



# A technological overview & design considerations for developing electric vehicle charging stations

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## ARTICLE INFO

### Keywords:

EV charging station  
Optimization  
Renewable energy  
Energy storage system  
Off-grid  
Battery electric vehicle  
Hybrid electric vehicle  
Hydrogen fuel cell electric vehicle  
V2G  
Battery swapping

## ABSTRACT

In recent years, it is seen that there has been a huge expansion in the electric vehicles market aiming to reduce the impact of greenhouse gases. The deployment of an optimal and cost-effective electric vehicle charging stations similar to petrol/diesel stations with advanced control algorithms is necessary for the successful implementation. This review paper gives an overview of electric vehicles and various configurations about the design aspects of charging station. The charging stations are categorized on the basis of power utilized with various optimization algorithms, methods and future directions are presented to have an optimal design. And also, the highlights of grid connected combination of renewable energy based and grid connected, off-grid mode are summarized along with the future scope. Incorporation of renewable energy along with storage systems in the charging station can reduce the high load taken from the grid especially at peak times. By providing an overview of these key areas, the review study aims to provide a deep insight to the industry experts and researchers for future developments.

## 1. Introduction

One of the significant contributions in the transport field is the development of Internal Combustion (IC) Engine vehicles. However, larger number of automobiles have created serious problems in the life of humans. Air pollutants, global warming and the rapid emptying of oil supplies on earth creates a major threat to the environment. The various factors related to fuel usage and carbon dioxide(CO<sub>2</sub>) emissions on the road are studied in [1]. With reference to the studies done in the motor vehicles, it has been estimated that majority of the exhaust gases are produced in the first 300 s. The major factors which causes pollution are dependent on the road, temperature, vehicle speed and mass [2]. In the analysis from China's passenger vehicles, it can be inferred that the emitted greenhouse gases will raise within 2027 at the level of 810 megaton(mt) carbon dioxide equivalent (CO<sub>2</sub>e) [3].

In recent years, researchers are focused in developing a clean, efficient and smart vehicles incorporating Renewable Energy Technologies. Therefore, there exist the deployment of Electric and Hybrid vehicles, Fuel cell vehicles in focus of a green transport sector. With reference to the studies conducted from the literature it can be seen that replacement of Internal Combustion Engine vehicles with Electric vehicles (EVs) in

2017 promoted reduction in oxides of nitrogen [4]. There are many technologies developed in the market of Electric vehicles. In order to enhance the safety of electric vehicles a new slip control system is proposed. The main focus includes safety of vehicles, better acceleration and braking, maintaining the driver's safety, comfort and reduced usage of power [5].

Even though there are many technologies which are incorporated in Electric vehicles, there are some obstacles which has to be tackled for the fulfilment of a green transport sector. The major limitations that the electric vehicles facing today includes lack of charging facilities, long battery charging time and range anxiety. Fostering the electric vehicle (EV) industry an efficient well-equipped charging station that meets the vehicles requirement should be constructed. In order to encourage the electric vehicle manufacturers, the foremost thing is to identify an appropriate location and sizing for a charging station [89-90]. There are wide developments in view of developing an Electric Vehicle Charging Station (EVCS).

The main moto of this paper is there are many literatures available in the open source research network. But many of the papers failed to explain the design requirements for EVCS in various aspects. This paper mainly focuses on an overview of Electric vehicles and various configurations in the design aspects of Electric vehicle charging stations.

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**List of Abbreviations**

A	Ampere	IC	Internal Combustion
AC	Alternating Current	kW	kilo-Watt
BEV	Battery Electric Vehicle	kWh	kilo-Watt hour
BFA	Binary Firefly Algorithm	Li-ion	Lithium-ion
BST	Battery Swapping Technology	MINLP	Mixed Integrator Non-Linear
CO <sub>2</sub>	Carbon dioxide	MPDIPA	Modified Primal-Dual Interior Point Algorithm
CO <sub>2</sub> e	Carbon dioxide equivalent	mt	megaton
DCFC	Direct Current Fast Charging	PFCEV	Plug-in Fuel Cell Electric Vehicle
EPRI	Electric Power Research Institute	PHEV	Plug-in Hybrid Electric Vehicle
ESS	Energy Storage System	PSO	Particle Swarm Optimization
EVCS	Electric Vehicle Charging Station	PV	Photovoltaic
EVCS	Electric Vehicle	RESS	Renewable Energy Storage System
FCEV	Fuel Cell Electric Vehicle	SAE	Society of Automotive Engineer
GA	Genetic Algorithm	SEL	Substation Energy Loss
GA-PSO	Genetic Algorithm - Particle Swarm Optimization	SOC	State-of-Charge
GOA	Grasshopper Optimization Algorithm	TEL	Transportation Energy Loss
HEV	Hybrid Electric Vehicle	V2G	Vehicle-to-Grid
HFCEV	Hydrogen Fuel Cell Electric Vehicle	V <sub>AC</sub>	AC Voltage
		V <sub>DC</sub>	DC Voltage

Design of EVCS is done based on the power utilized. Various Algorithms and optimization methods are incorporated in order to have an optimal design.

