Electric vehicles based electric power grid support: a review

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ABSTRACT

Grid connected electric vehicles (EVs) can provide energy quality services to ease intermittent renewable energy sources dependent, enhance grid stability performance, reliability and load balancing in the power system. Moreover, incorporating sufficient EVs into the power grid will assist reduce greenhouse gases. However, the unrestrained EVs charging impact the raise of peak request, frequency deflection, voltage instability, power quality from the acceptable limits. It can also cause overloading of the power system equipment and an increase in power losses. In this paper, the influences EV technologies on various energy systems, control scheme strategy, benefits, and motivational challenges are investigated. An overview of the impacts of uncontrolled EV loading on the electric power system and how controlled charging becomes benefit impacts is presented. Moreover, a review of the controlled charge and discharge benefits of EVs and the electrical serving involved in reduction of frequency deviation, voltage stability, power quality improvement is introduced. This review shows that integration of optimal control of EVs with a suitable optimization technique can improve and provide on time multi ancillary services of EV integrated with weak grid. In addition, this review provides research tracks which can be followed by researchers.

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1. INTRODUCTION

Transportation using fossil fuels accounts for around 26% of global CO_2 emissions, and this percentage is projected to rise rapidly as the industry grows [1], [2]. Nowadays, different countries' environmental pollution management strategies encourage a variety of transportation-related sources to improve energy quality and reduce emissions [3]. Interest in electric vehicles (Evs) has spread in the current era as another potential for vehicles powered by Gasoline, with the tender of various sorts of EVs. Due to environmental issues, governments drive EV encouragement, and hence, EVs are expected to dominate the passenger car market during incoming years [4]. Currently, a large part of oil consumption has been allocated in the transportation sector, where fuel-powered vehicles use a large proportion of oil according to the International Energy prospect. In the transportation sector, oil consumption will increase by 54% until 2035 [1], [5]–[7]. The total number of EVs is expected to reach 130 million by 2030, according to the International Energy Agency's "Global Prospects for EVs" report [8]. The intended transformation in the fundamental energy source from gasoline to the electricity grid has created numerous challenges for power grids around the world. For instance, by 2050, the National Grid (NG) in [9].expects the electricity demand for EVs to reach about 600 billion kilometers annually in Britsh streets. If it is assumed 75% of these forecasted distances will be provided by electric powered vehicles of 0.15 kWh/km, A 54 TWh is required which represent an increase of 18% as compared to the UK present consumption.

Most of the EV technologies were widely used and gained a lot of observation in the past years. In the last century, lead-acid batteries were used to derive fuel-powered vehicles combined with internal combustion engine cars (ICEVs). However, in recent years so many improvements are accomplished on EVs and batteries to improve their performance and reduce their cost [7]. Several terms are used for EVs based on their multiple levels of electrification. A hybrid EV (HEV) improves overall efficiency by combining a normal car with an EV propulsion system (combustion engine propulsion system) [2], [10]. While in the plug-in EV (PEV) conventional internal combustion engine vehicles is converted to HEVs. A plug-in hybrid vehicle (PHEV) connects to the electric grid to recharge its battery and then uses the battery as the source of motion. In this case, the normal car engine can provide back source propulsion whenever the charged battery is exhausted. A battery EV (BEV) relies on the power grid and does not have an internal combustion engine and receives power from the onboard battery [11]. On the other hand, the on-board electric motor of a Fuel Cell EV (FCEV) is powered by a fuel cell, depending on a small battery or a super capacitor. The electricity in the FCEV is generated by oxygen from compressed air. EV classified by their alternative fuels and technologies are presented in [2], [11]–[13]. In this paper, the acronym "EV" is used to refer to any type of vehicle that can be integrated into the network in order to recharge the battery or for saving coincident services to the network.

EV can help solve environmental problems by reducing greenhouse gas emissions and noise pollution [14], [12]. In addition, an EV with recharging batteries is a dispersed supply of energy, however, its integration with the network presents both benefits and challenges. From the customer's point of view, the small EV range and the shortage of charging stations are the biggest challenges [15]. For this reason, fast-charging stations will be placed where the cars could have long EV parks and the range will also be expanded [16]. The need and the progress required in the growth of EVs were discussed in [2], [4] and they indicated that EV has a vivid future and highlighted the significance of considering the challenges related to this transformation. The power system will be influenced directly by this transformation, Therefore the EV integration and its impacts in the context of a power system must be considered [16].

Several researchers have evaluated the economic cost and economic benefits of EVs over utility and distribution systems [10]. A global review of practices related to EV consumer education activities to explore actions that governments can take to promote market growth and to better understand how to implement such campaigns were assessed in [17], [18]. They summarized practices in consumer consciousness, and how to transact with EV. On the other hand, many studies demonstrated that even low penetration of EV charging can affect power system quality which includes voltage instability, frequency drift, losses, system thermal load, loss of transformer life, demand response, and harmonic distortion [19].

Many initiatives have been taken so far to mitigate these quality problems. Different charge control strategies were presented for improving system stability. Jadhav and Kalkhambkar [20], designed an intelligent control strategy to reduce the maximum load and improve the load profile based on the quadratic programming of EV was presented.

Several authors have analyzed the effect of EVs on the distribution network and the EV technologies concept was presented in detail in [21]. In the literature, most of the research work was focused on smart charging methodology, commercial models, and load profiles. This paper presents the concept of EV technologies, and various topics that can be explored in EV field technology. The main objective of this study is to examine the effects of EVs on the frequency regulation and voltage stability of the distribution network. The organization of the rest of this paper is as follows: Section 2 introduces aspects related to the integration of EVs into the power system and their impact on the energy quality of the system. Section 3 investigates the impacts of EVs on voltage stability in electric power systems and how to employ them to improve power quality. Section 4 deals with system frequency regulation depending on EVs. Section 5 discusses salient aspects and the trend research. Finally, Section 6 concludes the paper.

2. EV INTEGRATION IN POWER SYSTEM

In all EVs, the main source is the battery and characterized by weight, size, and cost component. DC batteries are electrochemical power sources that receive, store, and deliver direct current electrical energy [22]. Although it is important to understand the basics of chemistry, from an EV designer's perspective, the battery contains a set of performance-based criteria. Some of these criteria are battery state of charge, charging efficiency, charge/discharge depth of battery, and lifespan of battery.

Another important aspect of EVs is the charging station and its charging schemes. EV charging framework is categorized according to 'the types of charging' and 'the modes of charging'. Types are indicated by plugs and sockets that support power transmission. Modes refer to fast or slow charging modes where the consumption of power source to EV varies. There are four types of charging modes in which the EV substructure is categorized. Those mode types mainly depend on the power source, communication availability, and protection of the battery [23], [24].

