Study of xEV Charging Infrastructure and the Role of Microgrid and Smart Grid in its Development

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\textbf{ABSTRACT}

With galloping energy demands and limited energy resources, it is imperative to look for alternate energy resources to fuel vehicles. This will lessen greenhouse gas (GHG) emissions. In automobile industry, electricity is the clean fuel which will increase the demand for electric vehicles. In tune with reduction of carbon footprint, different technologies are being tried out to lessen gaseous and particulate matter emission. Due to these factors, automobile manufacturers are concentrating on electric vehicles which mainly depend on batteries, fuel cells and modified gasoline engines (either standalone or hybrid). Microgrid has emerged as a new field which can meet the energy demand of sensitive loads as well as the charging demand of electric vehicles with special emphasis on good power quality, reliability and security. Conventional methods of power generation cause high environmental pollution which can be reduce using renewable energy resources. A microgrid thus can contribute to sustainable and environmental friendly alternative with integration of distributed power generation in the renewable sector. This paper discusses major aspects of electric vehicles and microgrids covering extensive survey.

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1. Introduction

Nowadays, metropolitan areas are continuously facing the issues of pollution and GHG emissions \citep{1}. xEVs are gaining much focus in recent time because of growing concerns toward environmental responsibilities and fossil fuel limitations \citep{2–5}. Electric vehicles (EVs) and the sharing of EVs have the capability to provide a solution to many of these problems \citep{6}. Two major issues that hurdle the commercialization of electric vehicles are the high cost associated with large battery packs and the estimation of the energy storage capacity \citep{7,8}. In \citep{9} R. Shankar and J. Marco propose an approach based on Neural Network to calculate per km energy consumption of the electric vehicle under different scenarios.

Short cruising range and the limited infrastructural support are the two major reasons of restricting the development of EVs. Through navigation system and route planning approaches, the cruising range of EVs can be extended and these approaches provide the information of energy-efficient routes and the recharging requirement to the driver. Nowadays, the subject of eco-driving analysis is of great interest which focuses on how to drive in an economical and ecological way. According to eco-driving analysis, drivers try to maintain a steady-state velocity and try to avoid unnecessary use of acceleration (or deceleration). Vehicles, drivers, and infrastructure are all linked together through eco-driving. 10–15\% of savings in energy are possible with the help of eco-driving.
include various components like compressors, valves, fuel injectors, and pumps, which make them complex in operation. Other favorable factors of EVs are: no hoses or belts to replace, no filters, no need to change oil, and no need of water cooling system [12].

The question arises if EVs are so good then why did not the EVs come over long ago? The answer to this question mainly depends on three reasons: (i) on a single charge, EVs cannot cover much distance as compared to ICVs which can go on a fuel tank. (ii) EVs take much more time to charge a battery than ICVs to fill a gas tank. (iii) Also, cost of EVs is more than ICVs.

G. Graditi et al. present a methodology, which includes environmental and economic indicators to evaluate an operating cost of EVs and ICVs [2].

Accurate and reliable estimation of residual range is very important. Residual range can be defined as a distance that can be covered by the vehicle with the energy stored in the battery. The estimation of residual range is a two-stage process: firstly remaining battery energy is estimated and then to combine it with the vehicle efficiency estimate, i.e. the distance covered per battery kW-hr. In [13] M. Ceraolo and G. Pedeln discuss this concept in detail.

Study by an Electric Power Research Institute clearly shows that the replacement of Internal Combustion Vehicle by an electrically powered equivalent not only reduces air pollution where EV is driven, but also over the rest part of the map. This happens because of two main reasons: (i) It is better to use electricity from hydroelectric plants and nuclear reactor which are non-air polluting sources as compared to the transportation sector which is completely powered by petroleum products. (ii) A fossil fuel can be burnt by electric utilities in a more efficient and clean way than internal combustion engines [12].

Reduction in air pollution by switching over to the EVs varies from pollutant to pollutant. For example, carbon monoxide would disappear completely while reduction in sulfur dioxide, nitrogen oxide, and carbon dioxide depends on regional scenarios of generation and politics.

Several factors that favor EVs over ICVs are that they are quieter, more reliable, and require less maintenance. Electric motors are simpler in operation than internal combustion engines because they are controlled by solid-state electronics, whereas internal combustion engines have various components like compressors, valves, fuel injectors, and pumps, which make them complex in operation. Other favorable factors of EVs are: no hoses or belts to replace, no filters, no need to change oil, and no need of water cooling system [12].

