Overview of Electric Vehicle: Opportunities and Challenges with Smart Grid

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1 Introduction

EV uses electricity as a fuel and converts it into kinetic energy, which is required for running the vehicle. The electricity can be extracted either from a battery or renewable sources of energy. EV has many advantages such as high performance, high response, no noise, low maintenance and driving cost, highly safe, and there is no need of fuel tanks, carburetor, and smog controllers in them. EVs are not new, although they were around us since the 1800 s. At that time out of 4200 vehicles, 38% were EVs but due to low cost gasoline fuel, evolution, and development of electric starter for gasoline engine, the interest in EV declined. Gasoline vehicles are easy to operate due to electric starter which curb the need for hand crank for starting the engine and due to which most of the electric car manufacturer stopped their production [1]. EV has come into limelight due to the problem of environmental hazards related to the conventional vehicle. The first ever made EV was developed by 'Anyos Jedlik' in 1828. In early 1980s, EV activity again rose but with the development of plug-in hybrid EV (PHEV) and hybrid electric vehicles (HEV), the interest in pure EV again decline. In 2003, T (an automobile company) launched its first pure EV "Tesla roadster." Tesla overcome all the challenges of EV such as they use lithium-ion battery to power the vehicles, and the problem of short range is also overcome to some extent. Some issues related to EV development are: profit determination becomes uncertain considering the high capital cost and uncertainties in policies related to EV production. The government has made various comments about their thoughts for EV but nothing has been put down to policies. This discourages the investment industries. Cost of the EV is also an issue of concern [2]. There is a need for lowering the operating cost of the EVs by optimal usage of the renewable energy resource with the help of a microgrid. A

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O. H. Gupta and V. K. Sood (eds.), *Recent Advances in Power Systems*, Lecture Notes in Electrical Engineering 699, https://doi.org/10.1007/978-981-15-7994-3_14

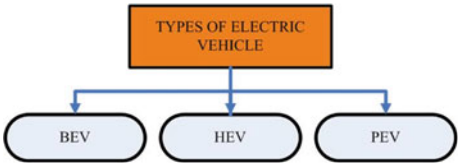

Fig. 1 Block diagram for types of EV

microgrid can extract information and be interfaced to technologies to manage loads [3]. The battery material made is quite expensive which hinders with the development rate of the EVs. The EV manufacturing unit must shift from mechanical to electronic component [4]. Since EV is a necessity these days and to overcome the problems mentioned above in manufacturing an EV, makes it the most researchable topic.

Lithium ion is the major ingredient for making the EV's battery. The main problem with EVs from the time of its development is that it has short range and choice of suitable propulsion motor [5]. Motor is a major component of EV which is going to replace the gasoline engines. Motor must possess high torque-to-inertia ratio, ruggedness, must be compact in size, convenience of control, low maintenance, and minimal cost. Several types of motor were used in EVs such as permanent magnet (PM), induction motor, switched reluctance motor, synchronous reluctance motor, etc. Some of the major factors for the choice of induction motor are its performance and efficiency. Induction motor can also be used as a generator for regenerative action which will help in recovering some of the lost energy and therefore increasing the range of EV per charge.

As far as EV is concerned, it is mainly of three types as shown in Fig. 1: (1) Battery electric vehicles (BEV) in which the batteries need to be charged again by removing from the vehicle. (2) Hybrid electric vehicles (HEV) in which the batteries are charged with the help of either regenerative braking or internal combustion engine. (3) Plug-in EV (PEV) in which the batteries are charged by direct plugging [6, 7]. Basically, both direct current and alternating current can be used to recharge the batteries. When the direct current is used, there is no need of an external charger as no conversion is required whereas when the batteries are charged by alternating current, then an external charger is required for conversion of the alternating current into direct current. Thus, EV can be used to reduce the per mile cost incurred [5].