The vehicle is plugged into ordinary house power or industry power sockets in charging mode 1 and 2, providing a current of no more than 13-16 A. A 230 V AC power supply from the distribution feeders to the house is suitable for charging the EV. Residual current device (RCD) protection that prevents fatal shocks is not available in mode 1. However, (RCD) protection is provided in the cable prepared by the manufacturer of EV in mode 2. In charging mode 3, there is an intended charging terminal with an install of the residual current device (RCD) and stream protection connected to the mains. This type of mode supports a single-phase AC power 16 A or 32 A. Compared to other modes, this mode is the preferred charging one due to its protection, scalable power features, and connectivity [4], [25]. In addition, the EV is rapidly charged using DC current in charging mode 4. Due to the high output voltage and current of 500 V and 200 A, 80% of the EV battery can be charged within 30 minutes. The charging stations installation costs of this mode are high and they cause overload of the distribution network [11].

It is worth mentioning that allowing EVs to charge/discharge without any control technology causes grid disturbances, voltage, and frequency fluctuations. On the other hand, when EVs are intelligently charged/discharged, they can support the quality of the electric power grid. In this direction, it is possible to take benefits from connecting EVs with the electric networks to improve the performance of the networks, which is called vehicle to grid (V2G) technology [15]. V2G technology allows EV batteries to store energy and discharge it back to the grid when it is most needed (i.e. peak times). V2G is a technology that consists of transmitting energy in two ways, either from the vehicle to the network or from the network to the vehicle [26]. This technology can help to regulate charging and discharging between EVs (EVs) and electric networks in order to increase the voltage stability of the distribution networks [27].

Figure 1 shows the general block diagram of the V2G architecture [27]. Due to the special characteristics of the EV, the grid operators around the world countenance significant challenges in integrating the EV load that differ from other loads in the grid [26]. It is not just about charging an EV from the grid compared to home charging, but it also has specific dynamic behavior. Furthermore, the real and reactive power that EV will use cannot simply be assessed, due to the difference in time and place where the EV will be connected to charge, and the duration of charging required [15]. EV is connected to the power system as a charging load or an EV battery works as a potential fellow used as a power source that creates a V2G technology.

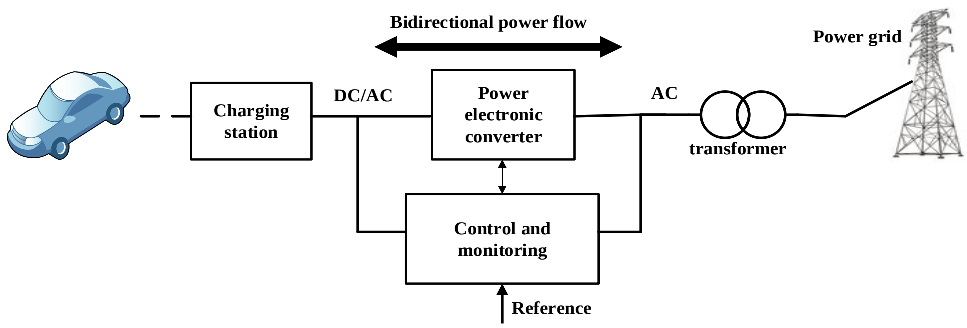

Figure 1. Block diagram of the V2G architecture [27]

According to the abovementioned discussions, it is important to pay attention to EV concerns with the power grid. The following substations present a general review of existing EV network impact studies. Several studies have discussed concerning policies and processes used to reduce the influence associated with EVs battery charging/discharging on a large scale [28]. A comprehensive literature review is also presented about research and developments concerning vehicles' charging/discharging and their integrations with the electric distribution networks. The conclusion of this part detects the gaps and durability of the current studies and makes a proposal for potential next work [13].

2.1. Impacts of EV on the distribution power system elements

Nowadays a large number of EV charging loads are connected to distribution networks. The EV load characteristics indicate that there will be an increased tension on elements of the weak network system [26], [28]. This issue is reviewed in this section to gain a clear vision of the probable and expected troubles of EV charging and discharging on an electric distributed system. Figure 2 shows a setup of an integrated power grid for the onboard charging scheme of EV with type 1 and 2 AC charging schemes [29]. Although EV gives a clear advantage to transportation, its impact on power systems cannot be condoned. Unregulated EV charging influences the distribution system with reference to its voltage profile, grid unbalance, power loss, frequency stability, as well as harmonic disturbance. Many research studies have identified the problems by suggesting several ways to control the charging of EVs [30]. Al-Ogaili *et al.* [31] briefly reviewed EV control charging strategies. They categorized EV charging control strategies into three approaches of clustering, scheduling, and forecasting. The models of EV charging control conditions are highlighted to evaluate and compare the methods used in charging EV. Moreover, the merits and demerits of the different applied methods were identified. However, dealing with a discrepancy between frequency and voltage drop is an important issue and it required more attention to EVs that respond together to a frequency and voltage signal. Lopes *et al.* [32] used a supervisory control scheme for local voltage and frequency based on EVs was introduced. The control points were sent to each vehicle or set of vehicles from the master console. The paper also introduced the power group grading to control the frequency and voltage drop.

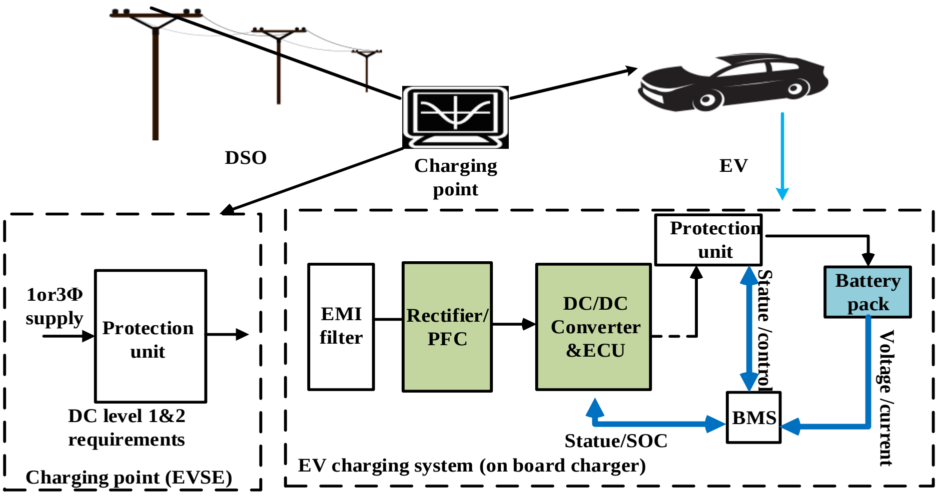

Figure 2. A facility integrated power grid setup for a type1 and type 2 AC charging scheme for an EV [5]

