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Review

A Comprehensive Review on Developments in Electric Vehicle Charging Station Infrastructure and Present Scenario of India

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Abstract: The transportation sector of the world is in the transformation stage, shifting from conventional fossil fuel-powered vehicles to zero or ultra-low tailpipe emission vehicles. To support this transformation, a proper charging station (CS) infrastructure in combination with information technology, smart distributed energy generating units, and favorable government policies are required. The motive of this paper is to address the key aspects to be taken care of while planning for the charging station infrastructure for electric vehicles. The paper also provides major indagation and developments in planning and technological aspects that are going on for the enhancement of the design and efficient management of charging station infrastructure. The paper addresses the present scenario of India related to electric vehicle charging station developments. The paper specially provides a critical review on the research and developments in the charging station infrastructure, the problems associated with it, and the efforts that are going on for its standardization to help the researchers address the problems.

Keywords: electric vehicle; charging station; EV charging Station; smart charging; charging infrastructure

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1. Introduction

In the present scenario, global warming and climate change are the major concerns that can severely affect the environment and life on earth [1]. Greenhouse gases (GHGs) are the prime factors that are responsible for climate change [2,3]. Air pollution and GHG emissions from the fossil fuel-based transportation sector in recent years have received the greatest ever attention, especially in large, dense cities [4–6]. Globally, in 2016, 7.87 billion tonnes of carbon dioxide-equivalents of GHG emissions were from the transportation sector [7] and it increased to 8.04 billion tonnes of carbon dioxide-equivalents of GHG emission in the year 2017. According to an estimate, 24 percent of the world's CO_2 emissions are due to the transportation sector in which 3/4th of these emissions account for road transportation [8]. In India, 291 Mt of CO_2 equivalent emission was from the transportation sector in the year 2017 [8] and it accounts for 18% of total energy consumption [9].

The use of electric vehicles plays an important role in improving the traffic and helps in maintaining a healthier living environment by zero or ultra-low tailpipe emissions and much lower noise [10–13]. Thus, the global automotive industry is shifting towards zero-emission vehicles [14,15]. In 2019, globally, almost 4.8 million battery electric vehicles (BEV) were in use and about 1.5 million new BEVs were added to the worldwide fleet [16].

The development of an electric vehicle charging station and its optimal location is very important for easier adoption of electrically-propelled vehicles and the use of cheap and clean electrical energy from grid and renewable energy resources [17,18]. A proper charging station network will help in alleviating the range anxiety of owners of electric vehicles (EVs), assuring the similar performance of EVs compared to that of the internal combustion engine vehicles [12,19]. To lay more emphasis on continuous improvement in recharging technology, the share of electric vehicles in the market must be increased. The present problem with the adoption of EVs can be related to the "chicken or egg" theory [20]. The consumers are waiting for proper charging infrastructure to get full assurance of successful trip completion with no or minimum delay in charging time. Moreover, the investors of charging infrastructure are waiting for enough EVs on the road to make the business profitable. The stakeholders also differ in opinion on the choice between fast charging or smart charging (SC) for EV charging stations [21]. To solve all these issues, government policies also play a very important role. Another important factor that plays an important role in the adoption of EVs is the lack of suitable batteries that can deliver a sufficient amount of energy for a longer duration of time to enhance the range of EVs [22,23].

At present, the transportation sector is going through three revolutions, i.e., autonomous driving, shared mobility, and electrification [24]. So, when planning for the charging infrastructure for the electric vehicles, it is crucial to take into account the synergies and potential interactions among these three emerging revolutions. With the increase in the adoption of electric vehicles, a new emerging significant electrical load is introduced to the power grid, which will require changes in the infrastructure [25]. The transfer of electrical energy is done only via the distribution grid, which limits the energy that is flowing in the transmission lines [26]. The large-scale reconstruction of the distributions grid to meet the EV's charging requirement is difficult.

It is crucial to accurately assess the possible impacts of large grid-connected renewable energy generation (REG) system and electric vehicle charging stations (EVCS) on the network performance. Such analysis will help the power utilities to become efficiently equipped so that the potential operational issues can be solved [27].

Figure 1 describes the basic charging infrastructure for the electric vehicles with the level of charging at each charging station [28]. Figure 2 shows the charging infrastructure for EVs with different charging station configuration. According to a study in [29], which was done on owners of battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), residential charging is found to be the most important and most frequently used location. The major challenges in developing an efficient charging infrastructure are to have an effective communication network for information exchange, an optimization unit to reduce the charging time at the charging station, and a prediction unit to help the optimization unit to make the best possible decision [30].

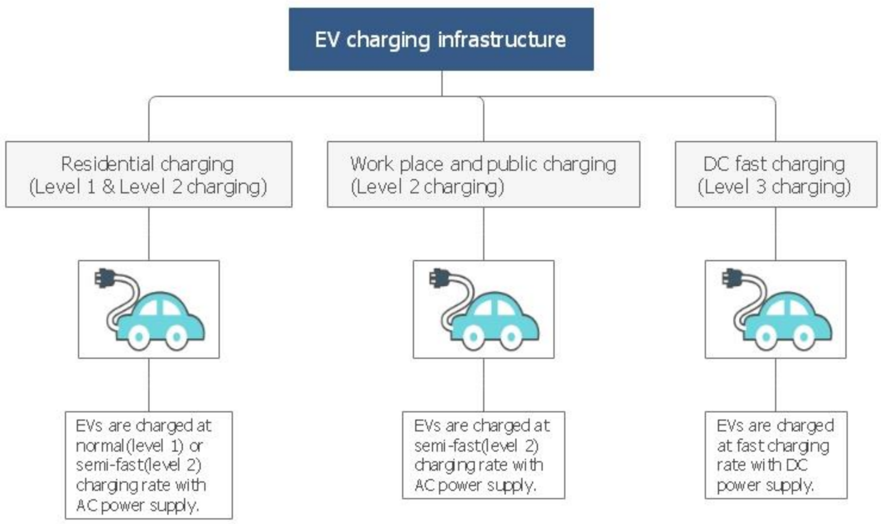

Figure 1. Basic electric vehicle (EV) charging infrastructure [28].

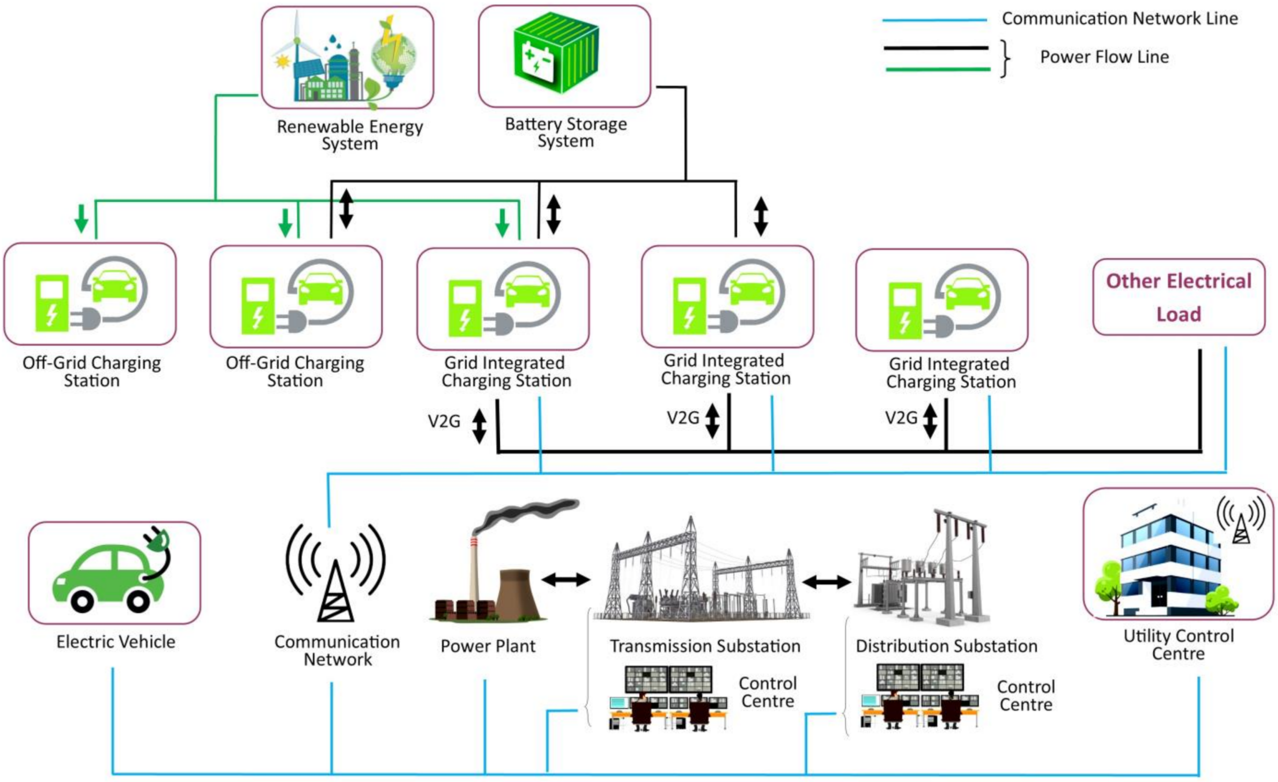

Figure 2. Generalized layout of charging infrastructure for electric vehicles.