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The intelligent and effective use of energy is possible through smart grid by optimized integration of vehicle with the grid. Several energy and environmental problems can be solved out with the help of Grid Enabled Vehicles (GEV). However, before this, various challenges like EV range, infrastructure, cost, charging access, and impact to the grid must be addressed to achieve the potential of GEVs. A. G. Boulanger discusses these challenges in a detailed way [5].

Hybrid electric vehicles (HEVs) mostly use Energy Storage System (ESS) as a secondary power source, but if it is used as a primary power source then size of the ESS would be the most important criteria in the design of HEVs. In addition to this, an intelligent strategy of energy management is required by HEVs in order to provide the best fuel efficiency in all the possible driving situations. The effect of the variation in size of the ESS on

![Figure 1. Energy management controller in the vehicle.](image-url)
the economy of fuel and the important design criteria of ESS is investigated by D. Somayajula et al. in reference [6].

Although electric vehicles have been the point of interest and focus for various stakeholders and industrialists since last two centuries, EVs started becoming popular from the beginning of twenty-first century. Figure 2 represents the evolution of electric vehicles.

2. xEVs Classification

In transport sector, xEVs (where xEVs can be categorized into various classes such as EVs, Battery Electric Vehicles (BEVs), Fuel Cell Hybrid Vehicles (FCHVs), HEVs, and Plug-in Hybrid Electric Vehicles (PHEVs)) are very favorable in reducing environmental impact by reducing GHG emissions and other air polluting emissions. The fuel cost can be set to zero using renewable energy resources for charging purpose or with on-board electricity generating operation [14].

In EVs either one or more than one electric motors are used for traction. Due to lack of infrastructure for battery charging, longer charging times, limited driving range, and shortfall in performance, they are not in much demand [15].

In BEVs, both electric machines and batteries are used to propel. They seem to provide an ideal solution for the issues related to global warming and energy crisis. Disadvantages associated with BEVs are that they take long time for charging and cover short distances [16].

Due to undeveloped technology and lack of availability of desired infrastructure, FCHVs are not ready for mass production in few coming years.

In the last few years, HEVs are gaining much attention as they do not necessarily require any new or external battery charging infrastructure. They have the capability to provide lower emissions, enhanced fuel economy, and better performance. In HEVs, both electric motor and Internal Combustion Engine (ICE) are used. More specifically, electric motors are used at low speeds and ICE is used at high speeds, for both propulsion and battery charging. The general diagram of propulsion power fluxes of the majority of HEVs is as shown in Figure 3.

HEVs can be categorized into three types: (i) the series hybrid system, (ii) the parallel hybrid system, and more recent type (iii) the power split hybrid system. Power split hybrid system has the advantages of both series and parallel type hybrid systems without compromising the cost effectiveness of the hybrid system [4,17]. The simplest architecture of configuration and control system of series, parallel, and power-split-type HEVs is shown in Figure 4(a)–(c), respectively.

PHEVs are very similar to HEVs, but PHEVs also include internal battery packs which are rechargeable from some external source in order to increase mileage of the vehicle. Competitiveness of PHEVs is increasing by enhancing the driving distance on electricity and by the reduction in battery cost. The energy capacity of the ESS module used in PHEVs is less than the ESS module used in EVs but larger than HEVs. PHEVs also have better fuel economy than HEVs. When the State of Charge (SOC) of a battery is high, then PHEVs run on electricity but when SOC is low, the ICE takes over and PHEVs run on gasoline.
When these vehicles are parked or plugged-in then they can be used as a Distributed Energy Storage (DES) unit to serve the grid. When the demand of electricity is low i.e. during the night time, PHEVs can be recharged, and when the demand of energy is high i.e. in the afternoon then they can be used as DES units. In this way, PHEVs can help in the peak load shaving of the grid [6]. Other benefits like reduction in total cost of charging, mitigating the variability and intermittency caused by renewable energy generation can also be achieved using coordinated dispatch approach [18].

