AC power from the power grid to the DC power during the EV charging mode and inverts the DC power to the AC power before injecting back to power grid in the discharging mode. On the other hand, the DC/DC converter is responsible in controlling the bidirectional power flow by using current control technique. The DC/DC converter acts as a buck or boost converter during charging or discharging mode, respectively.

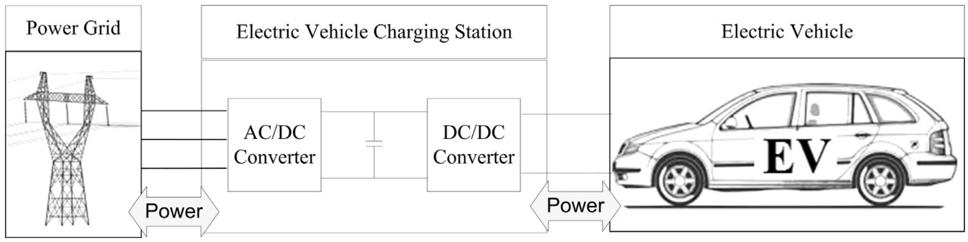

Fig. 2. Power flow diagram for V2G [13,14,29,30].

The bidirectional V2G provides larger flexibilities and possibilities to improve the power system operations. The main benefits are active power support, reactive power support, power factor regulation and support for the integration of renewable energy resources. Active power support from bidirectional V2G can achieve peak load shaving and load leveling services [31,32]. These services are achieved by charging the EV during the off peak hours and inject additional EV energy into power grid during the on peak hours. Other than providing active power support, bidirectional V2G has the capability to supply reactive power for grid voltage regulation [33]. This service can be implemented with adequate sizing of charger DC link capacitor and proper control switching. Power factor regulation is also one of the premium services offered by the bidirectional V2G technology, which can reduce the power losses in the power grid. Moreover, bidirectional V2G also helps the integration of renewable energy resources in the power grid [14,34]. The power generation of renewable energy resources, such as wind turbine and solar photovoltaic are unpredictable and inconsistent as these renewable energy resources are heavily dependent on the weather condition. Bidirectional V2G utilizes the EV mobility to act as energy buffering storage and supplier to solve the intermittency issue of the renewable energy resources.

At the present time, the implementation of bidirectional V2G encounters many challenges. One of the barriers is the battery degradation issue due to the frequent charging and discharging cycles required by bidirectional V2G implementation [35]. The complexity of bidirectional battery charger requires additional hardware and leads to the need for extra investments. Furthermore, social barrier issue is another significant challenge for the implementation of bidirectional V2G. For security reason, EV owners will usually try to acquire high battery state of charge for the unexpected traveling usage [11]. This will prevent them from actively participating in the bidirectional V2G services.

The successful implementation of V2G requires further technological improvements. Currently, unidirectional V2G is implemented in many countries to reduce the social barrier issue in order to stimulate the EV penetration into market. Bidirectional V2G has the potential to be adopted in the future when the market and technology are readied. Table 1 shows the comparison between the unidirectional V2G and bidirectional V2G in various ways, such as the hardware infrastructure, power levels, costs, available services, benefits and drawbacks.

Table 1
Comparison of unidirectional V2G and bidirectional V2G [8,18,29,36].

V2G power flow	Unidirectional	Bidirectional
Hardware infrastructures	Communication system	Communication system Bidirectional battery charger
Power level	Level 1, 2 and 3	Expected level 1 and 2
Cost	Low	High
Services	Power grid regulation Spinning reserve	Active power support Reactive power support Power factor correction Improve power system stability Harmonic filter Frequency regulation Energy backup
Benefits	Prevent power grid overloading Maximize profit Minimize emission	Reduce power grid losses Prevent power grid overloading Improve load profile Maintain voltage level Renewable energy intermittent Failure recovery Maximize profit Minimize emission
Drawbacks	Limited service available	Battery degradation Complex hardware infrastructure High investment cost Social barriers

4. V2G advantages and challenges

4.1. V2G services and advantages

V2G technology can provide many services to achieve various benefits. The implementation of V2G can provide frequency regulation, harmonics filtering and even failure recovery to the power system during blackout [33,37]. The advantages of V2G are not only the privileges for the power utility but also EV owners. The V2G technology can provide uninterrupted power support for home and backup energy storage for home renewable energy resources [14,38]. The major benefits of V2G will be further discussed in details, which include ancillary services, active power support, reactive power compensation and support for renewable energy resources.

4.1.1. Ancillary services

Unidirectional V2G provides the “load only” ancillary services to the power grid by controlling the EVs charging rates upon request from the power grid operators [39–42]. The aggregator manages and controls a large fleet of EVs in order to achieve the ancillary services. Ancillary services can be classified into two categories, which are power grid regulation and spinning reserve [10,41]. The power grid regulation provides frequency regulation to match the generation and load demand. The grid operators usually take direct real-time control of this regulation to respond to the grid demand by increasing or decreasing the generation [43]. Nevertheless, the power balance can be achieved by utilizing the unidirectional V2G technology to adjust the EV load demand under two operating modes, which are “regulation up” mode and “regulation down” mode.

Fig. 3 depicts the ancillary services concept using unidirectional V2G as explained in [44]. Two load types are considered in [44], which are the fixed loads and dynamic loads. Grid-connected EVs