Large-scale adoption of EVs is a great challenge for the energy sector. To overcome these issues, a lot of developments have been made. The advancements in the field of manufacturing, information sharing technology, smart energy subsystems like multi-energy microgrid at the distribution level emerged to solve the peak load problem on the main grid. In a smart grid system, microgrid plays an essential role in improving the consumption of distributed renewable energy (RE) and ensuring the power supply reliability [31,32]. Vehicle-to-grid (V2G) technology can also be used to sell electricity back to the grid and support the increased load on the grid. During the low demand period, the EV is charged and during high demand of electrical energy it is discharged and energy is given back to the grid [33]. With the use of V2G technology, EVs are now becoming a controllable resource in the distribution systems and providing lots of ancillary services (e.g., voltage regulation, peak power-sharing, spinning reserve, etc.) [34].

This paper aims to analyse the recent developments in the charging station from planning and designing to the operational management stage. This review paper also addresses the research on different ways to utilize renewables energy resources and improving the flexibility of the grid. The latest developments in India to promote electric vehicles are also presented in the paper. The paper provides critical research gaps that should be helpful to the researchers in their further research work.

2. Types of Electric Vehicle and Electric Vehicle Charging Station (EVCS)

The EVs among various developed technologies have gained tremendous attention as an alternative technology that is becoming a part of the modern transport system. The EVs are mainly classified into three types, based on the source of electricity for the propulsion of the vehicle, namely [35,36]:

(a) Hybrid electric vehicles (HEVs)
(b) Plug-in electric vehicles (PEVs)
(c) Fuel cell electric vehicles (FCEVs).

HEVs utilize two propulsion technology, i.e., an electric propulsion system and internal combustion engine. This is done to achieve better fuel economy, low emission, longer drive range, etc., when compared with conventional internal combustion engine vehicles [37].

PEVs include BEV and PHEV. The BEV operates on an electric propulsion system and is powered 100% by rechargeable batteries. PHEV primarily runs on an electric propulsion system powered by a battery, but it also has a gasoline engine to be used as a backup when the battery gets completely discharged. FCEVs operate on an electric propulsion system and uses fuel cell technology instead of the battery, or in combination with a battery or supercapacitor as the power source. Figure 3 shows the detailed classification of types of EV.

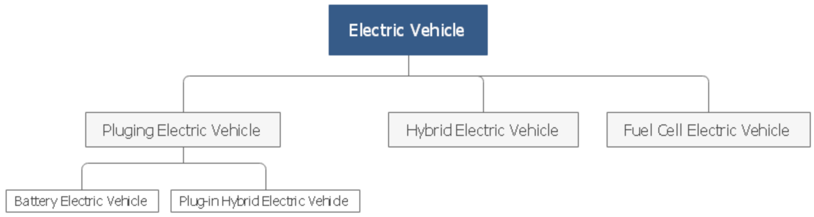

Figure 3. Types of electric vehicles.

An EVCS is an integral part of EV charging infrastructure. It is also known as electric vehicle supply equipment (EVSE). It supplies electrical energy to EVs for charging from different energy sources. Its classification depends on a wide variety of factors including the type of power supply, type of integration of the charging station with the power grid, power levels used for charging, type of charging infrastructure, mobility, and direction of power flow. Classification of EV charging stations based on different factors is given below.

Based on the type of power supply used for charging, it can be classified into two types [38]:

(a) Alternating current (AC) power supply based EVCS
(b) Direct current (DC) power supply based EVCS

Based on the type of integration of the charging station with the power grid, it can be classified into types [39–42]:

(a) Only grid-connected charging station: In this configuration, the only source for electric energy to charge EVs is from the main power grid system.
(b) Grid and renewable energy integrated charging station: In this configuration, the electrical energy is supplied by a coordinated energy sharing between the main power grid and the renewable energy system. The introduction of renewable energy systems reduces EV charging loads on the main power grid.
(c) Grid and renewable energy integrated charging station with energy storage: In this configuration, the energy storage system is also included in a grid and renewable energy integrated charging station. This configuration aims to minimize the grid dependency for EV charging.
(d) Off-grid renewable energy powered charging station with energy storage: In this configuration, EV charging is powered by a combination of a renewable energy system and energy storage system. The intermittent nature of renewable energy systems is stabilized by the introduction of the energy storage system.
(e) Off-grid renewable energy powered charging station without energy storage: In this configuration, EV charging is only powered by the electric energy generated by the renewable energy system. Generally, 2 or more renewable energy resources are integrated to provide a balanced energy supply for EV charging like Solar PV and Wind energy systems integrated renewable energy system.

Based on power levels used for charging, it can be classified into three types [10,43]:

(a) Normal charging (also known as Level 1 charging), i.e., use of standard power outlets that are mostly available in residential installations for charging of the electric vehicle. It is typically rated at 110 V/15 A.

(b) Semi-fast charging (also known as Level 2 charging), i.e., current levels exceeding the standard domestic outlet but that can be set up in the residential and commercial areas or buildings. The rate of charging is high compared to normal charging. It is typically rated at 220 V and between 15 and 30 A.
(c) Fast charging (also known as Level 3 charging), i.e., the power levels are very high compared to standard industrial or domestic socket outlets and a specific infrastructure is required for developing fast-charging stations. The voltage rating of DC fast charging often lies between 400–500 V and can charge a typical EV battery as quickly as in 30 mins only [44]. According to SAE J1772 standards, fast charging is classified into three different levels [45,46]:
    1. DC Level-1: 200 V/450 V, 80 A, up to power rating of 36 kW
    2. DC Level-2: 200 V/450 V, 200 A, up to power rating of 90 kW
    3. DC Level-3: 200 V/600 V, 400 A, up to power rating of 240 kW
(d) Ultra-fast charging (voltage rating is higher than fast charging and can go up to 800 V DC)

Based on the type of charging infrastructure, it can be classified into three types [47]:

(a) Distributed charging infrastructure: It includes charging at normal or semi-fast charging rates. In this, the charging units are distributed all across the power system in places like shopping, work, parking lots, home, etc.
(b) Fast charging infrastructure: It consists of fast charging stations set up at specified locations to charge EVs in a very short duration of time. Since a large amount of power is drawn to quickly charge the EVs, so a separate charging infrastructure for fast charging is setup.
(c) Battery swapping infrastructure: In this infrastructure, when EV comes to a battery swapping station, its battery is swapped with a fully charged EV battery. This reduces the charging time of EVs.

Based on mobility, it can be classified into two types [33]:

(a) Fixed charging station
(b) Mobile charging station

Based on the direction of power flow it can be classified into two types [38]:

(a) Unidirectional power flow charging station
(b) Bidirectional power flow charging station

3. Aspects, Challenges, Recent Research, and Technological Developments in Electric Vehicle Charging Station Infrastructure

To promote the easy adoption of electric vehicles, it is very important to ensure that a proper infrastructure must be provided to customers for recharging the electric vehicle [48]. The technology should be convenient, reliable, and fast. The main motive of adopting electric vehicles is to reduce the dependency on fossil fuels and promote environmentally friendly transportation systems. Increasing EV charging loads will also increase the emissions from conventional thermal and other power generating units [49]. Hence, large-scale utilization of available renewable energies to feed the increasing load demand should be promoted and the deployment of REG should be synchronized with increasing numbers of EVs [50]. The aspects, challenges, recent research, and technological developments in the field of electric vehicle charging station infrastructure are mentioned below.

3.1. Optimal Location for Electric Vehicle Charging Stations

An optimal location for EVCS plays a key role in mitigating the range of anxiety among the consumers of electric vehicles [51,52]. Various factors influence the location of charging station, which includes drivers' charging satisfactory, economy problem of operators, the power loss of vehicles, the safety of the power grid, and traffic jam of transportation system [53–57]. Table 1 describes some of the latest researches and developments in finding the optimal location for the EV charging station.

Table 1. Summary of work done in finding the optimal location for the charging station.

Reference No.	Type of Algorithm/Model	Type of Charging Station	Key Points/Aim of Research	Conclusions
[58]	Genetic Algorithm (GA)	DC Fast charging Station (Level 3)	Following problems are assumed while performing the research work: a. Charging demand (mainly by BEV) b. Charging Facility Features c. Charging fees and electricity cost d. Cost station installation, operation, maintenance, and land acquisition	• Boston network is chosen for the placement of an electric vehicle charging station (EVCS). • The result showed that the location of EVCSs should be mostly along major highways. • A five-year time span is chosen for the study. • To increase the profit of charging station, higher charging fees, shorter sessions of charging, and allowing a greater number of cords per site is important. • Expansion of Power grid and charging station up-gradation is important with the increase in demand to avoid on-site congestion problems maximizing profit over time.
[59]	A coverage location model with GA based algorithm is proposed	Public charging station (PCS) (A home charger and public fast is considered)	• The paper aims to maximumly maintain the existing activities of the EV owners by siting the public charging stations at optimal places. • The State of Charge (SOC) is threshold is set at 30%.	• The study was formulated in three steps: firstly, simulating the charging choice behavior of EV driver using deterministic process. Secondly, a coverage location model is presented for the EV public charging stations. Lastly, this location model is applied to the center area of Beijing, China for the case study. • The results of the case study showed that increasing the number of public charging stations and the ownership rate of the home charger (ORH) effectively decreases both missed trips and missed-trip EV drivers. • Moreover, an appropriate amount of charging network could support most of the EV drivers to accomplish their five weekdays' trips without changing their daily trips and activities.
[60]	An optimization model for slow and fast charging public station	Public charging station for slow and fast charging	The aim was the minimization of the total cost as well as the satisfaction of a certain amount of coverage goal.	• Two optimization models for public fast charging and slow charging are proposed and implemented in two locations in Canada. • Charging demands are represented by geometric objects instead of discrete points. • The polygon overlay method is used to solve the partial coverage problem (PCP) for the networks. • The proposed models showed that they are effective and practical in locating the charging station. Compared to the complementary partial coverage method (CP), this method can provide more accurate results and eliminated the PCP.