Prediction of PHEV charging load profile (PCLP) which can be defined as the total electricity demanded by PHEVs at any given time in a specific region is a very basic requirement to know about how a power system will respond to PHEVs. Various impacts of grids such as power losses, overloading, electricity market, generation rate, transformers, and power system utilization, cables can be analyzed with the help of PCLP. It is also helpful to analyze the effect of PHEVs on GHG emissions. Based on the additional load and its time distribution, PCLP is helpful in analyzing the emissions of marginal power plant like natural gas fired and coal fired plants. Data based on the type and number of PHEVs, their all-electric range, miles driven daily, and the driving patterns are the basic requirements to calculate the PCLP whereas charging...
level and charging start times are the factors that affect the PCLP [19].

After considering the related opportunities of charging including flexible recharging due to sensitivity of charging price, type of trip, duration of trip, and consumption during trip, P. Grahn et al. developed a model based on Markov chain to simulate the detailed mobility behavior of PHEVs [20].

Degradation in power quality, violation of voltage limits, energy losses, and network reinforcement are the major concerns of electrical grid operator due to high penetration of PEVs in electrical grid. These negative effects can be overcome if the PEVs charging behavior are properly controlled or regulated.

3. Charging Levels and Standards

EV chargers can be classified on the basis of power rating. Operating voltage and connector specifications are also described by it. In Table 1, basic standards commonly used for EV chargers are tabulated [21,22].

Different types of charging levels as well as their respective range of power are as follows: (i) Level 1 charging: 120-volt AC, single phase power, maximum of 16 amps current, and 2 kW of power is used to charge on-board charger of EVs. Connectors such as NEMA 5-15, SAEJ1772 are generally used by this type of chargers. (ii) Level 2 charging: 240-volt AC, single phase power, maximum of 12–80 amp current, and 2.9–19.2 kW of power is used to charge EVs in this category. IEC 62196, IEC 60309, SAEJ1772, IEC 62198-2-Mennekes, and 62198-2-Scare connectors are generally used by this type of chargers. (iii) Level 3 AC charging: In this type 400 volt, three-phase AC power is converted into DC and then this power is directly supplied to charge EVs. Maximum of 400 amps current and 240 kW of power can be supplied by this type of charger. Connectors which are generally used in this type are SAE J 1772 Combo, CHAdeMO, and IEC 62196 Mennekes Combo.

4. Energy Storage Systems (ESS)

Those technologies which are environment-friendly and more efficient are being preferred nowadays due to change in mindset of the people who preferred advance technologies in comparison to existing cheaper and conventional technology. In order to achieve this goal, it is necessary to minimize the use of hydrocarbons for electricity generation and transportation sector. More focus is being given to the generation of electricity through renewable energy resources such as photovoltaic arrays and wind turbines. Some issues like system reliability, stability, and power quality may arise due to the intermittent nature of these renewable energy resources and also owing to variable and unpredictable nature of renewable sources. These issues can be handled by introducing ESS for meeting the demand of the system since ESS can provide ancillary services to the grid to handle power quality issues. To avoid peak demand, use of expensive generators during peak times and to reshape the load curves, use of ESS are quite useful. To stabilize the power output, large capacities ESS are generally used along with renewable energy resources [23,24]. S. Vazquez et al. in [25] give a detailed description on ESS and storage technologies used in grid applications and transport sectors.

To reduce the cost of manufacturing, harmful gas emissions and to enhance fuel economy, optimization of ESS is very important. Objective function and constraints are the two parts related to the optimization problem of ESS. Objective function mainly deals with the cost associated with storage devices, volume/weight of the system, and fuel consumption whereas constraints deal with the range of driving, acceleration/deceleration of vehicle, and with other variable limitations such as SOC, current, voltage, and power [26].

Different types of technologies are available to store electrical energy, one of the most promising of which is batteries. Batteries are favorable as compared to other storage technologies because they have fast response time (in milliseconds). Due to this, they are quite useful in the cases where the curves of production or load change rapidly. Various factors such as number of cycles, the amount of current through which battery is charged or discharged, temperature, and the depth of discharge (DoD) are responsible for the degradation of a battery [27].