2.2. Positive impacts of EVs on electric power systems

This section reviews the effects of EV on power quality. A grid analysis on the district power grid was performed in Ada County, USA, for a projected 18% load stimulated to be equivalent to available EVs by 2040 [33]. EVs that are parked for days are linked to the charging ports for more than the standard recharge time. So, a battery of EV can be utilized to reserve network grid services and earn income for EV users by the supplied energy into the grid to maintain the demand or by the guided charging time and power consumption to reduce electric bill and cost of EV charging [7]. The smart grid voltage is regulated depending on EVs in [34] and an algorithm tis proposed to maximize the parking lot revenue in the line distribution network taking into account the charging demand of EV owners and voltage fluctuations, where the voltage is determined by the power distribution flow method [34]. Several studies have shown that controlled charging of EVs can enhance the efficiency of the power system [35], minimize operating costs [36], and reduce the contractility of renewable energy systems (RESs) [37]. The research in [38] aims to studies the system stability and EVs energy consumption by applying a modern control techniques. The controller of artificial neural network is proposed to estimate the required yaw direct torque to stabilize the EV dynamics with four internal motors for wheels. Furthermore, discharge control of EVs can improve electrical services and provide additional benefits. EVs can provide network servings due to the rapid reply of chargers like primary frequency control (PFC) and secondary frequency control (SFC) and reduced power loss due to the high capacity of the battery [39]. An overview of the positive and negative impacts of EVs as well as EV modeling as a grid load are presented in [40].

2.3. Power system issues with high penetration of EV charging in distribution networks

Although the ecological and economic advantages of EVs are evident, their effects on power systems quality still need to be analyzed [41]. System power quality is an important key in the security and efficiency of networks, particularly weak networks, and expect to be pretentious by the improvement of EVs over the upcoming years. EV interface systems use electrical transducers because of their infrastructure and the nature of the transducer power electronic components, which are highly nonlinear systems [41], [42]. Therefore, there are usually several dissimilar ways for reducing and dealing with the negative effects of the EV on the weak network. PEV can be used in power quality improvement, in both charge and discharge modes, generate good power quality (in terms of voltage optimization and frequency regulation).

The power quality of the system elaborates the potentiality of the system to keep synchronizing when tolerating any disturbances [18]. Understanding of the difficulties needs studying of the power quality issues. Change in generation and load, negative interaction among controllers, and fast exciters are reasons for system vacillations [18], [19].

Deflections must be mitigated, as the disturbances to which they have been subjected cause excessive wear and tear on the components of the power system. Moreover, these disturbances can increase in proportion, and if uncontrolled they may lead to unreliability and then power outages [43].

A comprehensive study with low and high penetration of EVs was conducted in a public low-voltage (LV) distribution network. The studies in [35], [44], [45] investigated the location, duration, and time of charge for EVs. An overload of distribution transformers was found once a day in winter [44]. This overload only took place in the summer with a high penetration level of EV load.

Vatandoust *et al.* [45] found that due to a Nissan leaf charger (6.6 KW) with 30% penetration, the system parameters can absorb the charging at type 1 of charging (120 V). But when charging at type 2 (240 V), there would be a big daily variation in the amplitude of heat on the cable which reduced the cable lifetime significantly. Another investigation in a local network [10] found that an increased level of EV penetration leads to an increase in overloaded lines.

The conclusion of the study system in [46] indicated that by 2025, its distribution system could reliably meet about 500,000 HEV penetrations. Likewise, a study of a system in Australia (Perth) [47] proved that existent high voltage (HV) system infrastructure had a significant potential to facing the entire permeation of EV market. On the other hand, in [24], [44] authors discussed the merit and demerit effects of charging EV on the lifetime of the distribution transformer. On one hand, they found an increase in mean operating temperature which led to insulating failures of transformers. furthermore, the coordinated load profile acquired by controlling the EVs charging lowered the temperature of the transformers. This was due to the reduced numeral of extensions and limitations of the transformer in a day.

In contrast, [28] has identified EV charging as a way to use the distribution feature in an environment of mobile smart grid. The capacity to scale up for stimulated energy demand due to EVs may be limited by the weakness of the grid. They comprise the capacitance and thermal constraints of the network segments. The study in [28] concluded that the voltage drop registered in some regions fell less than the standard constraints, and therefore, the system needed to be boosted. Subsequently, the studies must identify such limitations in each relevant network component.

Comparably, the presented study in [29] found that there is a voltage distract of 12.70-43.30% due to the estimated EV penetration of 20.0% and 80.0% for various rates of charging. Dulau and Bica [15] introduced an experimental model of a distribution system with connected EVs was presented and revealed that an on load tap commutators (OLTC) model could withstand a 20% penetration of EV load, but the voltage dropped lower than the limitation constraints in various locations at a 30% penetration of EV. However, the model voltage disturbance was kept within constraints except for the case of charging with a high current. A comprehensive study presented in [13], proved that in transmission and distribution systems there were obvious impacts on voltage even at low levels of penetration as low as 1-2% due to EVs located randomly in the grid. In another study on a low voltage distribution network with 50% to 100% EV penetration levels, the authors found that the valid voltage borders were transcended at the network end until a minimum load charge occurred in the network [48].

A study of a network with IEEE 34-bus at 24.9 kV presented in [49], confirmed that voltages on buses could be kept within limits of up to 8% of EV penetration for different charging scenarios. Researchers in [42], [50] have looked at the uncontrolled V2G mode of powering EVs. They found that voltage limits violated the permissible limits during minimum grid load terms. The search in [42] showed that OLTC can bear penetration of 10% but cannot tolerate penetration of 30%. In a medium-voltage system in a network with a voltage of 15 kV presented in [51], a similar result was obtained. As the level of penetration of electric chargers increased, there were voltage deviations in the overhead buses, as expected. Moreover, it revealed that although the considered system cannot withstand uncontrolled charging with a penetration of 10%, it can accommodate a double tariff structure with an EV penetration level of 13% [51], [52].

A controlled algorithm was proposed to regulate the network voltage, depending on the compensation of reactive power from EV [53], [54]. Decentralized coordination of EV charging and EV load management has been proposed in [55] to overcome negative influences on voltage stability. Finally, it was clear that voltage regulators may be useful based on the charging and network characteristics to achieve voltage stabilization requirements as explained in [46], [56].