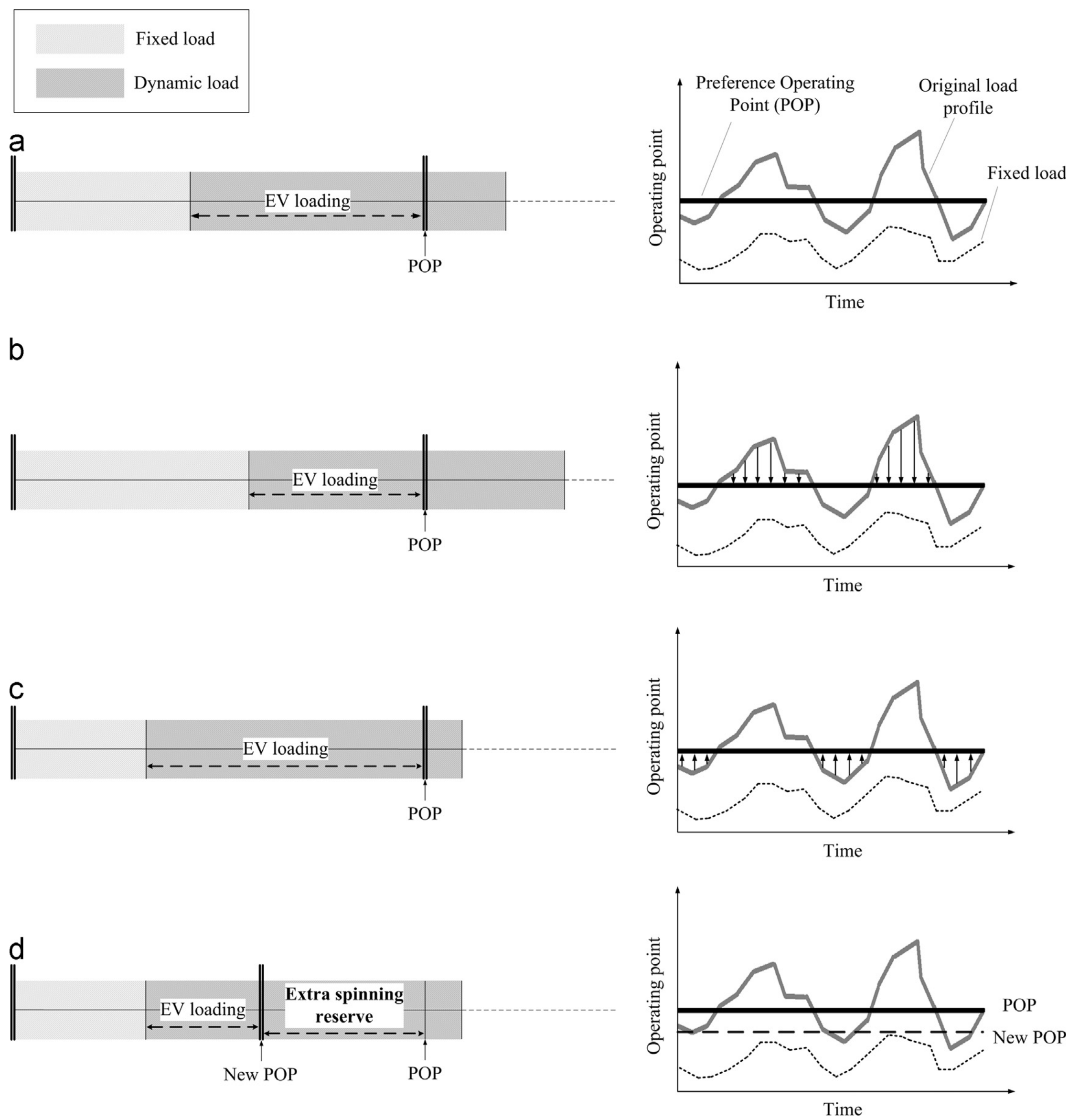

Fig. 3. Ancillary services provided by unidirectional V2G: (a) base case, (b) regulation down case, (c) regulation up case, and (d) spinning reserve case [10,44,45].

are considered as dynamic loads in the unidirectional V2G technology, where the charging rates of EVs are regulated up and down to meet the Preference Operating Point (POP). Fig. 3(a) serves as a base case to demonstrate the concept of ancillary services. As the fixed loads increase, the regulation down mode is performed by reducing the EVs charging rates to remain at the same POP as presented in Fig. 3(b). In contrary, Fig. 3(c) shows that EVs charging rates are increased to accomplish the regulation up mode due to a decrement of fixed load.

On the other hand, spinning reserve is an additional generation that provides fast response, generally within 10 minutes to compensate the generation outage [46,47]. In order to achieve the spinning reserve services using unidirectional V2G, the additional spinning reserve is attained by decreasing the EVs charging rates to a lower new POP as illustrated in Fig. 3(d) [10,45]. The ancillary services provided by each EV is compensated based on the amount of time the services are available even though there is no energy being supplied to the power grid. This policy is attractive to the EV aggregators and owners as revenues are guaranteed [41,48,49]. For instance in [49], a fuzzy optimization is proposed to investigate the benefits of ancillary services for unidirectional V2G and is compared to the other optimization techniques. With the aim to provide ancillary services, all the optimal unidirectional V2G scheduling shows high profits for the participated aggregators, especially for the proposed fuzzy optimization which is approximately six percent higher than the other optimization techniques.

4.1.2. *Active power support*

Another V2G service utilizes the excessive EVs energy to provide active power support to the power grid. The active power support requires EVs to discharge the batteries energy and therefore, could only be accomplished using bidirectional V2G but not unidirectional V2G. The goal of this service is to flatten the grid load profile by “peak load shaving” and “load leveling”. Fig. 4 shows the comparison of a typical residential load profile before and after the implementation of peak load shaving and load leveling. Peak power is usually needed for a short period of time throughout a day. Therefore, it will be more economical to supply the peak load demand from the distribution sources, for instance the grid-connected EVs [41]. EVs can be utilized to supply energy to the power grid during the peak load period to shave off the peak load. This can help to reduce the applied stress on power system

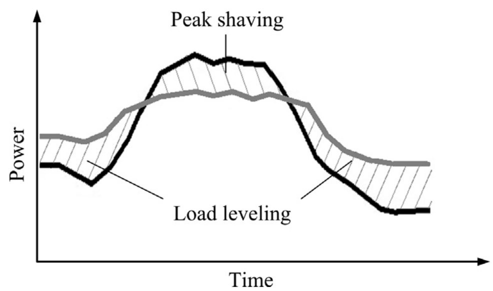

Fig. 4. Load profile comparison before and after peak load shaving and load leveling [41,52].

components during the peak load period and the EV owners will be paid with a premium energy rate. During the off peak hours, EV owners can charge their EV batteries with lower energy price.

Active power support is an important service of V2G due to the premium benefits it is able to attain. One of the advantages is the loss reduction. By maintaining the power system operating capacity at lower level, the overall power losses will be reduced [50]. Traditionally, power system is constructed to meet the highest peak of the load demand. Thus, the power equipment is underutilized during the off peak hour. The implementation of peak load shaving technique by utilizing the V2G technology can maximize the power equipment capacity and prevent additional equipment upgrade cost [31,51]. In addition, shifting EVs charging time to off peak hours is a good method to avoid power system overloading and equipment aging [52,53].

The V2G implementation to achieve peak load shaving and load leveling is determined by the availability of EV battery capacity connected to the power system. In managing the EV energy storages, many factors shall be considered, such as the probability of EV connection to the power grid, available energy in the EV battery and the Depth of Discharge (DOD) of EV battery [45,54]. Research is in progress to design a V2G control strategy that can flatten the load profile by considering the related constraints. The technique, also known as optimization technique can optimize the benefits for power utility and EV owners [31,51]. In [55], a decentralized demand response management using a multi-objective optimization algorithm is designed to employ the grid-connected EVs for active power support to a local micro grid. This algorithm can intelligently extract an appropriate amount of energy from the EVs fleet for power grid support during emergency grid condition.

4.1.3. Reactive power compensation

Reactive power compensation is a technique to provide voltage regulation in the power grid [56–58]. Reactive power support also provides power factor correction, which reduces the current flows from generation and power losses in power line [59]. Furthermore, this service can reduce the loading of power equipment, which leads to the increase in power system operating efficiency.

The conventional method for reactive power compensation is achieved by drawing reactive power from distribution generator or static Volt–Ampere Reactive (VAR) compensator [60,61]. In most cases, a capacitive reactive power is needed for the power grid compensation. Therefore, grid-connected EV is able to provide the reactive power compensation service due to the capacitive reactive power reserved in the DC-link capacitor of the EV bidirectional battery charger. Since the reactive power compensation is provided by the DC-link capacitor of the EV bidirectional battery charger, this service will not cause any degradation to the battery lifespan. The reactive power compensation is done by controlling the switching of the AC/DC converter with various control strategies [62,63].

The design and development of a bidirectional EV fast charging station with EV fast charging control, as well as the novel reactive power compensation control is proposed in [64]. The reactive power compensation control regulates the power grid voltage during the EV fast charging process. Therefore, the grid voltage drop issue due to EV charging operation can be catered by the proposed reactive power compensation control of the EV charging station. Meanwhile, a decoupled active and reactive power control is designed in the V2G charger in [65], which can provide appropriate reactive power supply to the power grid based on the reactive power command signal by the utility. The reactive power compensation control is experimentally validated by using a 12.5 kVA charger.

4.1.4. Support for renewable energy resources

Energy generation plants and transportation sector are the two major sources of carbon dioxide emission [1]. This has reached a level that threatens the public health and environment. The deployment of renewable energy generation can help to protect the environment. However, the power generation of renewable energy sources is strongly dependent on the environmental factors. The unpredictable and inconsistent energy production is the drawback of renewable energy resources.