Through inclusion of batteries, EVs can achieve high performance and good trade-off between ‘high reliability’

| Standards        | Description                                                                 |
|------------------|-----------------------------------------------------------------------------|
| IEC 62196        | Plugs, Socket outlets, Vehicle couplers and Vehicle inlets – Conductive charging of electric vehicles |
| IEC 61851        | On-board and Off-board equipment for charging electric vehicles               |
| SAE J2293        | Energy transfer system for electric vehicles                                 |
| SAE J2836        | Recommended practise for communication between plug-in vehicles and utility grid |
| SAE J1772        | Electric vehicle conductive charge coupler                                   |
| SAE J1773        | Electric vehicle inductively coupled charging                               |
| IEEE 1547.3      | Interconnected distributed resources with electric power systems             |
| CHAdeMO JAPAN    | DC fast charging standard                                                    |
| NEC 625 U.S.A.   | Electric vehicle charging system                                             |
and ‘drive performance.’ Drive performance deals with output power and vehicle autonomy whereas high reliability is associated with a maintenance free, longer lifetime, high level of safety, and energy regeneration capabilities. In order to obtain these two factors, an ideal battery for an EV system should include the following characteristics: high efficiency of charge and discharge, high-power output and energy density, long life, low internal resistance, low cost, high degree of reliability and safety, low cost, fast charging, good recycle ability, minimal self-discharge, no memory effects, good load characteristics, and high-temperature range. Cycle life of battery reduces by over discharging and over charging. Very accurate monitoring circuit for cell voltage is required in order to prevent from overcharging when the battery is fully charged. If the overcharge threshold is too high, then the battery may get damaged by overcharging and when it is too low then the battery will be prevented from being completely charged. To maximize energy storage, charge equalization of every cell of a battery is required [28,29].

Most of the customers are not interested in purchasing EVs, due to some battery limitations such as long charging times, limited range, accurate prediction of battery SOC, and high cost of replacement [30]. An undesirable factor associated with battery is long charging times, which can be avoided with the help of battery swapping stations (BSS) [31,32]. Some of the favorable energy storage technologies which can be used in the application of EVs are described here as follows.

4.1. Lithium-ion

Due to unique characteristics of Li-ion batteries such as high-energy density, low rate of self-discharge, high cell voltage, and due to no memory effect, the Li-ion batteries are gaining much attention nowadays [28]. Overcharging and over discharging of the Li-ion cells is a major safety issue and may cause irreversible damage. That is why a reliable monitoring for each cell voltage is required. Figure 5 shows a range in between the charging voltage limit (CVL) and discharging voltage limit (DVL) where the cell of Li-ion can be operated. Shaded area in the figure shows a restricted area where the cell voltage must not be entered [33]. Steep energy demands, low cost, and long lifetime of ESS which is very much required in the applications of vehicular propulsion have yet not been able to meet by the Li-ion batteries. Power electronic-based battery cell voltage equalizer deals with various issues and provides smarter solutions and finally improves the calendar life, cycle life, power and safety of batteries [30,34].

4.2. Fuel-Cell

Zero emission is very advantageous which we can get by the use of EVs but the commercialization of EVs is restricted by the energy storage problems. FCs can be considered as one of the promising solution related to the energy storage problems in EVs. Due to their cost effectiveness and enhancing reliability, FCs are being used more and more [35]. FCs are electrochemical conversion devices that produce electricity directly by oxidizing hydrogen. Based on electrolyte type and operating temperature, FCs can be categorized into several classes. Most types of FCs may not be suitable for automotive purposes because they operate at high range of temperatures, which may be difficult to handle as in the case of molten salts and phosphoric acid. Whereas FCs based on proton exchange membrane (PEM) types are suitable for vehicular applications. They are easy to handle and safe in manufacturing and later use, operate at 80 °C and use thin plastic sheet as electrolyte. High conversion efficiency, fast start-up, low emissions, fast response to transients, and similar performance and range as compared to ICE are some of the advantages of PEM fuel cells [36]. In contrast to storing energy as in batteries, FCs generate and deliver electrical energy as long as fuel supply is maintained. Due to some limitations of FCs such as high-cost per watt, slow rate of power transfer in transitory situations and low efficiency during low load demands, FCs are never used alone in the electric hybrid vehicles (EHVs) especially during transient and start-up events [37].
4.3. Ultra-capacitors

In contrast to batteries, ultra-capacitors have higher power density (approx. 10–100 times larger than that of battery), longer lifespan (approx. 10 years more), causing less chances of pollution but have much smaller energy density as compared to batteries [38].