The review paper is divided into mainly 6 sections. First section consists of introduction part where a brief overview of the review paper objective is presented. An overview of electric vehicles is described in the Section 2 where different categories of electric vehicles and the impacts of the electric vehicles are described. The Section 3 deals with Electric vehicle charging. Battery swapping, three different levels of charging are presented here. Section 4 deals with design aspects of EVCS, which is the core part of the review study. It consists of various optimization techniques used in the design and various configurations of Electric vehicle charging stations. Design of EVCS is categorized based on the power utilized. Results and discussion are presented in Section 5 and finally Section 6 presents the conclusion.

The main key contributions are:

- 1 Various Electric Vehicle Transportation Overview
- 2 The various configurations about the design aspects of charging stations are discussed and are categorized on the basis of power utilized.
  - a Battery Swapping Technology.
  - b Charging Station utilizing only grid power.
  - c Charging Station utilizing grid power and Energy Storage System.
  - d Charging station utilizing grid power and Renewable energy.
  - e Charging Station utilizing grid power, Renewable energy and Energy Storage System.
  - f Off-grid Charging Station.
- 3 And also, Various optimization algorithms, methods and future directions are described in this review study to have an optimal design.
- 4 The highlights of grid connected, combination of renewable energy based and grid connected, off-grid mode is summarized along with the future scope in the review study.
- 5 Incorporation of renewable energy along with storage systems in the charging station can reduce the high load taken from the grid especially at peak times.

## 2. An overview of electric vehicles

An Electric vehicle contains one or more electric motors for its traction and obtain its power from rechargeable batteries which is contained in the vehicle. In order to have a pollution free atmosphere, an

Electric vehicle is a suitable option. It is noted that the shift from IC engine powered vehicles to EVs reduces net CO<sub>2</sub> emissions. It is also estimated that the average CO<sub>2</sub> avoidance for the entire world is 16.24% under current conditions [6]. In order to promote the Electric vehicle industry, EVs tariffs should be such that it will minimize refuelling and grid reinforcement costs [7]. To promote Electric vehicle manufactures it is essential to establish a suitable charging location to improve vehicle range and anxiety regarding charging process [8,91,92].

### 2.1. Categories of electric vehicles

#### 2.1.1. Battery electric vehicles

Battery Electric Vehicle (BEVs) contains a battery, a motor and a controller. BEVs are powered by high-capacity battery packs that can be plugged into the mains from where the charging is done. Regenerative braking is also established in BEVs where the motor acts as generator and thereby the electrical energy obtained from the generator is stored in the batteries. With reference to the case studies done in taxis and private vehicles in Beijing, China, it can be identified that with home and public charging facilities, BEVs can replace a large portion of gasoline vehicles without affecting the transportation of individuals [9].

Lithium-ion (Li-ion) batteries are mainly used by the EV manufactures for storing energy. The significant features of Li-ion batteries are high energy density, less maintenance, various shapes, chemistries and performances [10]. Li-ion batteries are more reliable and plays a vital role in Electric vehicles [11]. Even though Li-ion batteries have a great impact in Electric vehicles, a systematic study in the failure mechanisms has to be considered for the smooth operation of Electric vehicles [12]. BEVs uses external socket for charging the battery. Due to the continuous improvement in the market of Plug-in electric vehicles, there are many technologies developed [13]. High fleet of Plug-in electric vehicles leads to development of an intelligent management system for avoiding negative impacts on distribution systems. Plug-in electric vehicles smart charging methods are presented in [14,86–88].

#### 2.1.2. Hydrogen fuel cell electric vehicle

The basic principle of a hydrogen fuel cell electric vehicles (HFCEVs) is that Hydrogen reacts with Oxygen to produce water and electricity which powers the wheels of the vehicle. Fuel cells are electrochemical devices similar to a battery that generates electricity to power an electric motor utilizing hydrogen and oxygen. There are various types of fuel cells based on the electrolyte used. Plug-in fuel cell electric vehicles

(PFCEVs) are the combination of BEVs and fuel cell electric vehicles (FCEVs). With reference to the case study done in California, the performance of PFCEVs are far better than BEVs and FCEVs [15]. According to the review status, it is seen that the current technologies are capable to perform better. But it can be inferred that it is not reliable and the intelligent methods are not satisfactory [16]. With the incorporation of well performed power electronic converters and improved research methods the performance of fuel cell system can be improved [17].