2 Components of EV

The different components of EV are shown in Fig. 2. The detail findings of the main components are as follows:

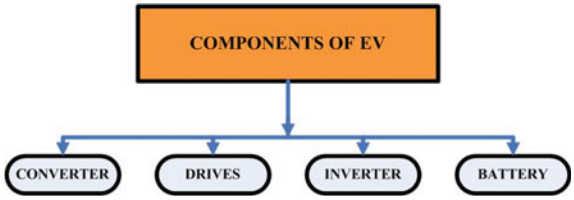

Fig. 2 Block diagram for components of EV

2.1 Converter

The designing of converters is one of the major issues in manufacturing of EV to ensure safety of the passengers. Its major use is to regulate circulation of power between battery and drives. EV can have both DC–AC and DC–DC converters. DC–AC converters are majorly used to power electric drives and other basic components such as air conditioners whereas DC–DC converters are used to supply low voltages in the electric vehicle. DC–DC converters can be soft switched or hard switched whereas they can also be classified on the basis of direction of power circulation, which implies they can be either bidirectional or unidirectional in nature. The switches used in these converters are either IGBT's or MOSFET's. The battery supplies power to the DC–DC converter which converts unregulated DC to regulated DC which then supplies power to the inverter that transforms DC into AC and that AC supply powers to the electric drives or motors of the electric vehicle [8].

2.2 Electrical Machines and Drives

Electrical machines and drives is one of the most important units of electric vehicles. The basic characteristics of these machines required in electric vehicles are high torque, higher power density, higher efficiency, high maximum speed capability, less noise, and low torque ripple. The typical machines required for traction purpose are induction machines (IM), brushless dc machines, and switched reluctance machines (SRMs) [9–17].

2.3 Inverter

Inverter is a device which converts DC to AC. An inverter can be a current source inverter or a voltage source inverter. A 3-phase VSI at 180° conduction mode is preferred. A 3-phase VSI inverter has 3 bridge networks each bridge containing apair of power MOSFET each. Now, why did we used MOSFET and why not BJT since MOSFET performs fast switching as compared to the BJT switching and losses are also less when both are compared. MOSFET can work on wide frequency range. The

DC supply is provided with the help of 12 V lithium batteries and the firing angle of the H-bridged inverter is controlled using peripheral interface controller which provides a proper ON–OFF duration to individual switches so that 180 degree conduction can be achieved. A capacitor is also connected across the branches so as to reduce the harmonics and a diode generally called a freewheeling diode is also connected across the branch. There are various methods for the control of output voltage of a VSI which are pulse width modulation control (PWM), space vector modulation control (SVM), phase displacement control, etc. Nowadays, the DC motors which control the wheels of the EV are directly connected through the converters, though this increases the complexity of the converters but gives a good performance [18].

2.4 Battery

Battery acts as a fuel for EVs. One of the major problems regarding the implementation of EV is its cost and the size of the battery required. The various types of batteries used are Lithium–nickel–cobalt, Lithium–iron–phosphate, Lithium air, Lithium titanate, Lithium-ion battery, Lithium–sulfur [19]. Nowadays, Lithium-ion (Li-ion) battery is the best choice among all rechargeable batteries, as it possesses high energy density, high range, lower self-discharge rate, longer life span, and efficient charging properties [20, 21]. Battery is a key component of an EV but their designing is more challenging as it is based on their chemical composition. Battery can also be destructive in nature due to thermal runaway and may catch fire both externally and internally. Therefore, it is important to wisely choose or design a battery for the safety of consumers [22–28].

3 Interaction of EV with Smart Grid

EV is an attracting concept to lower down the CO_2 emissions but it has also increased the load on grid by extracting power to get charged. So, there is a great need of renewable energy sources to mitigate power deficit issue and to increase the ratio of clean energy. There are great chances of randomness and intermittency of renewable energy sources [29].

There are various feasible networks of integrated technology such as DC, AC, and hybrid microgrid. The DC is most advantageous in respect to cost and efficiency as it requires least number of power electronics converters between renewable energy sources (RES) and DC bus. Also, no interference of harmonics would exist. A special DC microgrid based on PV has been designed which provides multiple ports for charging PHEV and HEV [30].