3. FREQUENCY STABILITY USING INDEPENDENT EV

The frequency of the power system is an important indicator of the balance of active power supply and request that must be maintained at nominal values for ordinary operation. Power imbalance takes place because of steady load versions or fluctuations in the RES era relying on atmospheric situations at the ordinary operation [40]. But power imbalance arises in emergencies when loads, generating units, or transmission lines are suddenly interrupted. Network shocks caused by big-scale loading and load shedding have a substantial impact on the electrical grid quality, power losses, and equipment usage [20], [40].

In traditional networks, weak grids are common in medium or low voltage levels. Weak networks feature with low inertia and high resistance compared with strong networks, also rated as exemplary low power classifications [57]. EVs can regulate the frequency of the distribution system as well as participate in power change of peak load. Frequency regulation may be realized locally via the transfer of active energy between the distribution network and the EV battery, which is controlled by a two-way power electronic converter [58]. The power electronics converter of EVs can be controlled in order to serve as frequency primary control.

In the primary frequency control (PFC) there are two control loops, droop control that reduced the dependence on traditional generators, which helps in reducing fossil consumption, and control the inertial that simulates the behavior of a traditional generator [37]. Figure 3 shows EV control block diagram for frequency regulation [39], [59]. Frequency is regulated in a conventional power system using synchronous generators in big stations. But in future power systems, adjustable loads such as EVs and heat pumps play an important role in frequency management [37]. The power network's inertia can compensate for load disruptions or imbalances induced by intermittent renewable sources. However, keeping frequency variations within acceptable ranges remains a challenge [60].

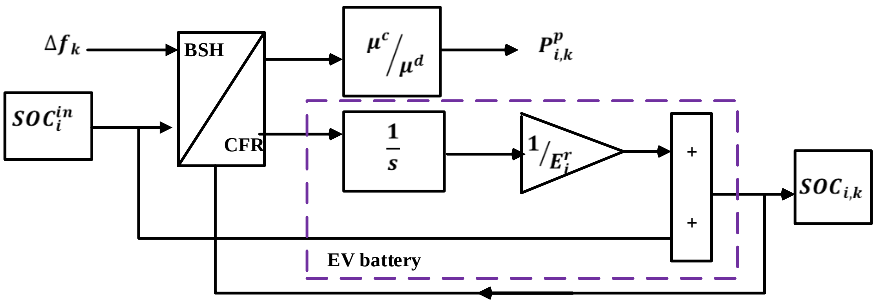

Figure 3. V control block diagram for frequency regulation [39]

Under such a transient state of affairs, it is critical to decrease frequency variations and restore the quality to the network's regular state as quickly as possible [61]. Many frequency regulation solutions examine the V2G approach to manage the frequency of a micro grid (MG)/weak grid with various levels of EV penetration [37]. A proposed methodology was presented in [62] to reduce the effect of EV on a 'weak' grid via frequency regulation is explored based on the control system of EV. The metering system based on the smart algorithm shown in Figure 4 is integrated along with the EV control scheme. Additionally, frequency regulation was investigated as part of the V2G control technique. Supplementary frequency regulation (SFR) was participated with many EVs through control of V2G approach considering both the control center organization and the state of charge (SOC) levels of battery anticipated from EV users in [63].

In addition, EV has evident advantages in the frequency regulation of the power system from a financial point of view for reducing the EVs charging/discharging costs [36], [64], [65]. However, controlling frequency in distribution feeders depended on a bi-directional V2G converter with two-stage for EV, SOC is disregarded, as well as battery age and health are ignored [58]. Additionally, EVs can be used for a one-way power flow network in frequency regulation service [66]. Given the power flow rate and the charging demands of EV owners, a decentralized V2G control approach was selected to include EVs in frequency management. Based on the best-integrated grid, the SOC battery control method hold effectively the EV battery SOC, whilst EV was concerned with regulating system frequency in the grid [59].

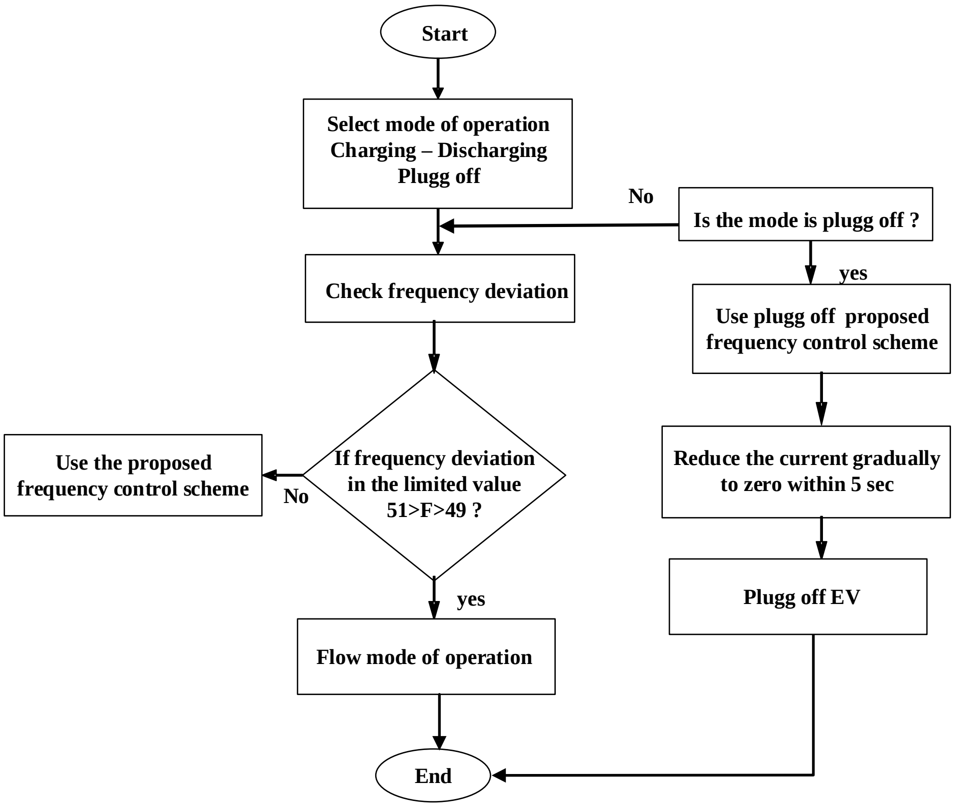

Figure 4. Flow chart of the proposed algorithm [62]

The distributed control strategy is discussed in [67], [68] to meet the expectations of battery SOC from EV by taking the charge state control approach of the EV battery to conserve the remaining battery SOC. The frequency deviation of the system is affected by the co-distribution, as shown in [69]. Ota *et al.* [69] determined the charging energy depending on the genetic frequency change data.