The integration of EVs in the power system can be a solution to the issues above [66]. The intermittency issue of renewable energy resources can be solved by utilizing a fleet of EVs as energy backups or energy storages [67–69]. The EV fleets act as the energy backups to supply necessary power when the renewable energy generation is insufficient. Meanwhile, they act as energy storages to absorb the excessive power generated by renewable energy resources, which would otherwise be curtailed [41]. Research has shown that larger renewable energy capacity can be accommodated into the power system with more grid-connected EV battery capacity. Therefore, EV is able to improve the economics of the renewable energy generation industry. With proper energy management between renewable energy resource and EV, the future power grid will be cleaner and more sustainable [70–72].

A Genetic Algorithm-based optimization algorithm is proposed in [73], which is able to optimally utilize the V2G capacity and minimize the power variation due to fluctuating wind power generation. The main objective of the proposed V2G optimization algorithm is to realize the full potential of EVs to maximize the profit and incentive for both power utilities and EV owners. Authors in [74] have considered the importance of optimal sizing and location for renewable energy EVs parking lot. Therefore, a multi-objective algorithm is developed to optimally find the sizing and allocation of renewable energy systems for V2G station. This algorithm can determine the best location and sizing for the V2G system at a minimal overall energy cost.

4.2. V2G challenges

V2G implementation will bring plenty of advantages and flexibilities to the power grid. Nonetheless, V2G is a new technology which has not matured. Many economical, technical and social challenges need to be overcome in order to adopt the V2G technology.

4.2.1. Battery degradation

Battery cells will deteriorate gradually under the battery charging and discharging cycles. The irreversible chemical reaction in the battery will increase the internal resistance and reduce the battery useable capacity [35]. The battery aging rate depends on many factors, which include the charging and discharging rates, voltage, DOD and temperature. Participations of EVs in the V2G technology require more battery charging and discharging cycles, which are likely to result in quicker battery degradation. Economical and technical factors are studied in [75] to investigate the feasibility of V2G implementation. This study indicates that rapid battery charging and discharging cycles will cause more battery degradation compared to the lesser cycles and concludes that V2G implementation should be avoided.

Equivalent Series Resistance (ESR) is a parameter used to predict the battery life cycle. Deeper battery DOD and frequent battery charge and discharge cycles will lead to increase in battery ESR. Studies in [76] and [77] show that the battery ESR increases at low battery temperature and extreme battery State of Charge (SOC). Hence, battery cycle should be maintained around the middle ranges of SOC to minimize the increase rate of ESR [9]. Another important factor to reduce the battery degradation is the battery DOD. Study in [78] shows that in order to maintain the battery life cycle within an acceptable range, it is very important to retain the battery DOD lesser than 60 percent. Therefore, the best battery usage range drops within 30 percent SOC to 90 percent SOC. Battery health should also be taken into consideration for the implementation of V2G technology. V2G control strategy and battery wear scheme are developed to prevent the abusive use of EV battery [43–45]. Balance between the financial factor and the battery technical factor is crucial to optimize the benefits for power utility and EV owners.

4.2.2. High investment cost

Another challenge to the V2G implementation is the high investment cost required to upgrade the power system. Improvements in hardware and software infrastructure are needed for the V2G implementation. Each EV that participates in the V2G system will require a bidirectional battery charger. A bidirectional battery charger is the hardware that consists of complex controller and high tension cabling with tight safety requirement. In addition, V2G has the potential to increase energy loss, which is another unfavorable issue in power system as it has a direct relationship to financial disadvantage. The V2G implementation requires frequent charge and discharge cycles and these processes involves energy conversions which will contribute to more conversion losses. Multiple energy conversions for a large fleet of EVs charging and discharging processes can denote serious energy losses to the power system [79].

4.2.3. Social barriers

The participations of a large number of EVs are crucial requirements for the V2G implementation. However, the social barrier has prevented the public acceptance of the V2G technology, which appears to be a huge challenge for V2G adoption. In most cases, EV owners will ensure a guaranteed amount of energy stored in the EV battery for emergency use and unpredicted journey [11]. Since taking part in the V2G technology requires them to share the EVs batteries energy with the power grid, this will create the range anxiety among the EV owners [80]. The lack of charging facility makes the situation becomes worse.

In order to reduce the social barriers for V2G implementation, a well-planned EV charging network is necessary. In addition, V2G management control needs to consider the EV SOC level. V2G connectivity needs to be cut off when the EV SOC is lower than an initially preset percentage [81]. This is to ensure the EV battery has enough energy for the daily driving usage.

5. Optimization of V2G algorithm

Power system involves multiple conflicting objectives that must be achieved, but are plagued with many uncertainties and nonlinearities [30]. Additionally, power system operations are also

Table 2
Summary of optimization for V2G control strategy.

V2G type	Service	Optimization objective	Constraints		Optimization method	References
			Power system	Electric vehicle		
Unidirectional	(a) Voltage regulation (b) Power grid regulation (c) Spinning reserve (d) Load shifting (e) Frequency regulation	(a) Minimize power losses (b) Maximize profit (c) Minimize operation cost (d) Minimize emission	(a) Voltage limit (b) Generation limit (c) Line thermal limit	(a) Battery energy exchange rate limit (b) Battery SOC limit (c) Battery capacity (d) EV availability (e) Energy price	(a) Genetic algorithm (b) Convex optimization (c) Linear programming	[18,19]
Bidirectional	(a) Demand response (b) Load leveling (c) Load peak shaving (d) Voltage regulation (e) Improve system reliability (f) Spinning reserve (g) Power grid regulation	(a) Minimize operation cost (b) Maximize renewable energy generation (c) Minimize error of load curve from target load curve (d) Minimize power losses (e) Minimize emission (f) Maximize profit	(a) Power balance (b) Voltage limit (c) Generation limit (d) Line thermal limit (e) Forecast load (f) Upstream supplier limit (g) System loading limit	(a) Battery energy exchange rate limit (b) Battery SOC limit (c) Battery capacity (d) EV availability (e) Energy price (f) System efficiency	(a) Particle swarm optimization (b) Genetic algorithm (c) Linear programming (d) Quadratic programming (e) Ant colony optimization	[17,18,28,31,51,68,82–88,90,91]

limited by numerous constraints in the process of achieving multiple objectives [82]. For the V2G system, the dynamic and random behaviors of EV mobility will further increase the power system complexity. In order to manage the power flow between each EV and the power grid, optimization technique is applied for the implementation of V2G system. The optimization of V2G algorithm is an intelligent technique that is able to utilize the EV mobility to achieve V2G services and specific objectives [83,84]. Table 2 shows the summary of the optimization for V2G control strategy.

5.1. Optimization approaches

Integration of EVs and power grid will create a complex V2G system, which involves large numbers of nonlinear variables. The associated unpredictable variables are related to the power system limitations and EV mobility constraints. Unit Commitment (UC) determines the optimal dispatch generation schedule for the available power grid generating resources. Various optimization techniques are used in solving the UC problems, which involve the V2G technology.

Traditionally, Linear Programming (LP) and Quadratic Programming (QP) are used for the UC optimization [19,85]. These methods are able to determine the best solution for an UC mathematical problem, but are limited to simple and linear objectives. For a more complicated UC problem, Nonlinear Programming (NLP) and Mixed Integer Nonlinear Programming (MINLP) are usually used. Nevertheless, these techniques have difficulties in handling the uncertain variables and require the involvement of large numbers of computational resources when dealing with the real world problems.

Apart from the mentioned optimization techniques, priority list method has fast computational speed but is highly heuristic [86]. Lagrangian Relaxation (LR) method focuses on determining a proper coordination technique to produce feasible primal solutions while reducing the duality gap [86]. The drawback of this method is the difficulty in attaining the feasible solutions. Furthermore, Artificial Intelligence (AI) provides alternative in solving the complicated V2G problems.

The most popular and feasible optimization methods for the V2G problems are Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) [28,87,88]. GA is an iteration method that is able to search for the global optimal solution under an execution time limit [28]. Meanwhile, PSO is a memory computational algorithm that searches for the global optima within a population of random solutions by updating the generations. PSO has the advantage where it requires lesser computational time and memory [17,87]. In the following sub sections, GA and PSO optimization techniques will be discussed in details.