Table 1. *Cont.*

Reference No.	Type of Algorithm/Model	Type of Charging Station	Key Points/Aim of Research	Conclusions
[61]	A mathematical model for the optimization of charging station location and Genetic Algorithm based method is used for the solution.	Plug-in electric vehicles charging station.	The study aims to optimize the location of the charging station, minimization of the total cost, and mitigation of range anxiety among the consumers.	• The model determines the charging station location and the no. of chargers required at each charging station. • An Expanded model is also presented and validated via numerical results. • There are some limitations of the proposed work like it is applicable mostly for weekdays, kinds of charging at the charging station not discussed, etc.
[62]	A multi-stage stochastic integer programming approach with two solution algorithms based on benders decomposition and genetic algorithm is used	Fast charging station (FCS)	The paper aims to determine the charging stations that should be opened at each period to maximize the satisfied recharging demand over the entire planning duration.	• The study is mainly done to model the problem of stochastic and dynamic aspects of the recharging demand. • The numerical results showed that compared to stand-alone mathematical programming solver, the two algorithms adopted in this paper performed very well both in terms of computational time and solution quality. • The simulation results showed that the multi-stage stochastic programming model has practical benefits as compared to a simpler multi-period deterministic model
[63]	Proposed a method for siting charging stations and A genetic algorithm is used to find optimal expansion plan for charging infrastructure.	FCS	The study aims to site the charging stations and provide the optimal plan for expansion of charging station taking into consideration three cases: a. fully autonomous vehicles with ride-sharing (future fleet) b. non-autonomous vehicles without ride-sharing (traditional fleet) c. Mixed case	• Applying the methodology in the case study of taxis in New York City, Results shows that • In traditional fleet, EV adoption requires fewer charging stations with more no. of charging ports compared to future fleet. • For future fleet, charging only reduces 2% of the service level with 100% adoption of EVs. • EV adoption can reduce CO_2 emission up to 1100 Tones/day for the traditional fleet and 861Tones/day for a future fleet of taxis in the New York city

3.2. Optimization of Charging Infrastructure Development, Planning and Operation Management

Optimization of charging infrastructure development requires proper planning in terms of location and size of the charging station. A large charging station can have a higher number of chargers to serve more EVs but at the same time, it will require higher electrical energy and construction cost [64]. The charging infrastructure needs are highly dependent on the battery sizes of EVs and the power rates and these both are likely to increase in the future [65].

Planning and operation management of the charging station are crucial for increasing the profit and success of the EV charging station. The planning step for the EV charging station is a brainstorming process that involves decision-making at various levels, like the level of charging, number of charges, space requirement, type of charging station, and energy storage technologies to be used, if any, etc. Operation management of the charging station network involves charging scheduling to support grid operation, minimizing the waiting time for charging, smooth charging operation, etc. [66].

Software like MATLAB, HOMER, PVsyst, EVLibSim, etc. are very useful in planning and designing, and for simulation and optimization, of the EV charging station infrastructure, including the distribution system. EVLibSim is a tool for simulation of EV activities at a charging station level and EVLib along with EVLibSim provide an efficient framework for management EV charging activities at the station level [67].

An optimal planning method can satisfy the charging demand as well as reducing the construction cost of the charging station [68]. This was done by using an improved approach based on a genetic algorithm to solve the mixed-integer nonlinear optimization problem. Moreover, in a study it was found that, optimal deployment of fast charging stations at optimal sites for long and local distance travel of EVs can increase the adoption of EVs [69]. Here, the availability of charging opportunity and local EV diffusion is taken into account for EV adoption. For optimization, mixed-integer linear programming formulation was proposed and rolling horizon-based heuristic efficiently provides a good solution.

To maximize the profit of the operator of the charging station in a one-way car sharing system, a multi-integer non-linear programming model (MINLP) was proposed [70]. Here, profit maximization is done by determining the station capacity and the EV fleet size. The challenges caused by the time-varying state of charge (SOC) of the vehicles and demand fluctuation are solved by using a rolling horizon framework, a shadow price, and the golden section line search method.

A large imbalance in the supply of vehicles in the one-way charging station is generally observed, which requires continuous relocation of vehicles to satisfy the demand [71]. To avoid the operational burden of relocation of vehicles in one-way EV sharing network, Deza et al. [71] developed a method to minimize the relocation of vehicles and maximize the balanced flow in the network by optimizing the charging station location. Here, mixed-integer linear programming formulation method is used. The network will now self-regulate over time and the trip satisfaction rate will increase.

For a charging station that includes both battery swapping and plug-in charging, a hybrid charging management framework is required. The sole purpose of this management system is to minimize the charging waiting time and drivers' trip duration, and also, maximize the charging performance gains for the station. Zhang et al. [72] proposed a hybrid charging management framework for electric taxis, which includes both battery swapping and plug-in charging stations. The proposed work provides an optimal choice between battery charging station and battery swapping station that is made based on time-varying requirements. The simulation results verified the effectiveness of the proposed work.

At battery exchange stations where charging, discharging, and exchange of battery take place, management of the optimal operation plays a very important role. In a literature work [73], a deterministic integer programming model was used for managing the optimal operation of PHEV battery exchange stations. Here, V2G technology is used in this model to support grid operation by discharging of batteries.

3.3. Development of Fast Charging, Ultra-Fast Charging, and Battery Swapping Stations to Reduce the EV Charging Time

The development of fast and ultra-fast charging stations and profit in its operation is highly affected by the EV adoption rate [74]. Potential users of PEV often expect the speed of public charging similar to conventional refueling, and for this reason the major researches and political interests are focused on fast charging with higher power rates [65]. Fast and ultra-fast charging stations will bring the charging time to a minimal level and plays a vital role in increasing the public acceptance of EV [75]. However, the adoption of these technologies will cause a negative impact on grid stability, resilience, and efficiency problems [76]. A battery swapping station (BSS) is also a new concept to handle the battery charging time problem by replacing the depleted battery with a previously fully charged battery to minimized the charging time of EVs [77].

There have been some hybrid DC fast charging technologies proposed in literature. To enhance the grid stability during peak load demand, Elma [70] proposed an algorithm for dynamic energy management system and proved its performance by reducing peak power demand on the grid by 45% and the life span of the battery is also extended. In another work on fast charging [78], two new methods were utilized to predict the future number of fast charging points required, its usage amount, future daily demand profile, and the charging rate required at the fast charging station to meet the consumer satisfaction level.

In the area of ultra-fast EV charging technology, a design was proposed in [43]. It has a DC microgrid based and battery energy storage system integrated ultra-fast EV charging station. The system successfully supports the charging of EVs at 800 V DC and charging time of fewer than 10 min. The control system designed utilizes the load-leveling power management technique to reduce the peak loading on the AC main grid.

The optimization process generally involves mathematical formulation of the problem and solving it using a selected algorithm. For a multi objective re-planning problem of EV FCS (taking into consideration economic issue and customers' satisfaction), a mathematical approach is employed and an improved Strengthen Pareto Evolutionary Algorithm-II was used to solve the problem [79]. Zhang et al. [80] modeled a grid integrated FCS equipped with energy storage system (ESS) and optimized using queuing theory and economic model. The analysis of the system states that under the condition of a high arrival rate, the charging power provided by the ESS exceeds that provided by the grid and it cannot effectively reduce the system loss rate. Hence, the configuration of ESS should have to be changed as per the charging load to get more profit. For the case of optimal charging of EV using BSS, a multi-objective programming model was developed in [77]. The model includes minimizing batteries charging time, power loss cost, voltage profile flattering, and network capacity releasing. The model was solved by the NSGA II algorithm and tested on the 33 bus IEEE test bus system, which successfully demonstrated the model functionality.

3.4. Provision of Strategy-Based Management of Queues at the Charging Station

To avoid heavy charging demand at one charging station and no or very little charging demand at other nearby stations, it is very important to regulate and properly schedule the available charging station to charge the EV. This will help in strategically managing the queues of EVs at EVCSs. An effective communication network will help in managing the queues at the charging stations.