Ota *et al.* [67], used half of the maximum V2G power was distributed ignoring the difference between the particular and scheduled duration of the plug-in. The demand for EV charging was considered, and V2G-based decentralized frequency regulation was developed based on EV. Moreover, Due to the quick response of electronic interface of the EV, chargers of EV batteries respond faster than conventional generating units. So, the charging and discharging of controlled EVs can be an effective choice for regulating the grid frequency [25].

An experimental test was carried out on the potential of commercially available EVs (e.g., Nissan Leaf) to offer primary frequency control (PFC) only by altering charging power and without V2G abilities [70] The results demonstrated the technical ability of EVs to achieve a PFC with a fast response time when a small, insulated, renewable power system was used as a test system. When EVs are shared in the load, the frequency deviations on both sides of generation and load respond by AGC. The potential and appropriate operation of AGC with EVs was investigated to substitute the characteristic response inability of conventional generating units [71]. Almeida *et al.* [71] have established two methods of engaging EVs in the PFC. Turning off EV charging was the first and the second method was to inject energy into the network in V2G mode. In addition, the V2G central control method for co-load frequency control (LFC) has been discussed. Tian *et al.* [72], a method was designed to track the LFC signal. However, there was no thought given to explain how to send the LFC signal to EVs. So an area control model (ACE) was instituted and connected two-area models containing V2G that were used to resolve the impacts of participating EV in secondary frequency regulation depended on ACE. The results showed the effectiveness of V2G for reducing the frequency variation and tie-line flow fluctuation by lowering the reserve capacity in the system.

A coordinated LFC control strategy and battery SOC has been proposed in [37], [73] based on EVs operating in V2G mode with conventional generation. The suggested control technique was put to the test on the British electricity grid for frequency regulation by coordinated LFC control between EV controller and conventional power plants (PPs). The priority in response was for EV controller than the controller of PPs when the system exceeded the permissible limits. Also, a proposed stability standard was improved to evaluate the stability for the LFC system while the inertia unsureness and delays in time-varying are considered simultaneously. In addition, the LFC of EV used a PI controller for frequency stability enhancement. The findings demonstrated the efficacy of the suggested method in enhancing frequency control and reducing energy mismatch. EVs operation based on two charging control modes was studied in [74] to regulate frequency taking into account the diving behavior of the EV owner. The first mode simply regulated charging and the second regulated both charging and discharging of EVs. Results revealed that EVs were successful in lowering frequency oscillations. The dynamic frequency regulation frame of EV is indicated in Figure 5 for the two modes of the strategy [74].

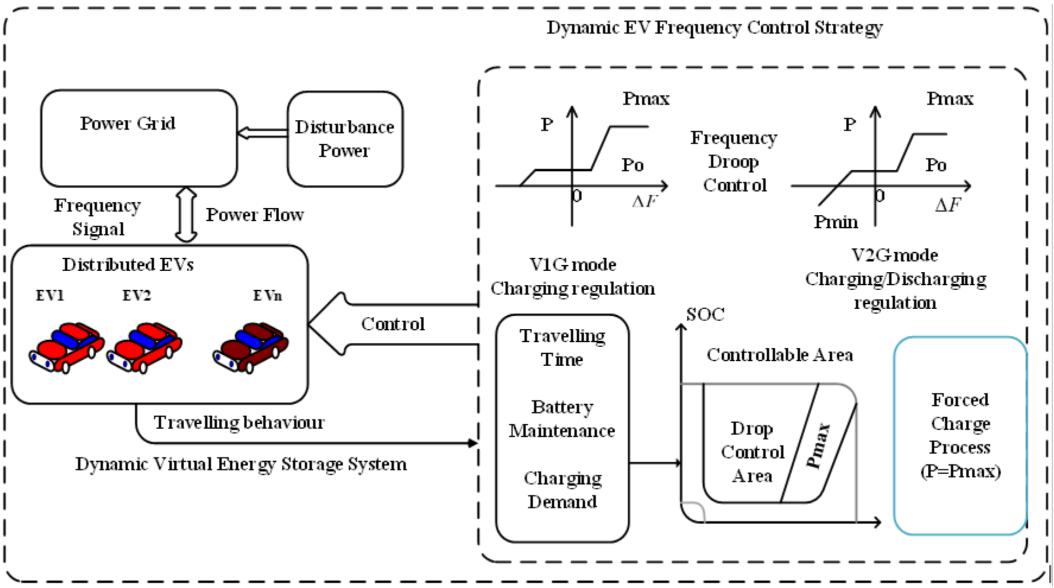

Figure 5. Dynamic EV frequency regulation frame with two control modes [74]

Wang and Chen [75] proposed a dual-level assented-based frequency control procedure to support PFC. The first control level aimed to reduce multi-zone power system frequency fluctuation, and the second one aimed to decrease the cost of regulating frequency and degradation expense of battery for individual EVs. The efficiency of EVs was tested to provide basic frequency regulation for an isolated power system with diesel generators, wind turbines, and hydro generators [76]. The study demonstrated the effectiveness of EVs in regulating frequency oscillation while controlling the energy consumed by EVs and coordinating charging time. Moreover, the effects of probably delayed actions were estimated. Donadee and Ilic [77], proposed a dynamic stochastic programming method was used to improve the charging decision of EVs and frequency regulation, considering the unpredictability of EV and wind power.

Furthermore, the output fluctuations of the traditional power were decreased as a result of EV integration in the system as an energy storage system. The EVs can engage in LFC in the isolated micro grid that operated in an autonomous mode of operation [78]. While economic distribution is a fundamental issue in operation and management, EVs are involved in frequency control based on economical transmission [78]. The economic dispatch model was created based on Incentive policy to match EVs and the grid operator [79]. The results showed that an additional network of EVs with an appropriate dispatch plan succeeded to close the gap between demand and supply at different time intervals and reduce fuel costs. While contracts and tariffs were modified to implement V2G integration, the implications of various forms of contracts on various marketplaces were examined [80]. A driver incentive scheme was designed, as well as "whole-deal" business models for potential EV participants. Long-term contracts provided a greater motivation than short-term committing. The predicted capabilities were ideal for the regulatory nodes between the network operator and the EV aggregator to create a queueing model for EVs and design a smart mechanism for charging [80].