High-power density and high-energy density can be obtained using flywheel storage system. Other advantages are higher charging/discharging rate and longer life span with no maintenance. But due to its complicated structure and unfavorable dimension, it is only suitable for the applications that have a suitable room to place it such as in the case of railway applications. In contrast, ultra-capacitor has flexible dimensions for energy storage and allows an easy adaptation to different power ranges, voltages, and installed energy content just by adjusting the number of parallel and series connected ultra-capacitor. The principle of storage in batteries and flywheel is based on transformation of energy whereas in ultra-capacitors it is purely based on electrical and achieves low maintenance cost due to high cycling load capability. Ultra-capacitors are also more efficient, provide peak power and energy storage by regenerative braking. Due to all these reasons, many researchers try to use ultra-capacitors in various HEVs applications [39,40].

4.4. Hybrid Energy Storage System

There are some challenges associated with every ESS so the best way is to combine these storage technologies in order to achieve desirable results. Many available literatures justify this approach.

There are two energy storage devices involved in most of the HEVs: (i) Main energy system (MES) and (ii) Auxiliary energy system (AES). MES deals with high capability of energy storage and provides an extended range of driving, whereas AES deals with high-power capability and reversibility and provides good acceleration and regenerative braking.

If two energy sources: batteries and ultra-capacitors are combined in parallel then the merits of battery such as high-energy density, capability to store energy in mass amounts, and merits of ultra-capacitor such as high-power density, capability to supply large burst of current can be obtained. This results in a light, small, and high-performance system which also provides the desired characteristic of the peak current and the storage availability [41–46]. To provide peak power during transients such as acceleration, start-up, sudden load changes, and to get the advantage of regenerative braking in EVs, a supercapacitor is required along with FCs [47]. A combination of bank of batteries, supercapacitors, and FCs is taken in [37,48–51] for reducing mass and volume of the electrical hybrid power source due to high power and energy density of the supercapacitor and battery is utilized, respectively. In [52,53], UCs and Li-ion batteries are considered for the latest EV application.

5. Existing xEV Charging Technologies

EVs are charged from electric grid supply. However, the advantage of no emission of EVs would be lost if the regional grid supply is fed mainly from coal-based thermal power plants. Moreover, wide use of EVs would require capacity expansion in generation, transmission, and distribution to meet charging needs. This calls for more investment. This can be mitigated to some extent using solar Photovoltaic (PV) system thereby reducing emission. Also, integration of solar PV system with EVs would not only reduce dependence on ESS required for PV, but also reduce dependence on grid supply. In order to develop infrastructure to charge EVs in short time, BSS can provide automated system to replace exhausted batteries with fully charged ones [54]. Integration of BSS into PV system would encourage development of EVs due to the environmental benefits offered by solar PV system. Nian Liu et al. [55] developed a new strategy for EV charging based on PV and BSS.

Free availability of solar energy has led to the development of PV technologies. These PV cells assembled as a module can provide energy supply to EVs either on-board or off-board mode. Off board can provide energy for charging of EVs in a charging station while an on-board mode, PV modules are mounted on vehicle for direct propulsion or can be used for some other vehicle application [56].

M. Abdelhamid et al. developed strategies for evaluation and selection of optimum commercial PV module for on-board EVs application. Authors have proposed constraints, evaluation factors and criteria of decision-making to determine the suitability of PV modules for on-board charging application.

P. Vithayasricharoen considered two situations: (i) EVs are charged immediately as and when these arrive at unmanned charging station. (ii) Manned charging stations where there is a synergy between PV generation and EV charging resulting in reduced demand, charging cost, and emissions. The second option is applicable for higher EV fleet size and moderate carbon prices [57,58].

Most of the studies reveal that to avoid increased electricity demand due to large-scale use of PEVs, charging needs to take place during off peak hours. This will eliminate the need for capacity building in generation and transmission. An uncontrolled charging system in Portugal has increased the power demand by 30% for PEV penetration level of 17%. Authors utilized demographical
statistical data to eliminate charging behavior. This information had been used to control PEVs charging. Using this approach, authors, devised different charging strategies and studied the impact on distribution system using load flow calculation [59].

The inherent intermittency of renewable energy sources is mitigated by battery storage system thereby improving frequency stability of the grid. The battery storage system has large potential for EVs. Hence, Vehicle to Grid (V2G) is expected to play a significant role in smart grid [60,61].