An agent-based negotiation scheme was proposed to distribute the EVs among the set of charging stations and scheduling for charging to the available charging station [81]. This method would be useful to regulate the queues at the charging station. In another study, Al-Obaidi et al. [82] proposed an algorithm for a grid-connected bidirectional smart charging (enabled using bi-directional converters) of EVs for peer-to-peer energy trade and provision of ancillary services to the grid. The scheduling model incorporates the EV user's input using soft constraints and optimization variables. The results from numerical studies verify that the aggregated revenue generated by the EV scheduling model was enhanced by incorporating user preferences in the scheduling process. Moreover, the developed user-centric model achieved about an 11% increase in ancillary service provision to the grid and a 90% increase in peer-to-peer energy transactions among the EVs.

3.5. Proper Structure for Grid Integration with Charging Stations to Maintain the Energy Balance

With the increasing adoption of EVs, the transport sector can be decarbonized effectively. However, the increasing charging demands with uncertainty in demand raised concerns for security operation of the power system. The increasing penetration of renewable energies and their intermittency is also a concern for the power system operation [83].

There have been several studies that evaluated the role of renewable energy generation and storage systems on power quality for charging systems. Farhoodnea et al. [27] evaluated the role of energy systems such as wind farm, photovoltaic and fuel cell power generation units and EVCS systems on the power quality of the distribution system while taking into account the varying weather and loading conditions. A radial 16-bus test system was modeled and simulated on MATLAB/Simulink software. Results showed that a severe power quality problem (voltage drop, frequency, and voltage variation, harmonic distortion, and reduced power factor) in the system components was caused by installed hybrid renewable energy generation and EVCS. Similarly, Yi et al. [84] modeled EVCS with an energy storage system (ESS) powered by a microgrid system with the help of a determination model and the simulated annealing algorithm is improved. The main aim is to increase the renewable energy (RE) consumption capacity in the microgrid and reduction in energy storage capacity. Results showed around a 50% reduction in EVCS and energy storage capacity and an increased benefit of about 7% for the investors of the microgrid. Ebrahimi et al. [85] formulated a method to determine the capacity and the probable locations to install the renewable energy resource, power switches, and the FCSs in such a way that the entire grid can be clustered as multiple active interconnected micro-grids (MGs). The user equilibrium-based traffic assignment model, the Monte Carlo method, and the queuing theory were used to produce the uncertainty scenarios for the renewable resources, load, and FCSs. The efficiency of the proposed method was evaluated on a sample IEEE 33-bus system and its corresponding Sioux Falls traffic network. Overall, the obtained results, after being aggregated using the risk-neutral probabilities method, indicated a significant reduction in the system's costs as well as the improvement of the technical status of the grid after applying the proposed method.

3.6. The Communication System for Grid Management

With the introduction of new concepts like "smart grid" or "V2G", the need for an appropriate communication protocol for EV charging arise to enable the following features [10]:

- Identification of vehicle and ease in the billing process.
- Optimization of charging cost by selecting the most appropriate time and lowest charging rates.
- Optimization grid load by controlling charger ampacity in the function of grid demand.
- Supporting the grid operation during peak loading by using V2G technology.
- Appropriate billing and user compensation functions for V2G operation.

For developing such a communication protocol, several participants, including both vehicle manufacturers and utilities, are included. The standardization of a communication protocol is being addressed by a joint working group uniting ISO TC22 SC21 (electric road vehicles), ISO TC22 SC3 (electric equipment on-road vehicles, including onboard communication systems), and IEC TC69 (electric road vehicles) [10]. Figure 4 shows the communication protocol based on the seven layers open system interconnection (OSI) reference model [86].

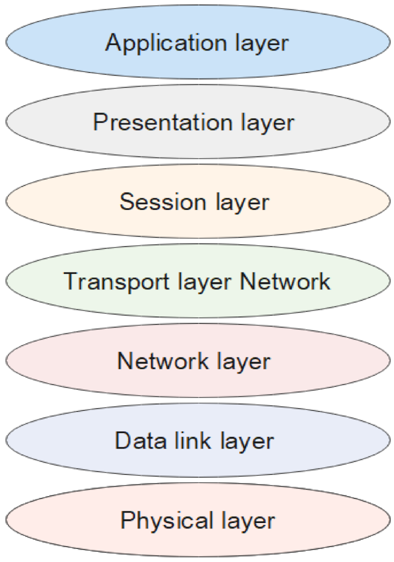

Figure 4. Layers of layers open system interconnection (OSI).

3.7. Impact of Charging Station Infrastructure on the Environment

The EVs promise many environmental benefits, including very low to zero tailpipe emissions, reduced noise, etc. [87]. However, its charging station requires land and energy in a very large amount. Hence, it is very important to assess the possible environmental problems caused by the development of EVCS [88]. Zhang et al. [89] performed a life cycle environmental impact assessment of four main types of chargers for EV charging in the context of China. Results showed that the cumulative energy demand and global warming potential is lowest in the home charger and increases from public alternating current (AC) and direct current (DC) chargers, to the public mix chargers (integrated AC and DC). Further, the use of home and public AC charges should be promoted and the ratio of EVs to chargers should be maintained. Liu et al. [90] investigated the location problem of PCS for EV charging to minimize CO_2 emissions using massive GPS-enabled trajectory data. The results of the case study state the necessity of including remaining electricity restrictions on charging decisions and CO_2 emissions in round trips to charging stations, to solve the CS location problem. It can lead to the 0.85–2.64% more charging demands being satisfied per day and the reduction of daily CO_2 emissions captured by about 0.14–0.37 ha of forests in one year. With the increasing popularity and adoption rate of EVs, it is very important to critically analyse the impacts of EV charging loads on the power system and future expansion plans according to it. The charging behaviour of large scale EVs will cause excessive power loss and decrease in the voltage level of the distribution network and will also result in local congestion in the road network [91].

3.8. Sizing of Energy Storage Technologies

For EV charging stations, especially fast and ultra-fast charging stations, energy storage technologies provide support for stable operation and increase customer satisfaction. Sizing of ESS is very important in charging station infrastructure to define their contribution level in terms of energy supply for EV charging. Table 2 describes some of the researches in which the sizing of energy storage technologies is defined.

Table 2. Summary of work done on the use of energy storage systems for EV charging.

Reference no.	Type of Charging Station	Energy Storage Technology Used	Specification/Results
[43]	Ultra-fast charging station	Ultra-high-power superior lithium polymer battery (UHSLPB) to support charging of EV battery size range from 16 kWh to 75 kWh at a voltage level of 800 V DC.	Life cycle > 6000, at the maximum continuous discharge of 8C and maximum continuous charge of 4C.
[92]	Workplace (dynamic or smart charging technique is used)	A 10 kWh Lithium-ion battery is integrated with an EV-PV charger to reduce the dependency on the grid for workplace EV charging by 25%.	• The battery is charged and discharged at a maximum C-rate of 1C corresponding to a maximum charging/discharging power of P_b^{max} = 10 kW. • The maximum depth of discharge is restricted to 80% (between the state of charge (SOC) of 10–90%) to ensure a long lifetime of the storage. • Efficiency charging/discharging of the battery including power converter is assumed to be 93% and the efficiency of power exchange with the grid is considered as 95%.
[93]	Standalone PHEV charging station	Fuel cell (FC) technology is designed for the charging of PHEVs. The charging station is powered by wind and solar energy and the role of energy storage is fulfilled by FC.	• The use of FC for storage is more profitable compared to the battery bank and has a permanent lifetime. • H-5000 PEM FC stack with the rated power of 5 kW is used.

4. Present Scenario of Electric Vehicles and Charging Stations in India

India has a vision of reducing greenhouse gas (GHG) emission and to do this, India is targeting various sectors of high GHG emission. The transportation sector and especially road transport is a major contributor to GHG emission and to overcome this, the use of electric vehicles plays a vital role. The government of India has taken various initiatives to increase the manufacturing and the adoption rate of EVs. However, to accelerate the adoption rate, an adequate amount of EVCSs should be made available.

The Ministry of Power issued the charging infrastructure guidelines and standards with clear roles and responsibilities of the various stakeholders at the central and state level. The Indian government has issued certain guidelines for public charging infrastructure, as described in Table 3. The Bureau of Indian Standards has issued IS:17017 as the basic standards for EV charging. It recommends both Combined Charging System Type-2 (CCS-2) (beside AC Type-2 charger) and CHAdeMO as the EVs standards for India [94]. Central Nodal Agency and State Nodal Agency will be responsible for the implementation of developing charging stations. The rollout of EV public charging infrastructure will be done in two phases. In phase 1 (1–3 years), all megacities and the important highways will be planned for EVCS. In phase 2 (3–5 years), big cities like state capitals, etc., and the important highways will be covered.

As per the revised guidelines, the tariff rate for power supply to the EV charging stations should not be greater than 15% of the average cost of supply of power [95]. In case of the location of the public charging station, at least one charging station shall be available in a grid of 3 by 3 km (9 km^2) and set up at every 25 km on both sides of the highway/road. For long-range EVs and/or heavy-duty EVs, there shall be at least one FCS at every 100 km on both sides of the highway/road. Public charging infrastructure specifications for long-range and/or heavy EVs are also specified in the revised guidelines. Moreover, the setting up of public charging stations shall be a de-licensed activity and any individual/entity is free to set it up provided it should meet the technical standards.

Table 3. Specification of requirements at public charging stations [96].