Smart pricing policies and mechanisms are able to improve the performance of frequency stability. On the other hand, some academics have suggested methods to stimulate the performance of EVs in frequency regulation based on the control cost mechanism [81]. It was able to recharge many EVs and adopted the non-linear pricing of the model. Some researchers have developed a price system to incentivize cars to voluntarily connect V2G on their own. Moreover, the mechanisms effectively set the proportional importance between the control of SOC and the revenue [81]. A control structure of real-time was suggested to perform the V2G system into the price-based schedule to manage the system effectively [82]. The collector profits from the contracted capacity of the sale and allocated the advantages to each EV participating in the program by developing an incentive scheme to coordinate benefits between the network side and the consumer side at frequency regulation [82].

In conclusion, EVs can support frequency regulation by controlling vehicle charging without V2G abilities or controlling the charging and discharging based on V2G capacity. The initial technique achieved frequency control solely by changing the power of EVs charging that required simple infrastructure and had little impact on battery life. In the second technique, frequency management is achieved by regulating both charging and discharging energy. This technique is more sophisticated, necessitates infrastructure upgrades such as bidirectional chargers, and has an impact on the battery life cycle owing to constant charging and discharging. After investigating the research that clarifies the impact of the EVs on frequency regulation, the next section represents the effect of the EVs on the voltage support.

4. IMPACTS OF EVS ON VOLTAGE STABILITY IN ELECTRIC POWER SYSTEMS

Even though voltage stability is a key problem in power system operations and planning due to the rising frequency or voltage disturbance occurrences, voltage stability associated with EV load integration is a very critical challenge in power system operation. The load parameters are the most important variables influencing voltage stability as shown in many searches [30], [82], [83]. However, few researches have studied the effect of EV loading on voltage stability in the system, considering the load of EV as a constant current load [84]. The work in [83] examined EV behavior by treating the load of EV as continuous power demand and analyzed experimentally whether coordinated integration of EVs could reduce voltage disturbance by using a smart charging algorithm relying on a drooping controller. The results showed the benefits of smart EV charging in enhancing the voltage stability of an extremely unstable network. The effect of V2G performance on network voltage stability was estimated in [44]. A single-phase EV charger was modeled to study the effect of EV chargers in a LV distribution feeder and a voltage analysis was estimated in [44]. The impacts on the feeder with various EV penetration levels as well as different load levels were studied. Through the analysis of results, the efficiency of the EV charger was improved by suggesting a suitable candidate eliminate the issues and include them in future work.

Since the voltage stability of a power system is greatly affected by the characteristics of the load, it is necessary to represent an accurate load as introduced in [48]. The voltage response of four various kinds of EVs was estimated and models of ZIP were improved for each and then they were utilized in V2G studies. The evaluations proved that there was a significant difference in behavior between the EVs types and thus a generic model cannot be accurate [48].

Therefore, a loading model for a fast charger of EVs was developed based on a common battery charger at the first stage, the voltage stability was examined with the improved model [85]. It has been proven that the system voltage limits were significantly influenced by the EV model. The second stage of that study illustrated how EV charging affected the stability of system voltage considering limits of voltage stability, power losses, and the flow ratings for a suitable place of EV fast-charging stations in the network. Moreover, the maximum permissible capacity of the station was estimated depending on the stability and reliability of the system. Due to numerous economic and environmental considerations, existing power systems are operating at or near their stability limitations [86]. Ultra-fast charging (UFC) technology has attracted great interest in research and industry. Thus, planning the locations and capacities of the UFC stations is critical to prevent adverse effects of the system [86]. The study firstly concerned planning for traditional charging stations. Next, it discussed the expectations for UFC planning outcomes by identifying patterns similar to the renewable energy (RES) source pattern. The pattern considered the stochastic properties and energy density of RES and UFC. The study focused on UFC design from a grid perspective, traffic flow, and EV owner behavior for potential integration of UFC inside smart cities [86].

EV load has characteristics that combine variable and constant exponential power load behaviors [23]. During system voltage drops due to system disturbance, passive exponential loads consume more power, which significantly degrades system voltage stability. Hence, estimating the influence of EVs charging on the power supply voltage stability is critical. Therefore, including voltage stabilization into the EV charging infrastructure development process is advantageous from a grid standpoint [9], [87].

4.1. Mitigating impacts of EV on voltage stability in the system

For a specific power grid, voltage stability is acceptable if all buses voltage are remained in their constraints during ordinary operation and after exposure to disturbances [88]. Significant voltage instability occurs when the system generation and transmission are not sufficient to meet system demand, and this results in the overloading of transmission lines. While the consumption of reactive power increases due to increased loads or due to a decrease in reactive power generation, crises in the system occur [84]. Allowing EVs charging or discharging without any control technology causes voltage deviation and system disturbances, but when EVs are smartly charged/discharged, they achieved to support the power system [3]. Many studies have been concentrated on how to utilize V2G technology to help stabilize the system voltage and thus how to mitigate the EV influence on stability. Figure 6 shows a block diagram of power quality management in the grid depending on EV technology [83]. Mohamed *et al.* [89] introduced a study was performed to determine the most effective location of a weak bus and a strong bus, to assign a vehicle station within the specific grid based on the controller output that has been modified, considering bus voltage and EV state of charge (SOC). A fuzzy voltage-dependent controller (FLC) was designed to notice its effect on the power system regarding voltage stability when the controller was just dependent on the charging status of the EV's batteries or bus voltage [89].

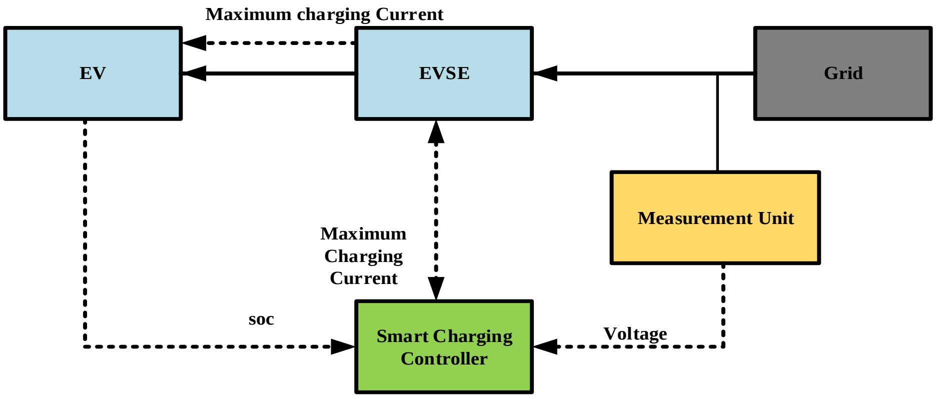

Figure 6. A block diagram of power quality management in the grid depending on EV technology [83]

Researches [42]–[44], [50], [90], [91] studied the methods used to take advantage of coordinated charge control of EVs to reduce their impact on system power quality. Increased system peak requirements, voltage stability limit violations, increased power system losses, and potential overloading of transformers, cables, and lines are among the identified network effects. An available EV charger was designed in Matlab to study EV chargers in and an inclusive harmonic analysis was performed in a low voltage distribution feeder. The feeder was influenced by different levels of EV penetration that charge at various load levels. From that study, it was shown that the system can bear up to 30% penetration of EV charger at normal load and up to 40% penetration of EV charger could be absorbed to the distribution feeder without exceeding system constraints. Karmaker *et al.* [43] the impact of EV charging stations on the distribution networks in Bangladesh was analyzed considering total power demand, voltage sag, voltage swell, harmonics, and transformer losses. The power quality disturbances were also analyzed to mitigate the negative influence of EV load. When EV chargers were integrated into the distribution system, the harmonic disturbances got higher. Thus, the THD of connecting one EV was about 4.82%, for three EVs about 12.35%, and for five EVs, and with various specifications, THD reached about 19.69% [43].