5.1.1. Genetic Algorithm (GA)

Genetic Algorithm is an optimization method, which is inspired by the living organism evolutionary process [89]. Initially, GA requires a representation of a potential solution as the genetic chromosome. This chromosome is a string of real numbers, typically a binary bit strings. A proper fitness function will compute and evaluate the score of the genetic chromosome. After the evaluation, the GA principle will repeat again to reproduce a new generation of chromosome. The iteration repeats until the stopping criteria are satisfied. Fig. 5 illustrates the flowchart of a GA optimization. GA operations can be classified into a few stages, as follows:

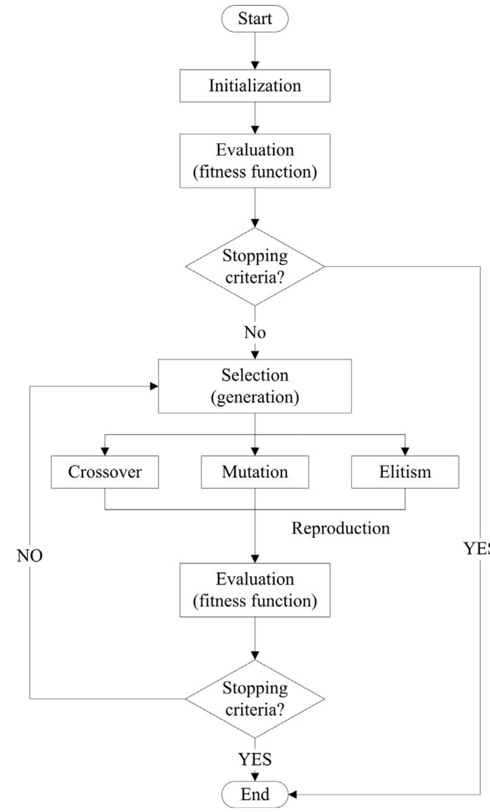

Fig. 5. General flowchart of a GA optimization [15,68,89].

1. Initialization: random chromosome is generated as to cover the entire range of search space. The potential solution is computed as followed to the nature of the problem. Then, the potential solution is encoded into the chromosome.
2. Selection: from the encoded chromosome, a selection session is performed to breed a new generation. Certain criterion is used to evaluate each solution in order to select the preferential new generation.
3. Reproduction: the next generation of chromosome is produced through the genetic operators, which include crossover, mutation and elitism. This new population is different from the previous generation. However, both share plenty of similar characteristics of their parents.
4. Evaluation: in this stage, the child chromosome will be decoded and evaluated using the fitness function. The evaluated individual will replace the least fit individual in the population.
5. Termination: during the evaluation stage, if the stopping criteria are satisfied, the final chromosome is considered as the solution. Therefore, the GA process will be terminated. Otherwise, the process will repeat step 2–4 to generate the next population of chromosome.

5.1.2. Particle Swarm Optimization (PSO)

PSO is a memory computational algorithm that searches for global optima within a population of random solutions by updating the generations. In PSO, random potential solution, named as particles, move through the multi-dimensional problem space in a specific velocity. Each individual particle in the swarm is able to interact with each other. This enables them to adjust their moving velocity according to the movement patterns of its own and other particles. The random movement of the particle swarms helps to prevent the solution to be trapped in the local minima. In the PSO iteration, each particle keeps track of its own position in the problem space. The particle's personal fitness solution is stored in pbest while the best value, gbest is the global best value among all pbest [86]. The equation for the personal best position of particles is as follows [87–89]:

$$y_{a,j}(t+1) = \begin{cases} y_{a,j}(t), & if\ f(x_a(t+1)) > f(y_a(t)) \\ x_{a,j}(t+1), & \text{else} \end{cases}, \ j \in [1, N] \tag{1}$$

where a is the particle number in the swarms, j is the dimension of search space, $x_{a,j}(t)$ is the jth dimensional component of the position of particle a at time t and $y_{a,j}(t)$ is the jth dimensional component of the personal best position of particle a at time t.

Since gbest is the best value among all pbest, therefore,

$$\Upsilon_j(t) = \min\{y_1(t), \ldots\ldots, y_S(t)\}, \ a \in [1, S] \tag{2}$$

where $\Upsilon_j(t)$ is the jth dimensional component of the global best position of swarm at time t.

The velocity, v and position, x of each particle can be computed by the following equation:

$$v_{a,j}(t+1) = w(t)v_{a,j}(t) + c_1 r_{1,j}(t)\left(y_{a,j}(t) - x_{a,j}(t)\right) + c_2 r_{2,j}(t)\left(\Upsilon_j(t) - x_{a,j}(t)\right) \tag{3}$$

$$x_{a,j}(t+1) = x_{a,j}(t) + v_{a,j}(t+1) \tag{4}$$

where w is the inertia weight, c_1 and c_2 are the acceleration constants while r_1 and r_2 are the random variables with a uniform distribution.

5.2. Optimization objectives

V2G technology allows power utility and aggregators to achieve V2G services, such as voltage regulation, spinning reserve, load shifting, peak load shaving and load leveling. A few objectives can be optimized to obtain the desired V2G services. For instance, operation cost minimization, power losses minimization and profit maximization are some of the optimization objectives for the V2G implementation. Fig. 6 presents the summary and relation between the V2G types, services, optimization objectives and constraints.

5.2.1. Operation cost

From the perspective of the power utility or system aggregator, minimizing the power system operation cost is an important goal in an UC problem. The power grid operation cost includes fuel cost, start-up cost and V2G cost [86,90]. Fuel cost, FC is expressed as a second order function of the unit generated power as shown below [17]:

$$FC_i(P_i(t)) = a_i + b_i P_i(t) + c_i P_i^2(t) \tag{5}$$

where P_i is the system output power, a_i, b_i and c_i are the coefficient for the positive fuel.

Meanwhile, start-up cost refers to the cost required to restart a generation plant. For a gas turbine generation plant, the start-up process is affected by the temperature of the boiler. For example, a cool boiler which has cooled down after long shut down period will consume more fuel to warm up the boiler during the generation plant start-up. Meanwhile, for a unit that only shuts down for a short period will require less fuel for start-up.

$$SC_i(t) = \begin{cases} h\_cost : MD_i \le X_i^{off}(t) \le H_i^{off} \\ c\_cost : X_i^{off}(t) > H_i^{off} \end{cases} \tag{6}$$

$$H_i^{off} = MD_i + c\_s\_hour_i \tag{7}$$

where SC, is the total start-up cost, h_cost is the high temperature start-up cost, c_cost is the low temperature start-up cost, MD_i is the plant minimum down time, X_i^{off} is the plant down time duration, H_i^{off} is the hot to cold start-up transition hour and $c\_s\_hour_i$ is the cold start hour. Finally, V2G cost is the cost paid to EV owner for their V2G services.