The AC microgrid is almost same as DC one except the fact that it requires more power electronic converters to provide final DC supply to the EV. The greatest advantage of an AC microgrid is V2G and this power reversal could be controlled through a switch at the point of common coupling (PCC).

The hybrid system utilizes the advantages of both AC and DC. The DC part provides fast charging whereas AC part provides with V2G. A smart charging method for EV is proposed which gets connected to both DC and AC [31]. However, this proposed scheme may have many disadvantages too, to mitigate it; the idea of vehicle-to-grid (V2G) was developed. V2G technology controls and manages EV loads via aggregators and by communication between vehicle and grid. The classifications of V2G are:

Unidirectional V2G: It controls the charging rate of EV which helps in preventing overloading of grids, fixing the overvoltage issue, and keeping the system stable. It exploits the communication between EV and the grid operators to perform this task. Spinning reserves is one of the main services provided by unidirectional V2G. Spinning reserve is additional power that is available due to increased power output of generators connected to the power system itself.

Bidirectional V2G: It allows power flow in both directions, i.e., it provides EV charging as well as grid support. Its major benefit is that it provides much more pliability for power transfer to regulate the energy of the battery so that it improves the reliability and power system sustainability. The major benefits that bidirectional V2G provides are: active and reactive power assistance, load leveling, power factor correction, it filters harmonics, controls frequency, provides the integration of RES with the power grid, etc. The bidirectional charger works as an active power filter [32]. It works either way, i.e., charger the battery via grid and transfers the power to grid when needed. The majority of modes of operation of battery chargers these days in smart grids and homes are discussed in [33]. Bidirectional V2G uses AC–DC and DC–DC converter to function. AC–DC converter converts AC power from the grid to usable DC power for charging of battery. Similarly, DC–AC conversion is required during energy transfer from vehicle to grid. Buck or boosts DC–DC converters are used during charging and discharging, respectively.

Challenges in V2G:

A. Degradation of battery

Due to frequent charging and discarding, battery quality gets degraded the most, although there are other factors like depth of discharge (DOD), temperature, and voltages.

B. Investment cost

Since two ways approach is required in bidirectional power flow, it requires more equipment to accomplish the task of power transfer. As the complexity of the structure increases, so does its cost. Social barriers: The presence of large number of EV owner is a must in V2G technology. Since the EV technology is not mature yet, there is less number of owners which proves to be a social barrier.

C. Optimization objectives

- Operation cost. The main aim is operating cost minimization.
- CO_2 emission. This too has to be minimized.
- Profit for V2G technique. There is a need to maximize the ease of the users and power system aggregators using optimization techniques.V2G serves this purpose.
- Sustenance of renewable energy generation. EV acts as battery banks for renewable energy sources. They can provide energy to them in times of insufficient renewable energy. During the time of high energy generation, EVs can store energy from them. This way, EV gives an opportunity to have green energy around [34].

4 Opportunities and Challenges

On the basis of energy sources available, i.e., diesel, battery, gasoline, etc., and the devices of propulsion, i.e., motor and engine, all kinds of vehicles whether EV or any other internal combustion energy vehicle (ICEV), are basically classified as Battery EV, hybrid EV or fuel cell electric vehicle. Hybrid EV is further classified into plug-in HEV, range-extended EV. The plug-in HEV, battery EV, and range-extended EV are capable of getting charged directly from power grid, therefore, all these are called as grid EV or GEV.

4.1 Vehicle to Home (V2H)

V2H configuration uses lead acid or Li-ion battery. This system is supported by reactive power with bidirectional charger capacitor. A single GEV can only be appointed for a single house. It is the simplest and least flexible of the three concepts and very easily installed with simple infrastructure requirements and negligible transmission losses. V2H EV acts as a home backup generator and cooperates with domestic electrical devices for load shift. Most of the time, EV's are parked at parking lots, with the help of bidirectional charger and controller EVs can used to deliver the stored energy to the building to reduce the high demand and EVs can be charged by taking supply from the building during low demand according to the necessary [35, 36]. Considering the power electronics for V2H, single-phase AC–DC converter is used for GEV on board charger. They provide reactive power support with capacitors [37–39]. This will help to reduce the electricity bills because during the peak load, when load demand is high, the distribution companies charges high price as compared to price during low load demand because sometimes, the distribution company had to brought electricity at high price to fulfill the load demands [40].