A coordinated charging was suggested in [44] to reduce power loss and increase the load factor. The optimum charging profile for PHEVs was calculated by reducing losses. Since it was not possible to accurately predict household loads, stochastic programming was presented in the study. quadratic and dynamic programming were the two main techniques that were analyzed. The power loss was rather negligible if the household load profiles were known. Results were obtained with the quadratic and dynamic programming techniques. The effect of EVs on a typical low-voltage network has been studied in [50]. A probabilistic approach was used to model the uncertainties associated with EVs behaviors and to assess charger location, times, and duration of charging. Two levels were used to penetrate EVs. Also, the study checked the usual days of the week in winter and summer for each level. Energy streams were run in half-hour time steps Sequentially for each of the four conditions. overheating of transformer, cable, voltage drops, and losses associated with each case were reported. Simulation results of a UK urban public grid model demonstrated that the transformer and ground cable serving 96 customers were significantly overburdened in terms of EV penetration levels. The high penetration level of EVs caused a voltage drop of less than 0.94 p.u. and increased energy loss [50].

A study of EVs charging effect on a low voltage (LV) distribution network in New Toshka city, Aswan, Egypt for different EV penetration levels (12.5%, 25%, 50%) was implemented in [90]. Two schemes of charging were investigated delayed and unsupervised charging. To conduct the study a power factor simulation software was utilized. The EV charging impact on loading transformer and cable, voltage stability at the end point in the system, and power loss were evaluated. The results showed that delayed charging has fewer effects on the low voltage network than uncontrolled charging.

A model of neighborhood electricity demand of ten houses was prepared in [91] depending on the home data, EV type, traveling miles, and time of leaving /arriving of EV. The study developed also a thermal model to determine the temperature of the hot spot and transformer life loss. The results showed that charging at type 1 (120 V) has little effect on transformer aging whereas charging at level 2 has a bad effect on the transformer as it failed because of overheating.

4.2. Voltage stabilization depending on EV control charging and discharging

Different components can be used to manage active energy including DGs, storage technologies, and programmable devices such as EVs and heat pumps. On the other hand, OLTC, capacitors, and static var compensation can be used to regulate reactive power. Several researchers have investigated the regulation of voltage stability using effective EV control based on conducting online tests of the regulated charging approach [92]. The goal was to increase the content of EV owners while keeping the distribution network restrictions in mind. Voltage drift, power loss, and transformer load were all reduced as a result of the method. Figure 7 shows a block diagram of a vehicle controller for voltage support [93].

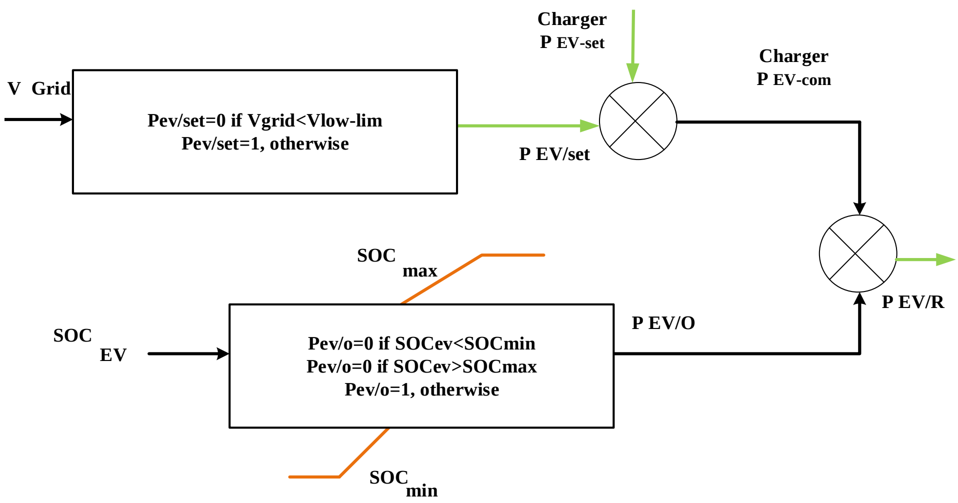

Figure 7. Voltage-controlled EV charging scheduled [93]

Nour *et al.* [94], proposed a decentralized/autonomous charge-control mechanism has been proposed. It suggested that, if the voltage was normal, EV charged at a rapid rate, but if the voltage was low, charging should be lowered or stopped. The power of charging was controlled depending on local voltage, battery SoC, while the charging precedence was given to EVs with lower SoC. In comparison to unregulated charging, the suggested approach decreased voltage loss and improved voltage profile. Mara *et al.* [95], suggested an EV-controlled charging technology was used to solve the problem of integrative voltage. A strategy to mitigate voltage spikes in feeders with PV, depending on a coordinated EV load as a storage system has been introduced. Results demonstrated the effectiveness of utilizing a coordinated EV load in feeders with PV to reduce voltage instability problems.

Another method for dependent voltage regulation of EVs is the use of capacitors in the DC link of bidirectional EV chargers to deliver reactive power. Even if the EV is disconnected to charge, the EV charger can accomplish this as illustrated in [96]. The EV bidirectional charger capacity was evaluated at type 1 to offer reactive power assistance. Therefore, the V2G process was illustrated by simulating various modes of operation the most important of which was the reactive power supply with/without PHEV battery charging. According to the findings, a DC jumper capacitor could offer reactive power support without any influence on the battery power system.

The direct voltage control method used in [53] to investigate the effect of the voltage according to the DC rapid charging of an EV in the low voltage distribution network during the condition of peak load.

The simulation displayed that the fast charging of six EVs pushed the grid to exceed the voltage constraints. Therefore, a two-way DC fast-charging station with a new control algorithm was proposed to solve the problem of voltage drop, manage the voltage and decrease power loss.