Charger Type	S. No.	Charger Connectors *	Rated Output Voltage (V)	No. of Connector Guns (CG)	Charging Vehicle Type (W = Wheeler)
Fast	1	Combined Charging System (CCS) (min 50 kW)	200–750 or higher	1 CG	4 W
	2	CHArge de Move (CHARdeMO) (min 50 kW)	200–750 or higher	1 CG	4 W
Slow/Moderate	3	Type 2 AC (min 22 kW)	380–415	1 CG	4 W,3 W,2 W
	4	Bharat DC-001(15 kW)	48	1 CG	4 W,3 W,2 W
	5	Bharat DC-001(15 kW)	72 or higher	1 CG	4 W
	6	Bharat AC-001(15 kW)	230	3 CG of 3.3 kW each	4 W,3 W,2 W

* Besides, any other fast/slow/moderate charger as per approved DST/BIS standards whenever notified; Note: Type-2 AC (min 22 kW) is capable of charging e-2 W/3 W with the provision of an adapter.

To promote the adoption of extremely low or zero-emission vehicles to make the transportation sector emission-free, countries across the globe, like the UK, Scotland, the US, Norway, France, India, China, etc., are working very hard both at the political and technological level [97]. India's Bharat Electronics Limited (BEL) has signed a Memorandum of Understanding (MoU) with US-based Triton Electric Vehicle for the development of EV, energy storage systems, and supporting infrastructure. Triton EV is involved in the business of energy storage systems, energy generation, load management, and EV charging infrastructure. They have recently announced the launch of the electric sedan N4 for the Indian market [98]. One of India's biggest Tata group companies, named Tata AutoComp, has recently signed an MoU with US-based Tellus Power Green for the supply of DC fast chargers and AC chargers for EV in India [99]. Tata Power has signed another MoU with MG motors to install a 50 KW DC superfast charger at a selected MG dealership, which will be accessible by MG ZS EV model and other EVs available in India with combined charging standard systems [100]. Energy Efficiency Services Ltd. (EESL), Mumbai, India have signed various MoUs with different companies for developing infrastructure of EV charging, with Apollo Hospital Enterprises to install EV charging at hospital infrastructure [101], with Bharat Sanchar Nigam Ltd. (BSNL) to set up public EV charging infrastructure at 1000 BSNL sites, and it will provide requisite space and power connection for installation [102] with National Highway Authority of India (NHAI) for developing infrastructure at toll plazas and highways and most of the stations will be run by renewable energy sources present at the site, as a part of Clean Development mechanism (CDM) to reduce dependencies on fossil fuels, reduce emissions, and achieve sustainable development at all toll plazas and Indian national highways [103].

The EV industry in India is still at the beginning stage, with less than 1% of the total vehicle sales. At present, the Indian roads are primarily dominated by conventional vehicles and have approximately 0.4 million electric two-wheelers and a few thousand electric cars only [9]. The EV industry in India has been on the back foot due to various challenges. The latest revised guidelines and standards for the charging infrastructure of EVs were released on 1 October 2019 with the prime objective of increasing the adoption rate of EVs in India. India has a vision of reducing its dependency on oil imports by 10% in the year 2022. Delhi, India, has set up a vision to deploy 500,000 or 25% of all new vehicles to be battery operated by 2024 [104]. The Indian government provides various incentives and subsidies on purchasing of EVs, as subsidies of Rs. 30,000 for two-wheelers and Rs. 1.5 lakh for four-wheelers to promote fast adoption of EVs, with direct transfer of subsidy to the beneficiary account holder. The government is modifying policies to waiving off-road tax and registration fees on EV. According to the India Energy Storage Alliance (IESA), it is expected that EVs will hit over 63 lakh units per annum by 2027 [105]. Moreover, the government has set up a target of 30% of all sold vehicles in India will be EVs by 2030 [106]. The Delhi government is targeting to set up 200 charging stations in the coming next year and eventually creating charging stations at every 3 km [107]. The National Electric Mobility Mission Plan was introduced in 2012 by the Indian government to promote the adoption of HEVs and PEVs and the Faster Adoption and Manufacturing of Hybrid and Electric vehicles (FAME) scheme in two phases was launched to provide incentives for EV adoption. The second phase of FAME started in 2019 and is planned to be complete by 2022. As an initiative of FAME II, by January 2020, 2636 EV chargers have been allotted the incentive in 24 states and union territories, out of which 1633 are fast chargers [10]. The State Electricity Board has set up flexible and separate electricity rates to influence EV charging behaviour. Delhi has issued the EV tariff of Rs.6–7/kWh, Andhra Pradesh has issued the EV tariff of Rs.6.95/kWh. Moreover, the various other states have refrained from adding fixed charges component to their EV tariffs and applied "Time-of-Day" (ToD) rebate/surcharge as part of their EV tariffs.

In the year 2020, due to the COVID-19 lockdown, major industries have to reassess their previous market outlook. Vehicle industry experts and many analysts have assessed that the year 2020 was to be the inflection point for the sale of EVs in India due to Auto Expo 2020 in Feb [108]. Due to the economic crises, there has been a falling of global crude price, which results in a relatively higher ownership cost of EVs in comparison to conventional ones. However, there has been positive news on EV adoption by new customers and citizens, as they are wishing to see a clear sky once again, breathe fresh air, and build a better home for the coming generation. The Indian government has remained committed to the implementation of the incentive on the sale of EVs and focusing on new and ambitious policies for EVs [109].

The current EV policy framework of India comprises of a public–private partnership to encourage the EV adoption rate, policies to provide incentives to EV owner along with regulatory reforms, expansion of EV charging infrastructure, and support indigenous production of EVs and other supply equipment along with battery manufacturing [110]. State governments in India like Delhi, Kerala, Andhra Pradesh, etc., through their policies and subsidies are also encouraging the easy adoption of EV [111].

5. Major Findings

The present work provides an in-depth analysis of the recent developments and challenges in the area of EVs and their charging infrastructure. The major finding from the present work is well elaborated below.

With the use of optimal charging scheduling technique, EVs can be utilized as a flexible load and minimizing the impact of the volatile nature of the renewable energy systems on the grid. Present researches showed that the use of metaheuristic techniques, along with the available optimization software, play an important role in the effective utilization of available resources. They have a wide area of application, including finding the optimal location for charging stations, planning and operation management of EV charging infrastructure, etc.

As a part of planning for EV charging infrastructure, the mobile charging station is conceptualized to assure EV owners that the charging facility will be made available to them if they are unable to reach the nearby charging station. Moreover, the bi-directional flow of energy using V2G technology provides ancillary services to the grid and maintaining the energy balance. The adoption rate of EVs is highly dependent on the availability of proper charging infrastructure with minimized charging time. The battery-swapping station showed its advantage of regulating the charging schedule of EV battery packs in a way to minimize its impact on the main grid. Moreover, it can serve as an energy backup unit and supply energy to the main grid at the time of peak load condition.

Developments in the area of EVs and their charging infrastructure with maximized utilization of available renewable energy sources have a vision of reducing the harmful emissions from the transportation sector. However, assessment of the damage that could be caused by the development of this new infrastructure on the environment is missing. The ongoing researches suggest that in the future, the hydrogen energy and fuel cell will play an important role in replacing the battery energy storage system, which at present is being used in the EVs.

The present scenario of electric vehicles and charging stations in India clearly explains its commitment towards the vision of reducing GHG emissions. The government of India has taken various initiatives to increase the manufacturing and the adoption rate of EVs. Along with this, suitable guidelines and policies are introduced to provide a favorable condition for the growth of EVs and its charging infrastructure. To proceed further in this step, various MoUs have been signed between public and private companies of India and abroad. Even in the time of economic breakdown due to the COVID-19 lockdown, the Indian government has remained committed to the implementation of the incentive on the sale of EVs and focusing on new and ambitious policies for EV.

6. Conclusions

The fast-depleting fossil fuels and increasing environmental concerns are playing a major role in promoting the developments in the field of EVs and their charging infrastructure. In the present study, it is found that the recent trends in researches are more focused on the development of new and fast EV charging infrastructure that can minimize the charging time of EVs, increasing the utilization of available renewable energies for EV charging, minimization of grid dependency for EV charging, and the optimal location of charging stations, which is mainly focused on planning a new location network. The part of reducing emission levels by using EVs and renewable energies for its charging is well addressed by the researches but for developing a fully environmental conscious EVCS infrastructure, it is important to take into account the environmental sustainability concerns that will be raised when new constructions for establishing EVCSs will take place. It may lead to accruing new lands, cutting trees, etc., which will further increase the problems. A solution to this would be the use of present infrastructure like parking lots at workplaces, shopping malls, etc., to develop EVCS. Moreover, acquiring the present refueling station and converting it into EVCS. The idea behind this is as the demand for petrol, diesel, etc., at the refueling station decreases with increase in the number of EVs and their charging demand, it would be more profitable to convert the existing refueling stations into EVCSs.