Remote charging of EVs through wireless and inductive charging is available, eliminating the need for conventional plug in EVs. Wireless charging is of two types: stationary charging and dynamic charging. Dynamic or move and charge or road way charging can charge vehicles in motion. The energy source is embedded below pavement and transfers energy wirelessly. This system allows use of smaller capacity batteries due to frequent charging through power tracks embedded beneath pavements. This dynamic charging enhances the life of EVs battery in comparison to stationary deep cycle charging. However, a number of power tracks and size of battery need to be optimized [62,63].

Hybrid electric technologies are being used to improve fuel efficiency and decrease emission levels of new EVs. Lithium-ion batteries are finding wide usage due to high power and energy density, quick response, and long life. Wind power, solar PV, and lithium-ion storage batteries are integrated to form a DC microgrid in [64]. The proposed system is suitable for car parks, corporate sites having grid connection. This system will allow smooth charging even during windless or cloudy days. Also if generation is more than demand, the excess power can be fed to the grid.

The growth of EVs though possessing environmental benefits is hampered by lack of charging facilities. Hence, development of this facility needs to be optimized to maximize the usage of EVs. Forecast of location and demand can help utilities to plan new loads [65].

N. Leemput et al. evaluated the impact of EV charging strategies on residential grid. Authors carried out unbalanced three-phase load flow analysis using a realistic residential feeder with actual household power profile. They further compared strategies for uncontrolled and on-board controlled charging systems [66].

Recent studies have focused on the impact of increased loading on network assets due to widespread usage of plug in EVs. It is revealed that existing distribution network can support substantial penetration levels of EVs. However, the charging need to be done on single phases that too at off peak hours. Advanced metering infrastructure (AMI) system for residential areas can help to enforce active demand side management or real-time pricing or both. This will ensure to predict the load patterns on distribution systems. Hence, charging strategies need to be devised to control the rate of charging of EVs.

K. Qian et al. simulated EV charging situations: uncontrolled public charging, uncontrolled domestic charging, uncontrolled off-peak domestic charging, and smart domestic charging. The proposed method considers charge in electricity tariff and regulations on charging EVs. Lead acid and lithium-ion batteries are chosen as EV charging load. It was found that a 10% market penetration of EVs would increase the daily peak load by 17.9%. A 20% penetration level would cause increase in daily peak load by 35.8%. This is in case of uncontrolled domestic charging which is the worst-case scenario [67].

EV charging station can be used as distributed energy storage resource in deregulated market to optimize the cost of usage. However, it requires quite accurate forecast of energy resources and their price which is difficult to achieve. P. Sarikrupec et al. devised a short-term market price forecasting technique for higher prediction reliability for non-spike and spike wholesale market prices [68,69].

Power flow in V2G charging system can be either unidirectional or bidirectional. Unidirectional system handles only certain services such as regulation to grid. Revenue can be generated by EV owners through charging and can also help in spinning reserve and frequency regulation in energy markets. Studies have established that to fully realize the benefits of V2G, aggregators are needed. In order to provide bidirectional power flow for V2G, additional hardware is needed to feed power to grid [70]. In addition to this, anti-islanding protection and other issues related to grid interconnection need to be addressed. Moreover, consumer may be reluctant to supply energy from their EVs. But full benefit of V2G can only be derived by bidirectional flow. However, studies have demonstrated that reduced capital cost of unidirectional EVs can generate profit in certain energy market [71]. All said, it is always advisable to begin with unidirectional V2G. An algorithm for unidirectional power flow for EVs has been developed due to its profitability [72]. The proposed system needs adjustment of charging around a set time which is average power drawn by EVs. The load curve of utilities can be matched with individual customer need to offer them price benefit. N. Y. Sultani et al. [73] investigated EV charging behavior with respect to different prices for optimal adjustment of price. Conditional Random Field (CRF) model explores price responsiveness among consumers. In order to track CRF parameters, online convex optimization algorithm is used.

High-performance permanent magnet motors are useful as drive for EVs. However, for mass production applications, these are not suitable due to scarce earth material.
energy storage which will enable to reduce peak demand and defers the addition of new generating capacity [77,78].

PHEV/PEV charging system can be broadly categorized as home charging and public charging, although public charging is expected to be more economical and beneficial. Hence, careful management of total charging load is required so as to prevent power failure when large numbers are connected for charging suddenly (e.g. during morning when people reach a place of work). So, a sophisticated controller can minimize grid disturbances due to a large number of battery loads of PHEVs/EVs. The controller has to consider various constraints such as variation of infrastructure and communication, different charging capacities, and number of parking stations. With large-scale usage of EVs through public charging system, the energy management system needs to regulate charging time in order to optimize utilization and effectiveness of existing transformers [21].