Therefore, the optimization objective for the V2G implementation is to minimize the power system operation cost.

$$\min TC = \text{Fuelcost} + \text{Start-upcost} + \text{V2Gcost} \tag{8}$$

5.2.2. Carbon dioxide emission

In order to reduce the emission to the atmosphere, the European Union (EU) has introduced and implemented an emission

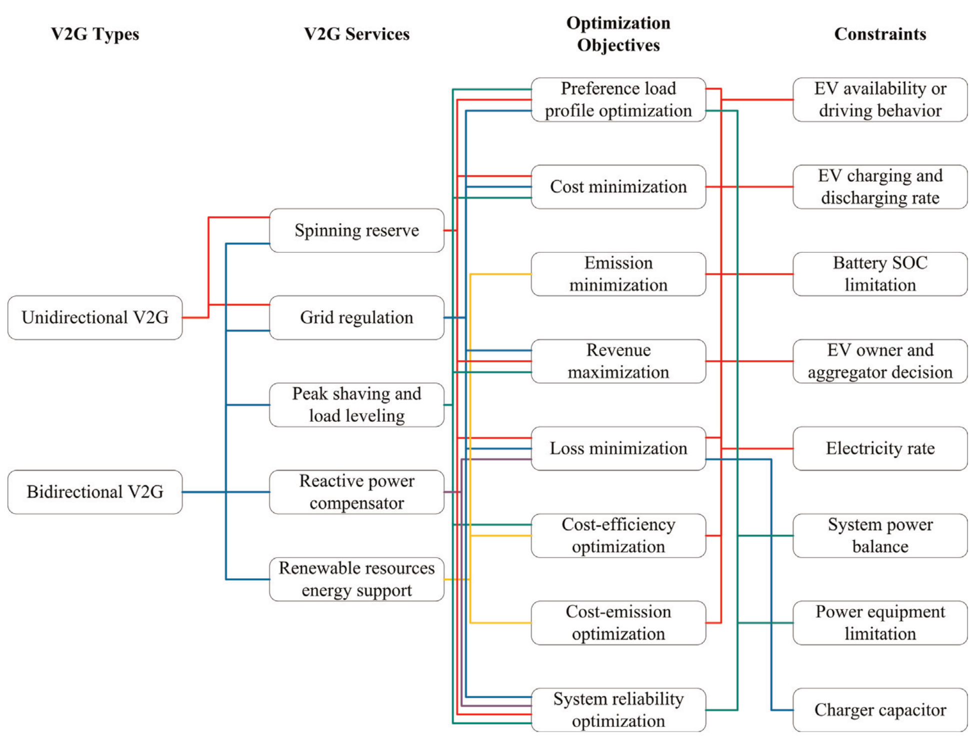

Fig. 6. Relation diagram for V2G types, V2G services, optimization objectives and constraints [17–19,28,31,51,68,82–88,90,91].

trading mechanism, named as Emissions Trading Scheme (ETS). According to ETS, each industry is limited to a specific amount of emission. The emission quota can be traded among the industries. For example, if the generation plant emission has exceeded the limit, it has to buy more allowance from the market or it will need to pay for a penalty [22].

Therefore, minimization of the emission is also a crucial objective to be achieved in the V2G implementation. This helps to protect the environment and reduce the expenses of the power utility. The emission is represented by a quadratic function, as follows [17,86]:

$$EC_i(P_i(t)) = \alpha_i + \beta_i P_i(t) + \gamma_i P_i^2(t) \tag{9}$$

where P_i is the system output power, α_i, β_i and γ_i are the coefficient for emission.

5.2.3. Profit

For the V2G operation, optimization methods can be used to maximize the benefits for the power system aggregator and EV owners [18]. V2G regulation services introduce numerous benefits to the power system operation. Therefore, V2G implementation will increase the profit for the power system aggregator. On the other hand, incentives will be paid to the EV owners based on their supplied EV batteries energy and the amounts of time the services are available.

The study in [82] has focused on the profit for EV owner in the V2G operation. The objective function is as follows:

$$\max EV\ owner\ income = \sum_{t=1}^{T}\left[\sum_{V=1}^{N}(P_{discharging(V,t)} \times C_{discharging(V,t)}) - (P_{charging(V,t)} \times C_{charging(V,t)})\right] \times \Delta t \tag{10}$$

where t is the time, T is the total number of time interval, V is the number of vehicle, N is the total number of vehicle, $P_{discharging(V,t)}$ is the power discharge of vehicle V in period t, $C_{discharging(V,t)}$ is the discharging price of vehicle V in period t, $P_{charging(V,t)}$ is the power charge of vehicle V in period t, $C_{charging(V,t)}$ is the charging price of vehicle V in period t and Δt is time interval.

5.2.4. Support for renewable energy generation

The EV fleets can act as backup batteries to supply the necessary power when the renewable energy generation is insufficient. Meanwhile, they act as energy storages to absorb the excessive power generated by the renewable energy resources [19]. By maximizing the accommodation of renewable energy into power grid, this action can create a clean power network and reduce the power generation cost. The authors in [28] have maximized the accommodation of renewable energy resources into the power grid by the optimization objective function, which minimizes the generation of the conventional generator. The optimization objective function is as follows:

$$\min F = \sum_{t=1}^{T} xP_{conv}^2(t) + yP_{conv}(t) + z \tag{11}$$

where x, y and z are the cost coefficient and $P_{conv}(t)$ is the power generated by the conventional generator.

5.2.5. Target load curve and power losses

V2G is able to utilize the excessive EV battery energy to provide the active power support to the power grid. The main objectives are to flatten the local load profile by peak load shaving and load leveling, as well as to reduce the power losses. In the studies in [31] and [87], the authors have obtained peak load shaving and load levelling services by minimizing the error between the real load curve and the target load curve. The objective function is as follows:

$$\min E = \sum_{t=1}^{T}(P_{Load,t} - P_{target,t}) \tag{12}$$

where T is the total number of time interval, $P_{Load,t}$ is the load demand at time t and $P_{target,t}$ is the target loading at time t.

On the other hand, authors in [88] have proposed a V2G control strategy that is able to provide load leveling as well as to minimize the losses. The objective function is as follows:

$$\min L = \sum_{t=1}^{T}\left[I_{Load}(t) - \sum_{V=1}^{N} I_{EV,V}(t)\right]^2 \tag{13}$$

where T is the total number of time interval, N is the total number of EV, I_{Load} is the demand load current and $I_{EV,V}$ is the demand current of EV number v.

5.3. Optimization constraints

The operations of power system are limited by many constraints. The optimization of the UC problem which involves V2G operation requires the compliance of two main types of constraints. The mentioned constraints can be categorized into power system and electric vehicle.

5.3.1. Power system

5.3.1.1. Power balance. The power supply from the power grid, which includes the grid-connected EVs, must satisfy the load demand and the system losses [86].

$$P_{grid} + P_{V2G} = D_{Load} + Losses \tag{14}$$

where P_{grid} is the power generated from grid generator, P_{V2G} is the power supplied from EV and D_{Load} is the load demand.

5.3.1.2. Generation limit. Power generation has predetermined maximum and minimum limits. The load demand and the system losses must be within these limits [30,68].

$$P_{Generation,min} \le D_{Load} + Losses \le P_{Generation,max} \tag{15}$$

where $P_{Generation,min}$ is the minimum grid generation, $P_{Generation,max}$ is the maximum grid generation and D_{Load} is the load demand.

5.3.1.3. Voltage limit. For the distribution system, power grid bus voltage must be maintained within the allowable limit [30,82,92].

$$V_{Bus,min} \le V_{Bus} \le V_{Bus,max} \tag{16}$$

where V_{Bus} is the bus voltage, $V_{Bus,min}$ is the minimum allowable bus voltage, and $V_{Bus,max}$ is the maximum allowable bus voltage.

5.3.1.4. Line thermal limit. The power cable has a maximum power carrying capacity that it can withstand. Overloading of the cable will lead to cable overheating problem [68,90].

$$P_{cable} \le P_{cable,max\_heat} \tag{17}$$

where P_{cable} is the cable carrying capacity, P_{cable,max_heat} is the cable maximum carrying capacity before overheat.

5.3.2. Electric vehicle

5.3.2.1. Battery energy exchange rate limit. For safety and battery health purposes, the exchange rate must not exceed the maximum limits [73,81,88,92–94].

$$P_{Battery,min} \le P_{Battery} \le P_{Battery,max} \tag{18}$$

where $P_{Battery}$ is the battery exchange power rate, $P_{Battery,min}$ is the minimum allowable battery exchange power rate, and $P_{Battery,max}$ is the maximum allowable battery exchange power rate.