A technique for regulating voltage in the distribution network was suggested in [97], which depended on the coordination between EVs, DGs format, and OLTC to provide reactive power support operating in the V2G scheme. The suggested method has proven effectiveness in regulating voltage, reducing OLTC operation periods, and reducing system active loss.

From the results of the above review, unregulated charging of EVs can cause large voltage dips in networks, in addition to violating voltage permissible limits, particularly in long-distance charging in feeders. It also necessitates upgrading the network's infrastructure such as the installation of voltage regulators. However, by employing regulated charging and discharging methods, the voltage in all areas of the distribution network may be kept within constraints, and the voltage profile can be improved without the need for voltage regulators.

5. DISCUSSION

Normally, low and medium voltage networks provide low inertia. Therefore, its weakness is considerable effect on the frequency and voltage drift/stability. EV is one important key to overcome fast variation as well as violation of the voltage and frequency limits via its designed battery control. Many researchers have investigated the operation of regulated and unregulated grid connected EV. Unregulated EV with high capacity introduces frequency as well as voltage fluctuation with weak grid during its plug in and plug off. Therefore, regulated EV solves this problem and provides seamless connection with weak grid and improves the voltage profile and frequency change when other heavy loads interconnected with the grid. Many aspects have been investigated such as frequency control, voltage control, power quality, economic impact, cost and optimal control as well as its integration with conventional operation and control of EV. Moreover, investigation of grid connected EV limit with specific grids over the world considering its power electronics interfacing components as well as passive components and its effect on the overall grid power quality (especially voltage and frequency control) have been reviewed. Table 1 (in Appendix) gives most related research/contribution during last years for grid connected EVs with ancillary services.

Yet, investigation of EV integration with multi-bus weak grids and its optimal location in order to improve the voltage profile, losses and voltage long term stability are hot research areas. In addition, more exploration based on low level control of EV in order to improve its integration with very weak grid as well as increase virtually system inertia are running. Moreover, application of multi-object optimization techniques for multi-job grid connected EV during its charging/discharging mode as well as multi agent systems, hourly electricity-based bill price, load profile and weather/generation modes are good research points.

6. CONCLUSION

EVs introduce many advantages to the grid (V2G mode) and generate revenue for EV users. However, operation of EV with power grid faces many challenges issues and are need to be properly addressed. The objective of this paper is to announce and address the latest researches and their results of activities related to different aspects of grid support depending on EV. This paper reviewed the current state of design of EVs, including EV types, batteries used in EV technology, and charging modes. The recent researches explain the function of the EV as a catalyst in improving the power grid support, as the EV represents a load on the network and has harmful effects and faces challenges. It also has positive and effective impacts in improving the power grid voltage and frequency. In addition, this work reviewed recent literature regarding the impact of EV charging stations on the power grid and EV role in improving its voltage and frequency profile. The negative effects of uncontrolled EV charging stations on the grid such as voltage instability and frequency deviation have been clarified. Finally, this paper reviewed and analyzed the works on the positive effect of EV charging stations that are achieved by implementing controlled V2G technology. It can be concluded that grid connected EV can be used to improve many aspects of electrical network based on proper control of its own battery. However, proper design and optimization techniques are required in order to ensure life and cost of the battery, proper plug in/off of EV without violation of grid limits and finally optimal location of its connection with the grid. Therefore, research on integration such EVs with different new technologies into weak grids based on multi object optimization and/or intelligent control will be conducted.

APPENDIX

Table 1. Most related research/contribution during last years for grid connected EVs with ancillary services

Reference	Contribution	Scope
[37], [70], [71], [75], [76]	The primary frequency control (PFC) is employed to reduce fossil consumption, and control system inertial	Frequency regulation
[60]	The power network's inertia compensated load disruptions or imbalances induced by intermittent renewable sources while keeping frequency variations within acceptable ranges remains a challenge	
[62]	V2G control technique using proposed methodology for reducing the effect of EV on a 'weak' grid via frequency regulation is explored based on the control system of EV	
[63]	Supplementary Frequency Regulation (SFR) is utilized with V2G control approach considering both the control center organization and the SOC levels	
[36], [64], [65], [78], [80]	Based on financial control aspects, EVs charging/discharging costs is proposed.	
[58]	bi-directional V2G converter with two-stage for EV is used ignoring the SOC and battery age.	
[59], [67]–[69]	decentralized V2G control approach for best-integrated grid considering the battery SOC	
[13], [72], [73]	A control model (ACE) was instituted using PI controller for frequency stability enhancement to resolve the impacts of participating EV in secondary frequency regulation depended on ACE	
[75]	frequency control procedure to support PFC and decrease the cost of regulating frequency and degradation expense of battery for individual EV	
[81], [82]	Control of SOC with the revenue are employed for incentivizing cars to voluntarily connect V2G on their own	
[83]	Depending on a smart charging algorithm, EV impact is examined for reducing voltage instability	Effect of EV on power system quality
[48]	Voltage response of four various kinds of EVs is estimated	
[86]	Ultra-fast charging (UFC) technology considering traffic flow, and EV owner behavior is studied due to numerous economic and environmental considerations	
[9], [87]	voltage stabilization into the EV charging infrastructure is advantageous from a grid standpoint	
[50], [90], [91]	Effect of EVs on a typical low-voltage network studied with high penetration level of EVs which proved that there was a voltage drop of less than 0.94 p.u. and increased energy loss	
[89]	A fuzzy voltage-dependent controller (FLC) is evaluated to determine the most effective location of a weak bus and strong bus	Voltage support
[42]–[44], [50], [90], [91]	Coordinated charge control of EVs to reduce their impact on system power quality with 30% 30% penetration of EV charger at normal load	
[43]	Impact of EV charging stations on the distribution networks is studied considering total power demand, voltage sag, voltage swell, harmonics, and transformer losses	
[44]	A coordinated charging control is employed using quadratic and dynamic programming to reduce power loss and increase the load factor	
[92]	Voltage stability is regulated using effective EV control based on conducting online tests of the regulated charging approach	
[93]	voltage support Based on a vehicle controller keeping the distribution network restrictions in mind. Voltage drift, power loss, and transformer load	
[94]	A decentralized/autonomous charge-control mechanism is proposed with determining the charging manner.	
[53] [95]	voltage instability problems are reduced depending on EV-controlled charging technology	
[96]	A capacitor in the DC link of bidirectional EV chargers is used to deliver reactive power support without any influence on the battery power system	
[97]	voltage regulation with reducing OLTC operation periods, and reducing system active loss is achieved depending on the coordination between EVs, DGs format	

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