Adoption of new technologies like V2G, Smart Grid, Smart charging technique, etc., for EV charging will be very helpful in maintaining the energy balance of the power system and effective utilization of available renewable energy. It will also help in meeting customer satisfaction and economic charging rates. The development of an efficient network of communication for information exchange, optimization unit for reduced charging time, and prediction unit to help the best possible optimization are the key to the efficient operation of EV charging infrastructure. In the coming future, the development of charging stations will grow at a ramping pace but it is strongly recommended to take into account the environmental burdens and the global warming potential from these developments. To feed increasing electrical loads in form of EVs, whose demand is dynamic, a stable distributed or microgrid system network with maximized energy generation from a renewable energy system needs to be promoted to fulfill the motive of reduced dependency on fossil fuels and zero emission of environment polluting gases. In India, both Central and State governments, through their policies and regulatory frameworks, are encouraging the adoption of EVs. The process of transformation of the transportation sector from fossil fuel-based vehicles to EVs is slow due to many reasons including the manufacturing of EVs, expansion of power system, etc. The impact of COVID-19 has deeply affected the Indian economy and it will further delay the development process of EVs and their charging infrastructure.

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References

1. González, L.; Siavichay, E.; Espinoza, J. Impact of EV fast charging stations on the power distribution network of a Latin American intermediate city. *Renew. Sustain. Energy Rev.* **2019**, *107*, 309–318. [CrossRef]
2. US EPA. Climate Change Indicators: Greenhouse Gases. Available online: https://www.epa.gov/climate-indicators/greenhouse-gases (accessed on 5 September 2020).
3. NASA. Causes. Facts–Climate Change: Vital Signs of the Planet. Available online: https://climate.nasa.gov/causes/ (accessed on 5 September 2020).
4. Cai, H.; Jia, X.; Chiu, A.S.; Hu, X.; Xu, M. Siting public electric vehicle charging stations in Beijing using big-data informed travel patterns of the taxi fleet. *Transp. Res. Part D Transp. Environ.* **2014**, *33*, 39–46. [CrossRef]
5. Fachrizal, R.; Shepero, M.; Van Der Meer, D.; Munkhammar, J.; Widén, J. Smart charging of electric vehicles considering photovoltaic power production and electricity consumption: A review. *eTransportation* **2020**, *4*, 100056. [CrossRef]
6. Delmonte, E.; Kinnear, N.; Jenkins, B.; Skippon, S. What do consumers think of smart charging? Perceptions among actual and potential plug-in electric vehicle adopters in the United Kingdom. *Energy Res. Soc. Sci.* **2020**, *60*, 101318. [CrossRef]
7. Ritchie, H.; Roser, M. Emissions by Sector-Our World in Data. Available online: https://ourworldindata.org/emissions-by-sector (accessed on 5 September 2020).
8. Data & Statistics-IEA. Available online: https://www.iea.org/data-and-statistics?country=WORLD&fuel=CO2emissions&indicator=CO2emissionsbysector (accessed on 5 September 2020).
9. Bureau of Energy Efficiency. E-Mobility. Available online: https://beeindia.gov.in/content/e-mobility (accessed on 7 October 2020).
10. Bossche, P.V.D. *Electric Vehicle Charging Infrastructure*; Elsevier BV: Amsterdam, Netherlands, 2010; pp. 517–543.
11. Sanchez-Sutil, F.; Hernández, J.; Tobajas, C. Overview of electrical protection requirements for integration of a smart DC node with bidirectional electric vehicle charging stations into existing AC and DC railway grids. *Electr. Power Syst. Res.* **2015**, *122*, 104–118. [CrossRef]
12. Gavranović, H.; Barut, A.; Ertek, G.; Yüzbaşıoğlu, O.B.; Pekpostalcı, O. Tombuş, Önder Optimizing the Electric Charge Station Network of EşArj. *Procedia Comput. Sci.* **2014**, *31*, 15–21. [CrossRef]
13. Guo, S.; Zhao, H. Optimal site selection of electric vehicle charging station by using fuzzy TOPSIS based on sustainability perspective. *Appl. Energy* **2015**, *158*, 390–402. [CrossRef]
14. Bräunl, T.; Harries, D.; McHenry, M.; Wager, G. Determining the optimal electric vehicle DC-charging infrastructure for Western Australia. *Transp. Res. Part D: Transp. Environ.* **2020**, *84*, 102250. [CrossRef]
15. Domínguez-Navarro, J.; Dufo-López, R.; Yusta-Loyo, J.; Artal-Sevil, J.; Bernal-Agustín, J. Design of an electric vehicle fast-charging station with integration of renewable energy and storage systems. *Int. J. Electr. Power Energy Syst.* **2019**, *105*, 46–58. [CrossRef]
16. Statista. Worldwide Number of Electric Cars. Available online: https://www.statista.com/study/11578/electric-vehicles-statista-dossier/ (accessed on 7 October 2020).
17. Alhazmi, Y.A.; Mostafa, H.A.; Salama, M.M. Optimal allocation for electric vehicle charging stations using Trip Success Ratio. *Int. J. Electr. Power Energy Syst.* **2017**, *91*, 101–116. [CrossRef]
18. Sathaye, N.; Kelley, S. An approach for the optimal planning of electric vehicle infrastructure for highway corridors. *Transp. Res. Part E: Logist. Transp. Rev.* **2013**, *59*, 15–33. [CrossRef]
19. Clemente, M.; Fanti, M.P.; Ukovich, W. Smart management of electric vehicles charging operations: The vehicle-to-charging station assignment problem. *IFAC Proc. Vol.* **2014**, *47*, 918–923. [CrossRef]
20. Greene, D.L.; Kontou, E.; Borlaug, B.; Brooker, A.; Muratori, M. Public charging infrastructure for plug-in electric vehicles: What is it worth? *Transp. Res. Part D Transp. Environ.* **2020**, *78*, 102182. [CrossRef]
21. Wolbertus, R.; Jansen, S.; Kroesen, M. Stakeholders' perspectives on future electric vehicle charging infrastructure developments. *Future* **2020**, *123*, 102610. [CrossRef]
22. Benysek, G.; Jarnut, M. Electric vehicle charging infrastructure in Poland. *Renew. Sustain. Energy Rev.* **2012**, *16*, 320–328. [CrossRef]
23. Nie, Y.; Ghamami, M. A corridor-centric approach to planning electric vehicle charging infrastructure. *Transp. Res. Part B Methodol.* **2013**, *57*, 172–190. [CrossRef]
24. Ghosh, A. Possibilities and challenges for the inclusion of the electric vehicle (EV) to reduce the carbon footprint in the transport sector: A review. *Energies* **2020**, *13*, 2602. [CrossRef]