5.3.2.2. Battery SOC limit. In order to minimize the battery degradation, EV battery SOC needs to be maintained within the predefined range. Moreover, the EV battery must not be fully discharged while certain amounts of energy shall be reserved for the EV driving usage [31,73,86,93,95].

$$SOC_{EV,min} \le SOC_{EV} \le SOC_{EV,max} \tag{19}$$

where SOC_{EV} is the SOC of the EV, $SOC_{EV,min}$ is the minimum allowable SOC for the EV, and $SOC_{EV,max}$ is the maximum allowable SOC for the EV.

5.3.2.3. EV availability. EV need to be connected to the power grid in order to provide the V2G service while EVs that are on the road or not connected to the power grid will be excluded from the V2G operation [83,84].

6. Conclusion

This paper reviews the framework, types, services, and challenges of V2G operation. V2G is a new technology, which allows power exchange between vehicle and power grid. This technology can be categorized into two different types, which are unidirectional V2G and bidirectional V2G based on the power flow between power grid and EV. Both V2G types are able to provide numerous services to the power grid, such as ancillary services, peak load shaving, load leveling and as solution for the renewable energy intermittency issue. This paper also presents the optimization techniques, objectives and constraints for the V2G implementation. The optimization technique is necessary for the V2G energy management as it has to cater for the complex power system constraints and to achieve various objectives.

The initial requirement to realize the V2G technology is the availability of the related technologies. Despite the notable improvements in the past decades, the practical EV battery and V2G charger are still in the experimental phase. Moreover, the complete EV charging station network with bidirectional communication infrastructure is essential for the future V2G deployment. The electrification of transport industry and V2G technology are undoubtedly long-term ambitions. Nonetheless, the V2G technology is a compelling prospect, which can bring environmental benefits and numerous services to the power grid. The accomplishment of the V2G technology needs the active participation and collaboration of government, power utilities, V2G aggregators and EV owners. Appropriate V2G management system with incentive-based policy will be the important catalyst towards the successful V2G technology implementation.

References

[1] U.S. Energy Information Administration (EIA). International Energy Outlook, Report No.: DOE/EIA-0484(2013). Washington, DC: Office of Energy Analysis, U.S. Department of Energy; 2013 20585.

[2] Organization of the Petroleum Exporting Countries. World Oil Outlook, Report No.: ISBN 978-3-9502722-6-0. Helferstorferstrasse 17, A-1010 Vienna, Austria: OPEC; 2013.

[3] Lin CH, Hsieh CY, Chen KH. A Li-ion battery charger with smooth control circuit and built-in resistance compensator for achieving stable and fast charging. IEEE Trans Circuits Syst I 2010;57(2):506–17.

[4] Affanni A, Bellini A, Franceschini G, Guglielmi P, Tassoni C. Battery choice and management for new-generation electric vehicles. IEEE Trans Ind Electron 2005;52(5):1343–9.

[5] Richardson DB. Electric vehicles and the electric grid: a review of modeling approaches, impacts, and renewable energy integration. Renew Sustain Energy Rev 2013;19:247–54.

[6] De Ridder F, D'Hulst R, Knapen L, Janssens D. Applying an activity based model to explore the potential of electrical vehicles in the smart grid. Proc Comput Sci 2013;19:847–53.

[7] Shi L, Xu H, Li D, Zhang Z, Han Y. The photovoltaic charging station for electric vehicle to grid application in smart grids. In: Proceedings of the IEEE ICIAfS 2012: 6th international conference on information and automation for sustainability; 2012 Sep 27–29. p. 279–84.

[8] Yilmaz M, Krein PT. Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces. IEEE Trans Power Electron 2013;28(12):5673–89.

[9] Yilmaz M, Krein PT. Review of benefits and challenges of vehicle-to-grid technology. In: Proceedings of the IEEE ECCE 2012: energy conversion congress and exposition; 2012 Sep 15–20. p. 3082–89.

[10] Sortomme E. Combined bidding of regulation and spinning reserves for unidirectional vehicle-to-grid. IEEE PES ISGT 2012: innovative smart grid technologies. 16–20: 2012. p. 1–7.

[11] Fasugba MA, Krein PT. Cost benefits and vehicle-to-grid regulation services of unidirectional charging of electric vehicles. In: Proceedings of the IEEE ECCE 2011: energy conversion congress and exposition; 2011 Sep 17–22. p. 827–34.

[12] Gallardo-Lozano J, Milanés-Montero MI, Guerrero-Martínez MA, Romero-Cadaval E. Electric vehicle battery charger for smart grids. Electr Power Syst Res 2012;90:18–29.

[13] Verma AK, Singh B, Shahani DT. Grid to vehicle and vehicle to grid energy transfer using single-phase bidirectional AC–DC converter and bidirectional DC–DC converter. In: Proceedings of the international conference on energy, automation and signal, ICEAS; 2011 Dec 28–30. p. 1–5.

[14] Pinto JG, Monteiro V, Goncalves H, Exposto B, Pedrosa D, Couto C, et al. Bidirectional battery charger with grid-to-vehicle, vehicle-to-grid and vehicle-to-home technologies. In: Proceedings of the IEEE IECON: 39th annual conference of the industrial electronics society; 2013 Nov 10–13. p. 5934–39.

[15] Liu C, Chau KT, Wu D, Gao S. Opportunities and challenges of vehicle-to-home, vehicle-to-vehicle, and vehicle-to-grid technologies. Proc IEEE 2013;101(11):2409–27.

[16] Pode R. Battery charging stations for home lighting in Mekong region countries. Renew Sustain Energy Rev 2015;44:543–60.

[17] Wu D, Chau KT, Gao S. Multilayer framework for vehicle-to-grid operation. In: proceedings of the IEEE VPPC: vehicle power and propulsion conference; 2010 Sep 1–3. p. 1–6.

[18] Sortomme E, El-Sharkawi MA. Optimal charging strategies for unidirectional vehicle-to-grid. IEEE Trans Smart Grid 2011;2(1):131–8.

[19] Ahn C, Li CT, Peng H. Optimal decentralized charging control algorithm for electrified vehicles connected to smart grid. J Power Sources 2011;196(23):10369–79.

[20] Hota AR, Juvvanapudi M, Bajpai P. Power quality of actual grids with plug-in electric vehicles in presence of renewables and micro-grids. Renew Sustain Energy Rev 2015;46 289–200.

[21] Guille C, Gross G. A conceptual framework for the vehicle-to-grid (V2G) implementation. Energy Policy 2009;37(11):4379–90.

[22] Akhtar GMA, Al-Awami, AT, Khalid, MW. Coordinating emission-aware energy trading with V2G services. IEEE EUROCON; 2013. p. 1293–98.

[23] Sousa T, Morais H, Soares J, Vale Z. Day-ahead resource scheduling in smart grids considering vehicle-to-grid and network constraints. Appl Energy 2012;96:183–93.

[24] O'Connell N, Wu Q, Østergaard J, Nielsen AH, Cha ST, Ding Y. Day-ahead tariffs for the alleviation of distribution grid congestion from electric vehicle. Electr Power Syst Res 2012;92:106–14.

[25] Quinn C, Zimmerle D, Bradley TH. The effect of communication architecture on the availability, reliability, and economics of plug-in hybrid electric vehicle-to-grid ancillary services. J Power Sources 2010;195(5):1500–9.

[26] Tomić J, Kempton W. Using fleets of electric-drive vehicles for grid support. J Power Sources 2007;168(2):459–68.

[27] Kempton W, Tomić J. Vehicle-to-grid power implementation: from stabilizing the grid to supporting large-scale renewable energy. J Power Sources 2005;144(1):280–94.