Frequency regulation is a critical ancillary service which maintains supply demand balance to minimize frequency fluctuations. Hence, this service has high market value for PEVs and market operators. Two types of regulation services are used viz. regulation down service and regulation up service. Regulation down service is used to balance generation and load when there is excess power in grid while regulation up service is used when there is shortage of power in the grid. Hence, regulation services can be provided to balance generation and load demand [79]. Fast responding generators are required to maintain frequency stability such as photovoltaic generators, wind power generators, coal, or natural gas units. But these systems are expensive and have large carbon footprints. Some energy storage devices such as flywheel and batteries could be used to regulate frequency by switching on or off. But these are unidirectional regulating services. Another option could be to use PEVs when stationed and plugged to grid as large distributed energy source. This system is termed as vehicle to grid operation. Hence, PEVs offer bidirectional energy flow [65].

6. Scope of Microgrid and Smart Grid in the Optimization of xEVs

Transfer of energy demand from crude oil to electricity by PHEVs/PEVs in personal transportation sector would minimize energy security issues and pollution. Moreover, PHEVs/PEVs can be used to feed power to grid for reduction of peak demand and also to provide ancillary services. There is a need to evaluate issues generated by PHEVs/PEVs as energy storage is the basic need for EVs whose performance is affected by it. Connection of large number of PHEVs/PEVs to grid endangers the stability and quality of the grid power. It is anticipated that V2G would not be a reality in near future due to technical and economic issues. Successful implementation of EVs usage would be determined by communication technologies. An intelligently planned usage can become a source of distributed energy storage which will enable to reduce peak demand and defers the addition of new generating capacity [77,78].

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Frequency regulation is a critical ancillary service which maintains supply demand balance to minimize frequency fluctuations. Hence, this service has high market value for PEVs and market operators. Two types of regulation services are used viz. regulation down service and regulation up service. Regulation down service is used to balance generation and load when there is excess power in grid while regulation up service is used when there is shortage of power in the grid. Hence, regulation services can be provided to balance generation and load demand [79]. Fast responding generators are required to maintain frequency stability such as photovoltaic generators, wind power generators, coal, or natural gas units. But these systems are expensive and have large carbon footprints. Some energy storage devices such as flywheel and batteries could be used to regulate frequency by switching on or off. But these are unidirectional regulating services. Another option could be to use PEVs when stationed and plugged to grid as large distributed energy source. This system is termed as vehicle to grid operation. Hence, PEVs offer bidirectional energy flow [65].
EVs can be used as load as well as distributed source of energy storage. In a smart grid, EVs when not being charged but connected to grid can act as a source of energy storage to mitigate the effect of peak load on grid. This technology is known as V2G technology. Considering large volume of EV load, the capacity of EVs could be substantial. However, usage of large number of EVs requires extra work from network operators such as communication link to know the status of mode of charging of EVs (IEC 61850 communication standard regulates substation communication). The latest version of IEC 61850-7-420 includes distributed power generation, but V2G technology has been left out. This standard can be revised to include these components [80].

There is a major difference between other controllable loads and EVs due to mobility of latter and uncontrolled behavior [81]. Conventional vehicles possess low conversion efficiency of 20% compared to 22.5–45% of EVs. With large-scale usage of EVs anticipated in future, overloading of feeder’s transformers is predicted. Literature contains very few papers investigating the impacts of EVs on distribution network. The impact of EVs on distribution network could be less significant due to diversified nature of usage. But a proper load shaping would ensure delay in capacity expansion of grid assets. One such tool could be demand side management in the form of shifting loads at the time of high wholesale market prices through price incentive/penalty. This requires studies on management of household loads maintaining same privacy and comfort level [82–84].

Latest trend is to move toward distributed generation using renewable energy resources such as wind and solar due to the need for diversification of energy sources, energy efficiency, and environmental concerns. With the increase in higher level (more than 10%-30%) penetration of distributed energy resources, a mechanism would be needed to create transaction-based networks which can tackle unpredictability and variability of renewable energy sources so that peak demand is shifted to improve grid efficiency by removing need for spinning reserve and peak load power plants [85]. Authors proposed a method for real-time management and scheduling of EVs using PV generation, curtailable load, and battery storage backup. Apart from minimization of power cost of microgrid, distributed energy resource controller must ensure no violation of line parameters [86].