25. Green, R.C.; Wang, L.; Alam, M. The impact of plug-in hybrid electric vehicles on distribution networks: A review and outlook. *Renew. Sustain. Energy Rev.* **2011**, *15*, 544–553. [CrossRef]
26. Zhang, C.; Huang, Q.; Tian, J.; Chen, L.; Cao, Y.; Zhang, R. Smart grid facing the new challenge: The management of electric vehicle charging loads. *Energy Procedia* **2011**, *12*, 98–103. [CrossRef]
27. Farhoodnea, M.; Mohamed, A.; Shareef, H.; Zayandehroodi, H. Power quality impact of renewable energy based generators and electric vehicles on distribution systems. *Procedia Technol.* **2013**, *11*, 11–17. [CrossRef]
28. Borlaug, B.; Salisbury, S.; Gerdes, M.; Muratori, M. Levelized cost of charging electric vehicles in the United States. *Joule* **2020**, *4*, 1470–1485. [CrossRef]
29. Lee, J.H.; Chakraborty, D.; Hardman, S.J.; Tal, G. Exploring electric vehicle charging patterns: Mixed usage of charging infrastructure. *Transp. Res. Part D Transp. Environ.* **2020**, *79*, 102249. [CrossRef]
30. Shukla, R.M.; Sengupta, S. Cop: An integrated communication, optimization, and prediction unit for smart plug-in electric vehicle charging. *Internet Things* **2020**, *9*, 100148. [CrossRef]
31. Hao, Y.; Dong, L.; Liang, J.; Liao, X.; Wang, L.; Shi, L. Power forecasting-based coordination dispatch of PV power generation and electric vehicles charging in microgrid. *Renew. Energy* **2020**, *155*, 1191–1210. [CrossRef]
32. Wang, S.; Lu, L.; Han, X.; Ouyang, M.; Feng, X. Virtual-battery based droop control and energy storage system size optimization of a DC microgrid for electric vehicle fast charging station. *Appl. Energy* **2020**, *259*, 114146. [CrossRef]
33. Atmaja, T.D.; Amin; Amin, M.S. Energy storage system using battery and ultracapacitor on mobile charging station for electric vehicle. *Energy Procedia* **2015**, *68*, 429–437. [CrossRef]
34. Luo, L.; Wu, Z.; Gu, W.; Huang, H.; Gao, S.; Han, J. Coordinated allocation of distributed generation resources and electric vehicle charging stations in distribution systems with vehicle-to-grid interaction. *Energy* **2020**, *192*, 116631. [CrossRef]
35. Miele, A.; Axsen, J.; Wolinetz, M.; Maine, E.; Long, Z. The role of charging and refuelling infrastructure in supporting zero-emission vehicle sales. *Transp. Res. Part D Transp. Environ.* **2020**, *81*, 102275. [CrossRef]
36. ScienceDirect Topics. Fuel Cell Electric Vehicle-An overview. Available online: https://www.sciencedirect.com/topics/engineering/fuel-cell-electric-vehicle (accessed on 18 October 2020).
37. Sun, X.; Li, Z.; Wang, X.; Li, C. Technology development of electric vehicles: A review. *Energies* **2020**, *13*, 90. [CrossRef]
38. Das, H.; Rahman, M.; Li, S.; Tan, C. Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. *Renew. Sustain. Energy Rev.* **2020**, *120*, 109618. [CrossRef]
39. Mohammad, A.; Zamora, R.; Lie, T.T. Integration of electric vehicles in the distribution network: A review of PV based electric vehicle modelling. *Energies* **2020**, *13*, 4541. [CrossRef]
40. Khan, S.; Ahmad, A.; Ahmad, F.; Shemami, M.S.; Alam, M.S.; Khateeb, S. A comprehensive review on solar powered electric vehicle charging system. *Smart Sci.* **2017**, *6*, 54–79. [CrossRef]
41. Zhou, B.; Littler, T.; Meegahapola, L.; Zhang, H. Power system steady-state analysis with large-scale electric vehicle integration. *Energy* **2016**, *115*, 289–302. [CrossRef]
42. He, F.; Fathabadi, H. Novel standalone plug-in hybrid electric vehicle charging station fed by solar energy in presence of a fuel cell system used as supporting power source. *Renew. Energy* **2020**, *156*, 964–974. [CrossRef]
43. Iannuzzi, D.; Franzese, P. Ultrafast charging station for electrical vehicles: Dynamic modelling, design and control strategy. *Math. Comput. Simul.* **2021**, *184*, 225–243. [CrossRef]
44. Xi, X.; Sioshansi, R.; Marano, V. Simulation–optimization model for location of a public electric vehicle charging infrastructure. *Transp. Res. Part D Transp. Environ.* **2013**, *22*, 60–69. [CrossRef]
45. Rajagopalan, S.; Maitra, A.; Halliwell, J.; Davis, M.; Duvall, M. Fast charging: An in-depth look at market penetration, charging characteristics, and advanced technologies. In Proceedings of the 2013 World Electric Vehicle Symposium and Exhibition (EVS27). IEEE, Barcelona, Spain, 17–20 November 2013; pp. 1–11.
46. Khan, W.; Ahmad, F.; Alam, M.S. Fast EV charging station integration with grid ensuring optimal and quality power exchange. *Eng. Sci. Technol. Int. J.* **2019**, *22*, 143–152. [CrossRef]
47. Sachan, S.; Deb, S.; Singh, S.N. Different charging infrastructures along with smart charging strategies for electric vehicles. *Sustain. Cities Soc.* **2020**, *60*, 102238. [CrossRef]
48. Illmann, U.; Kluge, J. Public charging infrastructure and the market diffusion of electric vehicles. *Transp. Res. Part D Transp. Environ.* **2020**, *86*, 102413. [CrossRef]
49. Tulpule, P.J.; Marano, V.; Yurkovich, S.; Rizzoni, G. Economic and environmental impacts of a PV powered workplace parking garage charging station. *Appl. Energy* **2013**, *108*, 323–332. [CrossRef]
50. Luo, Z.; He, F.; Lin, X.; Wu, J.; Li, M. Joint deployment of charging stations and photovoltaic power plants for electric vehicles. *Transp. Res. Part D Transp. Environ.* **2020**, *79*, 102247. [CrossRef]
51. Gagarin, A.; Corcoran, P. Multiple domination models for placement of electric vehicle charging stations in road networks. *Comput. Oper. Res.* **2018**, *96*, 69–79. [CrossRef]
52. Xu, M.; Yang, H.; Wang, S. Mitigate the range anxiety: Siting battery charging stations for electric vehicle drivers. *Transp. Res. Part C Emerg. Technol.* **2020**, *114*, 164–188. [CrossRef]
53. Kong, W.; Luo, Y.; Feng, G.; Li, K.; Peng, H.; Keqiang, L. Optimal location planning method of fast charging station for electric vehicles considering operators, drivers, vehicles, traffic flow and power grid. *Energy* **2019**, *186*, 115826. [CrossRef]

54. Cassandras, C.G.; Geng, Y. Optimal dynamic allocation and space reservation for electric vehicles at charging stations. *IFAC Proc. Vol.* **2014**, *47*, 4056–4061. [CrossRef]
55. He, F.; Yin, Y.; Zhou, J. Deploying public charging stations for electric vehicles on urban road networks. *Transp. Res. Part C Emerg. Technol.* **2015**, *60*, 227–240. [CrossRef]
56. Lee, C.; Han, J. Benders-and-Price approach for electric vehicle charging station location problem under probabilistic travel range. *Transp. Res. Part B Methodol.* **2017**, *106*, 130–152. [CrossRef]
57. He, J.; Yang, H.; Tang, T.-Q.; Huang, H.-J. An optimal charging station location model with the consideration of electric vehicle's driving range. *Transp. Res. Part C Emerg. Technol.* **2018**, *86*, 641–654. [CrossRef]
58. Huang, Y.; Kockelman, K.M. Electric vehicle charging station locations: Elastic demand, station congestion, and network equilibrium. *Transp. Res. Part D Transp. Environ.* **2020**, *78*, 102179. [CrossRef]
59. Pan, L.; Yao, E.; Yang, Y.; Zhang, R. A location model for electric vehicle (EV) public charging stations based on drivers' existing activities. *Sustain. Cities Soc.* **2020**, *59*, 102192. [CrossRef]
60. Huang, K.; Kanaroglou, P.; Zhang, X. The design of electric vehicle charging network. *Transp. Res. Part D Transp. Environ.* **2016**, *49*, 1–17. [CrossRef]
61. Zhu, Z.-H.; Gao, Z.-Y.; Zheng, J.-F.; Du, H.-M. Charging station location problem of plug-in electric vehicles. *J. Transp. Geogr.* **2016**, *52*, 11–22. [CrossRef]
62. Kadri, A.A.; Perrouault, R.; Boujelben, M.K.; Gicquel, C. A multi-stage stochastic integer programming approach for locating electric vehicle charging stations. *Comput. Oper. Res.* **2020**, *117*, 104888. [CrossRef]
63. Lokhandwala, M.; Cai, H. Siting charging stations for electric vehicle adoption in shared autonomous fleets. *Transp. Res. Part D Transp. Environ.* **2020**, *80*, 102231. [CrossRef]
64. Iqbal, M.; Kütt, L.; Lehtonen, M.; Millar, R.; Püvi, V.; Rassõlkin, A.; Demidova, G. Travel activity based stochastic modelling of load and charging state of electric vehicles. *Sustainability* **2021**, *13*, 1550. [CrossRef]
65. Gnann, T.; Funke, S.; Jakobsson, N.; Plötz, P.; Sprei, F.; Bennehag, A. Fast charging infrastructure for electric vehicles: Today's situation and future needs. *Transp. Res. Part D Transp. Environ.* **2018**, *62*, 314–329. [CrossRef]
66. Bhattacharjee, A.; Mohanty, R.K.; Ghosh, A. Design of an optimized thermal management system for LI-ion batteries under different discharging conditions. *Energies* **2020**, *13*, 5695. [CrossRef]
67. Rigas, E.S.; Karapostolakis, S.; Bassiliades, N.; Ramchurn, S.D. EVLibSim: A tool for the simulation of electric vehicles' charging stations using the EVLib library. *Simul. Model. Pr. Theory* **2018**, *87*, 99–119. [CrossRef]
68. Liu, J.; Peper, J.; Lin, G.; Zhou, Y.; Awasthi, S.; Li, Y.; Rehtanz, C. A planning strategy considering multiple factors for electric vehicle charging stations along German motorways. *Int. J. Electr. Power Energy Syst.* **2021**, *124*, 106379. [CrossRef]
69. Anjos, M.F.; Gendron, B.; Joyce-Moniz, M. Increasing electric vehicle adoption through the optimal deployment of fast-charging stations for local and long-distance travel. *Eur. J. Oper. Res.* **2020**, *285*, 263–278. [CrossRef]
70. Huang, K.; An, K.; Correia, G.H.D.A. Planning station capacity and fleet size of one-way electric carsharing systems with continuous state of charge functions. *Eur. J. Oper. Res.* **2020**, *287*, 1075–1091. [CrossRef]
71. Deza, A.; Huang, K.; Metel, M.R. Charging station optimization for balanced electric car sharing. *Discret. Appl. Math.* **2020**, 1–11. [CrossRef]
72. Zhanga, X.; Peng, L.; Cao, Y.; Liu, S.; Zhou, H.; Huang, L. Towards holistic charging management for urban electric taxi via a hybrid deployment of battery charging and swap stations. *Renew. Energy* **2020**, *155*, 703–716. [CrossRef]
73. Nurre, S.G.; Bent, R.; Pan, F.; Sharkey, T.C. Managing operations of plug-in hybrid electric vehicle (PHEV) exchange stations for use with a smart grid. *Energy Policy* **2014**, *67*, 364–377. [CrossRef]
74. Schroeder, A.; Traber, T. The economics of fast charging infrastructure for electric vehicles. *Energy Policy* **2012**, *43*, 136–144. [CrossRef]
75. Sadeghi-Barzani, P.; Rajabi-Ghahnavieh, A.; Kazemi-Karegar, H. Optimal fast charging station placing and sizing. *Appl. Energy* **2014**, *125*, 289–299. [CrossRef]
76. García-López, F.D.P.; Barragán-Villarejo, M.; Maza-Ortega, J.M. Grid-friendly integration of electric vehicle fast charging station based on multiterminal DC link. *Int. J. Electr. Power Energy Syst.* **2020**, *114*, 105341. [CrossRef]
77. Amiri, S.S.; Jadid, S.; Saboori, H. Multi-objective optimum charging management of electric vehicles through battery swapping stations. *Energy* **2018**, *165*, 549–562. [CrossRef]
78. Bryden, T.S.; Hilton, G.; Cruden, A.; Holton, T. Electric vehicle fast charging station usage and power requirements. *Energy* **2018**, *152*, 322–332. [CrossRef]
79. Shi, R.; Lee, K.Y. Multi-objective optimization of electric vehicle fast charging stations with SPEA-II. *IFAC PapersOnLine* **2015**, *48*, 535–540. [CrossRef]
80. Zhang, Y.; He, Y.; Wang, X.; Wang, Y.; Fang, C.; Xue, H.; Fang, C. Modeling of fast charging station equipped with energy storage. *Glob. Energy Interconnect.* **2018**, *1*, 145–152. [CrossRef]
81. Seitaridis, A.; Rigas, E.S.; Bassiliades, N.; Ramchurn, S.D. An agent-based negotiation scheme for the distribution of electric vehicles across a set of charging stations. *Simul. Model. Pr. Theory* **2020**, *100*, 102040. [CrossRef]
82. Al-Obaidi, A.; Khani, H.; Farag, H.E.; Mohamed, M. Bidirectional smart charging of electric vehicles considering user preferences, peer to peer energy trade, and provision of grid ancillary services. *Int. J. Electr. Power Energy Syst.* **2021**, *124*, 106353. [CrossRef]