[28] Ghofrani M, Arabali A, Etezadi-Amoli M. Electric drive vehicle to grid synergies with large scale wind resources. In: Proceedings of the IEEE power and energy society general meeting; 2012 Jul 22–26. p. 1–6.

[29] Ferreira RJ, Miranda LM, Araujo RE, Lopes JP. A new bi-directional charger for vehicle-to-grid integration. In: Proceedings of the IEEE PES ISGT 2011: 2nd international conference and exhibition on innovative smart grid technologies Europe; 2011 Dec 5–7. p. 1–5.

[30] Gould C, Colombage K, Wang J, Stone D, Foster M. A comparative study of on-board bidirectional chargers for electric vehicles to support vehicle-to-grid power transfer. In: Proceedings of the IEEE PEDS 2013: 10th international conference on power electronics and drive systems; 2013 Apr 22–25. p. 639–44.

[31] Wang Z, Wang S. Grid power peak shaving and valley filling using vehicle-to-grid systems. EEE Trans Power Deliv 2013;28(3):1822–9.

[32] Ghosh DP, Thomas RJ, Wicker SB. A privacy-aware design for the vehicle-to-grid framework. In: Proceedings of the 46th hawaii international conference on system sciences, HICSS 2013; 2013 Jan 7–10. p. 2283–91.

[33] Monteiro V, Pinto JG, Exposto B, Goncalves H, Ferreira JC, Couto C, et al. Assessment of a battery charger for electric vehicles with reactive power control. In: Proceedings of the IEEE IECON 2012: 38th annual conference on industrial electronics society; 2012 Oct 25–28. p. 5142–47.

[34] Pillai JR, Bak-Jensen B. Integration of vehicle-to-grid in the Western Danish power system. IEEE Trans Sustain Energy 2011;2(1):12–9.