Juan Van Roy et al. [87] discussed the charging of plug-in hybrid electric vehicles in an office building microgrid supported by PV system and combined heat and power (CHP) unit. There is a trend toward development of dc microgrid using dc sources due to higher efficiency and robustness in industry, commercial buildings, and residential clusters [88]. Such systems operate at low-voltage levels due to low source supply voltage (PV panels) and loads such as EVs [89–94].

Three types of power balancing strategies are used viz. centralized, decentralized, and distributed [95]. For centralized systems, the controllers take care of task scheduling, control decisions, and global optimization. However, communication failure could jeopardize system reliability. Decentralized system prevents such system occurrence by localized measurement and decisions. However, such systems lack global optimization. Use of distributed control strategy overcomes failure of two systems. This strategy is used in dc microgrid as dc bus signaling (DBS). The operation models of converters are determined using predefined threshold voltages. This helps to maintain overall system redundancy [89].
To decrease system loss and to improve electric power quality, co-ordination of EV charging system is required [96,97]. More penetration of renewable energy resources with the help of a microgrid technology can improve supply reliability and reduce load variability. The future microgrid structure would be characterized by secure and efficient communication technology, smart distributed network management, and use of power electronics technology including bidirectional power flow between microgrid and EVs [98–101].

By 2025, 1.5 million zero emission vehicles are expected in U.S.A. China too has initiated massive promotion of EVs in the last decade. However, successful electrification of transport sector is dependent upon quality of service, affordability, and availability. The expected future scenario is shown in Figure 7 [102].

7. Research Gaps

- A new strategy for charging of electric vehicle based on service availability and self-consumption can be devised based on artificial intelligence system considering number of energy reserve slots available, number of electric vehicles available in queue.
- An in-depth study of relative cost of different charging sources such as battery, fuel cell, ultra-capacitor based on energy economy, cost, and life can be carried out.
- An investigation into determination of energy flows on different drive trains of hybrid electric vehicles can be carried out.
- Negative impact of electric vehicle charging on economic and secure operation of power system can be considered based on predefined level of electric vehicle penetration.
- A detailed investigation into switching losses and conduction losses in different types of converter models can be considered to identify most suitable model for a specific condition of operation.
- An investigation into various systems of energy storage for applications into electric vehicle can be considered. This may include batteries and other sources of energy in stand-alone and hybrid combinations. The comparison can be on predefined parameters such as charging/discharging time, self-discharge, life, and cost.
- A loss optimal charge strategy can be decided which can minimize impact on a distribution system to improve penetration of PEV/PHEVs.
- An investigation can be carried out in the area of hybrid electric vehicles for use of hydrogen fuel cell as standalone energy source.
- A study can be conducted for sizing of external battery pack PHEVs considering impact of short duration charging and fast charging.
- A comparative study of various hybrid topologies (EV, PHEV, HEV and FCHV) vis-à-vis conventional vehicles can be conducted based on certain parameters.
- An effective voltage equalization circuit can be developed for series connected ultracapacitors and its impact by high equalization current can be studied.
- A design of dynamic EV charging system can be investigated using stochastic driving cycle under uncertain traffic situations w.r.t. power and energy requirement of EV.
- A study on reliability and cost of renewable energy sources for charging of EVs can be carried out employing different hybrid combinations.
- An investigation into extended utilization of EV batteries for energy management of building can be done especially for peak shaving.
- An optimal placement of charging infrastructure for EV in a grid can be investigated w.r.t. voltage profile, line congestion, and system demand profile.

8. Conclusion

Nowadays, technologies like electric vehicles and microgrids are accepted globally because of various economical and environmental benefits. These technologies are relatively new and require a lot of research especially in developing countries. This paper gives an in-depth review of various publications covering the period from 1992 to 2015. The survey is subdivided into six different topics with each topic describing the overview of related literature. The information collated here covering past 23 years will be of immense help to researchers, practicing engineers, graduate, and postgraduate working in the field of electric vehicles, microgrid, energy storage technologies etc. Based on wide extensive literature review, research gaps have been identified which will help researchers to identify new areas thereby contributing to the field of electric vehicles.

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