83. Singh, S.; Jagota, S.; Singh, M. Energy management and voltage stabilization in an islanded microgrid through an electric vehicle charging station. *Sustain. Cities Soc.* **2018**, *41*, 679–694. [CrossRef]
84. Yi, T.; Cheng, X.; Chen, Y.; Liu, J. Joint optimization of charging station and energy storage economic capacity based on the effect of alternative energy storage of electric vehicle. *Energy* **2020**, *208*, 118357. [CrossRef]
85. Ebrahimi, J.; Abedini, M.; Rezaei, M.M.; Nasri, M. Optimum design of a multi-form energy in the presence of electric vehicle charging station and renewable resources considering uncertainty. *Sustain. Energy, Grids Netw.* **2020**, *23*, 100375. [CrossRef]
86. ISO. ISO/IEC 7498-1:1994-Information Technology—Open Systems Interconnection—Basic Reference Model: The Basic Model. Available online: https://www.iso.org/standard/20269.html (accessed on 18 October 2020).
87. Napoli, G.; Polimeni, A.; Micari, S.; Andaloro, L.; Antonucci, V. Optimal allocation of electric vehicle charging stations in a highway network: Part 1. Methodology and test application. *J. Energy Storage* **2020**, *27*, 101102. [CrossRef]
88. Li, J.; Wang, F.; He, Y. Electric vehicle routing problem with battery swapping considering energy consumption and carbon emissions. *Sustainability* **2020**, *12*, 10537. [CrossRef]
89. Zhang, Z.; Sun, X.; Ding, N.; Yang, J. Life cycle environmental assessment of charging infrastructure for electric vehicles in China. *J. Clean. Prod.* **2019**, *227*, 932–941. [CrossRef]
90. Liu, Q.; Liu, J.; Le, W.; Guo, Z.; He, Z. Data-driven intelligent location of public charging stations for electric vehicles. *J. Clean. Prod.* **2019**, *232*, 531–541. [CrossRef]
91. Luo, Y.; Zhu, T.; Cao, K.; Li, K. The impacts of large scale electric vehicles charging behaviour on distribution system and local traffic system. *IFAC Proc. Vol.* **2013**, *46*, 651–657. [CrossRef]
92. Mouli, G.C.; Bauer, P.; Zeman, M. System design for a solar powered electric vehicle charging station for workplaces. *Appl. Energy* **2016**, *168*, 434–443. [CrossRef]
93. Fathabadi, H. Novel stand-alone, completely autonomous and renewable energy based charging station for charging plug-in hybrid electric vehicles (PHEVs). *Appl. Energy* **2020**, *260*, 114194. [CrossRef]
94. Pillai, R.K.; Suri, R.; Dhuri, S.; Kundu, S. Electric vehicle policies and electricity tariff for ev charging in India. *India Smart Grid Forum Rep.* **2019**. Available online: https://indiasmartgrid.org/reports/ISGF-Study-Report-EVCharging-India_July2019.pdf (accessed on 18 October 2020).
95. Guidelines Revised for EV Charging Infrastructure-Mercom India. Available online: https://mercomindia.com/guidelines-revised-ev-charging-infrastructure/ (accessed on 18 December 2020).
96. Revised Guidelines and Standards. Available online: https://powermin.nic.in/sites/default/files/webform/notices/Charging_Infrastructure_for_Electric_Vehicles%20_Revised_Guidelines_Standards.pdf (accessed on 8 October 2020).
97. Bayram, I.S.; Galloway, S.; Burt, G. A probabilistic capacity planning methodology for plug-in electric vehicle charging lots with on-site energy storage systems. *J. Energy Storage* **2020**, *32*, 101730. [CrossRef]
98. Mukherjee, S. ET Bureau Triton Electric Vehicle Inks MoU with BEL for Development of EVs and ESS-The Economic Times. Available online: https://economictimes.indiatimes.com/industry/auto/auto-news/triton-electric-vehicle-inks-mou-with-bel-for-development-of-evs-and-ess/printarticle/80742904.cms (accessed on 10 February 2021).
99. Express Drives Desk Tata AutoComp Signs MoU with Tellus Power Green to Install Electric Vehicle Charging Stations. Available online: https://www.financialexpress.com/auto/electric-vehicles/tata-autocomp-signs-mou-with-tellus-power-green-to-install-electric-vehicle-charging-stations-india-electricity-grids-rates/1988532/ (accessed on 10 February 2021).
100. The Hind Tata Power Signs MoU with MG Motor for EV Chargers. Available online: https://www.thehindubusinessline.com/companies/tata-power-signs-mou-with-mg-motor-for-ev-chargers/article31777096.ece (accessed on 10 February 2021).
101. Parikh, A. Signs MoU with Apollo to Install EV Charging Stations in its Hospitals Across India-Mercom India. Available online: https://mercomindia.com/eesl-mou-apollo-ev-charging-hospitals/ (accessed on 10 February 2021).
102. ET Bureau BSNL. EESL, BSNL in MoU for 1000 public EV Charging Stations. Available online: https://economictimes.indiatimes.com/industry/auto/auto-news/eesl-bsnl-in-mou-for-1000-public-ev-charging-stations/articleshow/74189836.cms?from=mdr (accessed on 10 February 2021).
103. EESL. NHAI Sign MoU for Solar Power, EV Charging Stations & LEDs at Toll Plazas. Available online: https://www.constructionweekonline.in/business/16398-eesl-nhai-sign-mou-for-solar-power-ev-charging-stations-leds-at-toll-plazas (accessed on 10 February 2021).
104. GNCTD, EV. Available online: https://ev.delhi.gov.in/ (accessed on 10 February 2021).
105. PTi Electric Vehicle Market in India Expected to Hit 63 Lakh Units per Annum Mark by 2027. Available online: https://auto.economictimes.indiatimes.com/news/industry/electric-vehicle-market-in-india-expected-to-hit-63-lakh-units-per-annum-mark-by-2027-iesa/79878253 (accessed on 11 February 2021).
106. Ranjan, A. Budget 2021 Electric Vehicle Expectation, Electric Vehicle Manufacturing India, Electric Vehicle Charging Station. Available online: https://www.indiatvnews.com/business/news-budget-2021-electric-vehicle-industry-expectation-manufacturing-charging-station-india-681440 (accessed on 11 February 2021).
107. Roy, S. Electric Vehicles Push: Subsidy to be Sent to Bank Account Soon. Available online: https://timesofindia.indiatimes.com/city/delhi/ev-push-subsidy-to-be-sent-to-bank-a/c-soon/articleshow/78470144.cms (accessed on 10 February 2021).
108. Taumar, D.; Priya, S. COVID-19 Impact on Electric Vehicles: Post COVID-19: Will Electric Vehicles Have to Wait in India? Available online: https://auto.economictimes.indiatimes.com/news/industry/post-covid-19-will-electric-vehicles-have-to-wait-in-india/75198159 (accessed on 12 February 2021).

109. Khurana, J. COVID-19 Outlook for Eectric Vehicles in India. Available online: https://www.wbcsd.org/Overview/News-Insights/WBCSD-insights/COVID-19-outlook-for-electric-vehicles-in-India (accessed on 12 February 2021).
110. International Energy Agency Global EV Outlook 2020. *IEA* **2020**. [CrossRef]
111. NRDC. Review of State EV Plans Across India Amidst COVID-19. Available online: https://www.nrdc.org/experts/anjali-jaiswal/review-state-ev-plans-across-india-amidst-covid-19 (accessed on 18 January 2021).