[35] Dogger JD, Roossien B, Nieuwenhout FDJ. Characterization of Li-ion batteries for intelligent management of distributed grid-connected storage. IEEE Trans Energy Convers 2011;26(1):256–63.
[36] Mullan J, Harries D, Bräunl T, Whitely S. The technical, economic and commercial viability of the vehicle-to-grid concept. Energy Policy 2012;48: 394–406.
[37] Han S, Han S, Sezaki K. Development of an optimal vehicle-to-grid aggregator for frequency regulation. IEEE Trans Smart Grid 2010;1(1):65–72.
[38] Yong JY, Ramachandaramurthy VK, Tan KM, Mithulananthan N. A review on the state-of-the-art technologies of electric vehicle. Renew Sustain Energy Rev 2015;49:365–85.
[39] Lefeng S, Qian Z, Yongjian P. The reserve trading model considering V2G reverse. Energy 2013;15(59):50–5.
[40] Srivastava AK, Annabathina B, Kamalasadan S. The challenges and policy options for integrating plug-in hybrid electric vehicle into the electric grid. Electr J 2010;23(3):83–91.
[41] Tu Y, Li C, Cheng L, Le L. Research on vehicle-to-grid technology. In: Proceedings of the CDCIEM 2011: international conference on computer distributed control and intelligent environmental monitoring; 2011 Feb 19–20. p. 1013–1016.
[42] Mou Y, Hao X, Lin Z, Minyue F. Decentralized optimal demand-side management for PHEV charging in a smart grid. IEEE Trans Smart Grid 2014;6(2): 726–736.
[43] Kempton W, Tomić J. Vehicle-to-grid power fundamentals: calculating capacity and net revenue. J Power Sources 2005;144(1):268–79.
[44] Lopez MA, de la Torre S, Martin S, Aguado JA. Demand-side management in smart grid operation considering electric vehicles load shifting and vehicle-to-grid support. Int J Electr Power Energy Syst 2015;64:689–98.
[45] Sortomme E, El-Sharkawi MA. Optimal combined bidding of vehicle-to-grid ancillary services. IEEE Trans Smart Grid 2012;3(1):70–9.
[46] Han S, Aki H, Han S. A practical battery wear model for electric vehicle charging applications. In: Proceedings of the IEEE power and energy society general meeting; 2013 Jul 21–25. p. 1–5.
[47] Bandyopadhyay A, Wang L, Devabhaktuni VK, Green RC. Aggregator analysis for efficient day-time charging of plug-in hybrid electric vehicles. In: Proceedings of the IEEE power and energy society general meeting; 2011 Jul 24–29. p. 1–8.
[48] Richardson DB. Encouraging vehicle-to-grid (V2G) participation through premium tariff rates. J Power Sources 2013;243:219–24.
[49] Ansari M, Al-Awami AT, Sortomme E, Abidoeric MA. Coordinated bidding of ancillary services for vehicle-to-grid using fuzzy optimization. IEEE Trans Smart Grid 2015;6(1):261–70.
[50] Turker H, Hably A, Bacha S. Housing peak shaving algorithm (HPSA) with plug-in hybrid electric vehicles (PHEVs): vehicle-to-home (V2H) and vehicle-to-grid (V2G) concepts. In: Proceedings of the fourth international conference on power engineering, energy and electrical drives, POWERENG 2013; 2013 May 13–17. p. 753–59.
[51] Soares J, Sousa T, Morais H, Vale Z, Canizes B, Silva A. Application-specific modified particle swarm optimization for energy resource scheduling considering vehicle-to-grid. Appl Soft Comput 2013;13(11):4264–80.
[52] Mets K, Verschueren T, De Turck F, Develder C. Exploiting V2G to optimize residential energy consumption with electrical vehicle (dis)charging. In: Procedings of the IEEE SGMS 2011: first international workshop on smart grid modeling and simulation; 2011 Oct 17. p. 7–12.
[53] Sheikhi A, Bahrami S, Ranjbar AM, Oraee H. Strategic charging method for plugged in hybrid electric vehicles in smart grids; a game theoretic approach. Int J Electr Power Energy Syst 2013;53:499–506.
[54] Baker E, Chon H, Keisler J. Battery technology for electric and hybrid vehicles: expert views about prospects for advancement. Technol Forecast Soc Chang 2010;77(7):1139–46.
[55] Ramachandran B, Srivastava SK, Cartes DA. Intelligent power management in micro grids with EV penetration. Expert Syst Appl 2013;40(16): 6631–6640.
[56] Silvestre C, Sousa DM, Roque A. Reactive power compensation using on board stored energy in electric vehicles. In: Proceedings of the IEEE IECON 2012: 38th annual conference on industrial electronics society; 2012 Oct 25–28. p. 5227–32.
[57] Zhao D, Zhu L, Wang W, Chen N, Zhang H, Ni F. Calculation of harmonic suppression and reactive power compensation device's capacity configuration in electric vehicle charging stations. In: Proceedings of the CICED 2012: international conference on electricity distribution China; 2012 Sep 10–14. p. 1–4.
[58] Bolognani S, Zampieri S. A distributed control strategy for reactive power compensation in smart microgrids. IEEE Trans Autom Control 2013;58 (11):2818–33.
[59] Vovos PN, Kiprakis AE, Wallace AR, Harrison GP. Centralized and distributed voltage control: impact on distributed generation penetration. IEEE Trans Power Syst 2007;22(1):476–83.
[60] Jiang B, Fei Y. Decentralized scheduling of PEV on-street parking and charging for smart grid reactive power compensation. IEEE PES ISGT 2013: innovative smart grid technologies; 2013 Feb 24–27. p. 1–6.
[61] Lee SY, Wu CJ, Chang WN. A compact control algorithm for reactive power compensation and load balancing with static Var compensator. Electr Power Syst Res 2001;58(2):63–70.
[62] Kisacikoglu MC, Ozpineci B, Tolbert LM. Examination of a PHEV bidirectional charger system for V2G reactive power compensation. In: Proceedings of the IEEE APEC 2010: twenty-fifth annual applied power electronics conference and exposition; 2010 Feb 21–25. p. 458–65.
[63] Kisacikoglu MC, Ozpineci B, Tolbert LM. Reactive power operation analysis of a single-phase EV/PHEV bidirectional battery charger. In: Proceedings of the IEEE ICPE & ECCE 2011: 8th international conference on power electronics and ECCE Asia; 2011 May 30–Jun 3. p. 585–92.
[64] Yong JY, Ramachandaramurthy VK, Tan KM. Bi-directional electric vehicle fast charging station with novel reactive power compensation for voltage regulation. Int J Electr Power Energy Syst 2015;64:300–10.
[65] Kesler M, Kisacikoglu MC, Tolbert LM. Vehicle-to-grid reactive power operation using plug-in electric vehicle bidirectional offboard charger. IEEE Trans Ind Electron 2014;61(12):6778–84.
[66] Romo P, Micheloud O. Issues and solution approaches in PHEV integration to smart grid. Renew Sustain Energy Rev 2015;30:217–29.
[67] Jin C, Sheng X, Ghosh P. Energy efficient algorithms for electric vehicle charging with intermittent renewable energy sources. In: Proceedings of the IEEE PES 2013: power and energy society general meeting; 2013 Jul 21–25. p. 1–5.
[68] Fazelpour F, Vafaeipour M, Rahbari O, Rosen MA. Intelligent optimization to integrate a plug-in hybrid electric vehicle smart parking lot with renewable energy resources and enhance grid characteristics. Energy Convers Manag 2014;77:250–61.
[69] Rao S, Berthold F, Pandurangavittal K, Blunier B, Bouquain D, Williamson S, et al. Plug-in hybrid electric vehicle energy system using home-to-vehicle and vehicle-to-home: optimization of power converter operation. In: Proceedings of the IEEE ITEC 2013: transportation electrification conference and expo; 2013 Jun 16–19. p. 1–6.
[70] Goebel C, Callaway DS. Using ICT-controlled plug-in electric vehicles to supply grid regulation in California at different renewable integration levels. IEEE Trans Smart Grid 2013;4(2):729–40.
[71] Peas Lopes JA, Almeida PMR, Soares FJ. Using vehicle-to-grid to maximize the integration of intermittent renewable energy resources in islanded electric grids. In: Proceedings of the international conference on clean electrical power; 2009 Jun 9–11. p. 290–95.
[72] Raslavicius L, Azzopardi B, Kersys AStarevicius M, Bazaras Z, Makaras R. Electric vehicles challenges and opportunities. Lithuanian review 2015;42:786–800 Feb.
[73] Ghofrani M, Arabali A, Etezadi-Amoli M, Fadali MS. Smart schedulling and cost-benefit analysis of grid-enabled electric vehicles for wind power integration. IEEE Trans Smart Grid 2014;5(5):2306–13.
[74] El-Zonkoly A. Intelligent energy management of optimally located renewable energy systems incorporating PHEV. Energy Convers Manag 2014;84:427–35.
[75] Peterson SB, Apt J, Whitacre JF. Lithium-ion battery cell degradation resulting from realistic vehicle and vehicle-to-grid utilization. J Power Sources 2010;195 (8):2385–92.
[76] Krein PT. Battery management for maximum performance in plug-in electric and hybrid vehicles. In: Proceedings of the IEEE VPPC 2007: vehicle power and propulsion conference; 2007 Sep 9–12. p. 2–5.
[77] Han S, Han S, Sezaki K. Economic assessment on V2G frequency regulation regarding the battery degradation. IEEE PES ISGT 2012: innovative smart grid technologies; 2012 Jan 16–20. p. 1–6.
[78] Millner A. Modeling Lithium Ion battery degradation in electric vehicles. In: Proceedings of the IEEE CITRES 2010 conference on innovative technologies for an efficient and reliable electricity supply; 2010 Sep 27–29. p. 349–56.
[79] Dehaghani ES, Williamson SS. On the inefficiency of vehicle-to-grid (V2G) power flow: potential barriers and possible research directions. In: Proceedings of the IEEE ITEC 2012: transportation electrification conference and expo; 2012 Jun 18–20. p. 1–5.
[80] Yuan X, Liu X, Zuo J. The development of new energy vehicles for a sustainable future: a review. Renew Sustain Energy Rev 2015;42:298–305.
[81] Bashash S, Fathy HK. Optimizing demand response of plug-in hybrid electric vehicles using quadratic programming. In: Proceedings of the ACC 2013 American control conference; 2013 Jun 17–19. p. 716–21.
[82] Soares J, Vale Z, Canizes B, Morais H. Multi-objective parallel particle swarm optimization for day-ahead vehicle-to-grid scheduling. In: Proceedings of the IEEE CIASG 2013 symposium on computational intelligence applications in smart grid; 2013 Apr 16–19. p. 138–45.
[83] Saber AY, Venayagamoorthy GK. Optimization of vehicle-to-grid scheduling in constrained parking lots. In: Proceedings of the IEEE power & energy society general meeting; 2009 Jul 26–30. p. 1–8.
[84] Saber AY, Venayagamoorthy GK. Unit commitment with vehicle-to-grid using particle swarm optimization. IEEE Power Tech 2009:1–8.
[85] Sortomme E, El-Sharkawi MA. Optimal scheduling of vehicle-to-grid energy and ancillary services. IEEE Trans Smart Grid 2012;3(1):351–9.
[86] Saber AY, Venayagamoorthy GK. Intelligent unit commitment with vehicle-to-grid-a cost-emission optimization. J Power Sources 2010;195(3):898–911.
[87] Han HY, He JH, Wang XJ, Tian WQ. Optimal control strategy of vehicle-to-grid for modifying the load curve based on discrete particle swarm algorithm. In: Proceedings of the DRPT 2011: 4th international conference on electric utility deregulation and restructuring and power technologies; 2011 Jul 6–9. p. 1523–27.
[88] Celli G, Ghiani E, Pilo F, Pisano G, Soma GG. Particle swarm optimization for minimizing the burden of electric vehicles in active distribution networks. In: Proceedings of the IEEE power and energy society general meeting; 2012 Jul 22–26. p. 1–7.
[89] Kiranyaz S, Ince T, Gabbouj M. Multidimensional particle swarm optimization for machine learning and pattern recognition. ; 2012.

[90] Ghanbarzadeh T, Goleijani S, Moghaddam MP. Reliability constrained unit commitment with electric vehicle to grid using hybrid particle swarm optimization and ant colony optimization. In: Proceedings of the IEEE power and energy society general meeting; 2011 Jul 24–29. p. 1–7.
[91] Ma Y, Houghton T, Cruden A, Infield D. Modeling the benefits of vehicle-to-grid technology to a Power System. IEEE Trans Power Syst 2012;27(2):1012–20.
[92] Rostami MA, Kavousi-Fard A, Niknam T. Expected cost minimization of smart grids with plug-in hybrid electric vehicles using optimal distribution feeder reconfiguration. IEEE Trans Ind Inform 2015;11(2):388–97.
[93] Igualada L, Corchero C, Cruz-Zambrano M, Heredia FJ. Optimal energy management for a residential microgrid including a vehicle-to-grid system. IEEE Trans Smart Grid 2014;5(4):2163–72.
[94] Bai X, Qiao W. Robust optimization for bidirectional dispatch coordination of large-scale V2G. IEEE Trans Smart Grid 2015;6(4):1944–54.
[95] Akhavan-Rezai E, Shaaban MF, El-Saadany EF, Karray F. Online intelligent demand management of plug-in electric vehicles in future smart parking lots. IEEE Syst J 2015;99:1–12.