4.2 Vehicle to Vehicle (V2V)

This configuration is supported by bidirectional charger capacitor. It is a convenient but less pliable configuration due to small transmission losses. It acts as an energy source to other local GEVs. It reduces tariff by trading with local grid. Single-phase current or voltage source converter is used in V2V scheme. This configuration is flexible in power transferring between the chargers within the GEVs.

5 Charging Station

There are two kinds of charging station one is the slow charging station which is generally used for residential purposes and the other one is the fast charging stations which are used during emergencies [41]. Moreover, charging station must be at a place where it is easily accessible and a power grid close to its proximities will be very appreciable. Taking into account the users interest such as outside a mall or a restaurant or at any parking area will make it convenient for the user to charge their vehicle while they are busy with their own interest.

Now let us analyze the effect of fast charging station on the distribution system, talking about the load density, it is seen that there is a nominal increase in the load density which is quite less than the other installed loads in the system. To dismiss the possibility of overloading in the transmission line, a possible strategy must be implemented which leads the EV owner to charge their vehicle at low load density areas, and the results shows that there is no overloading if we follow this trend. The apparent power flow in a distribution system is toward the place where the power consumption is more as compared to the other places. The study shows that the places not having fast charging station do not report a significant change in the apparent power whereas the places having a fast charging station draw the apparent power from the neighboring feeders. Now taking into account the voltage drop and it is noticed that only few percentage increases is observed up to 0.2%. The main factor that must be taken into account is the effect on the harmonic distortion which mainly tells us the quality of power that is being supplied. Total harmonic distortion (THD) factor for the voltage is likely to increase by 1–2% and the distortion of current from its fundamental value is under acceptable range as proposed by the IEEE standard 519-2014 [42].

5.1 Smart Charging

First of all, why do we need SCMA (smart charging management algorithms)? It is because our fossil fuels are depleting, we have a storage problem and due to environment degradation and to all this, we have only one solution EV. So, there is a need for a SCMA for improving its efficiency. Power grid is affected because of uncontrolled charging time. Moreover, control of 1000 s EVs at one time will be a challenge and that too when we are unaware of the charging habits of the consumer. The SCMA model proposed has various benefits; it not only provides the driver the most effective path to reach the nearest parking lot or a charging station (CS) but also reduces time and money of the driver and the problem of congestion on the roads and CS.

The proposed model also helps in reducing the peak power and voltage drop. First of all, we need to have a clear view of all the components of the model such as workplace, charging station, EV, and distribution system of the place under observation. Workplaces like campus where there are a lot of parking lots are very best places to start the observations such as the driving habits of the people. Distribution system of that area taking into account the number of transformers connected to supply the whole workplace. An EV present in the area is also important to note as the type of EV and the driver's behavior will decide the amount of load that it would exert on our system. Recharging is the main problem; this strategy helps in suggesting the best possible route to reach the CS. There are some objectives which the consumer must follow and some prerequisites which the system must get before proposing a model. According to the transformer loading rate, the strategy and the optimum path proposed can change to decrease the voltage drop of the system. Connecting vehicle to grid is also a very good option as their will be no unbalancing at any point of time [43].

Due to short range and large recharging time of EV, there is need for the fast charging stations. We know that it is impossible to charge the batteries alike that of filling the tanks of oil-based vehicles with the present technology but with DC fast charging, it possible to boost the battery level from 0 to 80% of a 39 kWh battery pack in 57 min. This paper demonstrates the consequences of DC fast charging station for an EV [44]. Basically, DC fast charging stations connect the EV to the grid via a charger to charge the batteries. Power electronic devices such as IGBT, Thyristor, and MOSFET are used in inverter units for AC to variable DC conversion for the EV charging. The major problem faced by the EV consumer is the lack of infrastructure of EV stations. The same problem was faced in case of oil-based vehicles at the starting. Although, number of EVs are on roads have increased but there are only few recharging stations.

Apart from charging stations, charging is also a major concern. The new launched Hyundai 'Kona' takes about 1 h to charge up to 80% with DC fast charging station. Therefore, we need station where up to 8–10 vehicles can be charged simultaneously without affecting the main grid.

5.2 Solar-Powered Electric Vehicle

EV has not become an acceptable solution due to its short range and large recharging time. For improving driving range of EV, we require a high energy density battery with less weight. Till date, we have Lithium-ion battery which are fulfilling requirement but their charging time is large. These problems of EV can be overcome to some extent by using solar power. Basically, an EV completely or partially powered by direct solar energy by using solar panel is known as the solar vehicle, by using photovoltaic cells in solar array which converts the sun light directly into electrical energy [45]. Many cities in India has good solar electrical potential, so we can use solar energy to recharge Lithium-ion batteries of EV which eliminate the time required for charging at workplace or EV charging stations. The existing solar panel which can be mounted on the top of vehicle has a capacity to produce 125 W per hour. At least 3 solar panels can be used with the existing dimension of EV [46]. As we know solar power produced by solar panels are DC which can be directly stored in batteries which will result in a large range per charge. Solar energy can also be used to charge EV with Solar Edge inverter integrated EV charger which allows fast charging as compared to level 1 charger (Household charger). Basically it is an EV charger that is integrated with an inverter. This charger combines the DC power provided by the solar panel and the AC power by the grid which results in fast charging and further reducing the electricity bills. EV level 1 charger adds 5 miles in 1 h but by using Solar Edge inverter integrated EV charger, we can charge 25–30 miles in 1 h which is more effective. Therefore, EV owner can charge 6 times faster than the standard level 1 charger [47].

It uses single-phase inverter for converting DC power from the solar panel to AC power and combines it with the AC power from the grid. It is the most economical, simpler, and reliable method [48]. Can really the EV have a positive impact on the Economics of Electric Energy Usage?

"TIME OF USE" policy [49] is used by several companies. This policy changes the price of the electricity as per usage of it during the day. The price of electricity rises when its demand is at peak whereas it reduces when the demand is low.

5.3 Future Trends

Charging time is also a vital factor while considering for implementation of EV. The e-rickshaw launched by Mjindal Group [50] also known as "SHAGUN" takes about 6 h to charge and gives a mileage of 90 km. The major cost of the vehicle is covered by the battery. About 50–60% of the quoted price includes just the battery. So, one solution to the problem is that battery size should be reduced. But if the battery size is reduced, the mileage of the EV would further reduce thus making the condition worse of long distance travels. But if the vehicle is charged while it is moving, then the battery size can be reduced without compromising with the mileage. The concept of wireless charging comes from smart phones which use electromagnetic induction to charge. Similarly, here, the load is the vehicle which is in motion. A metal plate named power track [51] is laid on the road which has coils beneath it. The power track is connected to an inverter which turns ON only when a vehicle passes over it. As the vehicle passes over the power track, the battery is charged due to electromagnetic induction. These tracks can be laid at equal distances thus the battery gets charged while the vehicle is not idle. Thus there is no need of using battery with high rating. This can lead to more economical and convenient way of implementing an EV. The vehicles need not to be charged for long hours continuously thus reducing the impact on supply grid. As compared to conventional vehicle, the EV charged by wireless charger would be more cost effective and cheaper. This could lead to a reduction in the price of the EV.

6 Conclusions

EV is the major means of transportation for tomorrow. The future demands a large-scale development of EV and as per the present scenario, it is going to be an inevitable trend. In this paper, there are various types of EVs discussed. The characteristics, design requirements, and control schemes of battery, inverter, and converter and various machines and drives have been reviewed. Also, the upcoming technology of power exchange between grid and vehicle is highlighted. EV and its integration with grid are long-term goal which is quite beneficial for the environment as well as to the grid itself but it requires government support, power utilities to make it happen. Also, mathematical analysis regarding performance of EV is required to observe its challenges to integrate with the grid.

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