### 2.1.3. Hybrid electric vehicles

Hybrid Electric Vehicles (HEVs) combines the features of Electric vehicle and Internal Combustion Engine vehicles. It has two or more power sources. In order to establish a proper hybrid system, it is essential to have a power management strategy. Thereby by implementing an optimal controlled method hybrid vehicle can provide better fuel economy and improves efficiency of the system. [18]. Dynamic Programming, a global optimization technique is essential in the applications of Energy Management Strategy research [19]. It is seen that Adaptive Energy Management Strategy have better fuel economy rather than rule based [20]. The most prominent classification of Hybrid Electric vehicle is Plug-in Hybrid Electric vehicles [PHEVs]. Due to the large penetration of Plug-in Hybrid Electric vehicle, there needs a control mechanism to regulate the multiple loads fed to the grid. An estimation of distribution Algorithm [EDA] for effectively managing a huge number of PHEVs is proposed in [21]. It is seen that the proposed method were also compared with other techniques in order to specify its uniqueness. There are various categories of Hybrid Electric vehicle based on the configurations arrangement [22–25].

The Fig. 1 describes the general variants of Vehicle Transportation. The Table 1 exhibits the comprehensive view of IC Engine, HEV, HFCEV, and BEV.

## 2.2. Impacts of electric vehicles

Due to the tremendous progress in the field of Electric vehicles in view of depletion of greenhouse gas emissions, there have been more demand for electric power. Deployment of Electric vehicles have created more impacts in the power grid, Environment and Economy [25]. There have been both positive as well as negative effects due to the deployment of Electric vehicles. Fig. 2 describes an Outline of the effects of Electric Vehicles. As described there are several affects will impact the power grid, environment and economy. Due to vehicle charging methods the grid will affects with several voltage fluctuations, notches, flickering, imbalances, sag, swell and harmonics will restrict the power grid to operate with several limitations. The grid technology to be improved in the area of V2G (Vehicle-to-Grid), incorporation of smart grids and renewable energy systems with advanced technologies, control system designs and complex power system network. By keeping these factors, the overall cost of the system will increase and complexity of the system will ruin the efficiency. The EV's are bestowed towards the improvement of air quality which implies, CO<sub>2</sub> can also be substantially reduced when compared to conventional vehicles. However, EV's are silent

which can refine the environment with reduced noise levels [93–97].

## 3. Electric vehicle charging modes

### 3.1. Charging modes

Tremendous increase in the market of Electric vehicle necessitates the deployment of charging stations. Regulatory framework for charging Electric Vehicles is proposed in [29]. Based on that various charging modes such as EV private home charging mode, public charging mode and fast charging modes are formed. The Electric Power Research Institute (EPRI) and the Society of Automotive Engineers (SAE) classifies charging levels as alternating current (AC) Level 1, AC Level 2, and direct current fast charging (DCFC) Level 3 [30]. Level 1 charging is considered as the slowest charging due its long-time consumption for charging the electric vehicles. Whereas level 3 is considered as the fastest charging level. The Table 2 describes types of charging modes.

#### 3.1.1. Level 1 charging

This type of charging is mainly used in homes. It uses 120 V AC with a current rating of 15 A or 20 A. This type of charging can take 8 to 16 h for full charge of an EV battery. Level 1 charging are considered as the cheapest method, provided it is time consuming. It doesn't need any additional equipment for charging. Home charging can draw a power of 1.4–1.9 kW.

#### 3.1.2. Level 2 charging

Residential and Commercial charging stations incorporates Level 2 charging. It needs the installation of a charging unit and a cable. It also requires single phase 240 V AC having a current rating up to 40 A for private places. In additional three phase 400 V AC having a current handling capacity up to 80A is needed for public installation [30]. The charging time of level 2 charger is faster than level 1 charger. Level 2 charging mode takes 4 to 8 h for charging. This type of charging draws a power of 7.7–25.6 kW Power. There are some benefits offered for Electric Vehicle owners regarding installation of Level 2 home charging stations [31].

#### 3.1.3. Level 3 charging

Level 3 charging is also termed as DC (Direct Current) fast charging. It is considered as the most efficient and fastest charging method for Electric vehicles which gives answer regarding range anxiety of electric vehicles. DC Fast chargers are incorporated in commercial and public places. This type of charging provides 80% charge in 10–15 min. It is one of the promising technologies which will create a great impact in Electric vehicle charging stations. Level 3 chargers require a 480 V or higher rating of three phase circuits [32]. It is estimated that cost of DC fast charging differs according to the station and usage pattern [33]. Table 3 describes some of the latest Electric Vehicles and its specifications in India.

## 4. Design of electric vehicle charging station

The paramount concern of Electric vehicle is to establish a well-equipped charging station that meets the requirements of Electric vehicles such as range anxiety, charging facilities and minimum charging time. One of the threats faced by Electric vehicle is its charging time duration when compared with Internal Combustion vehicles which takes very few minutes for refuelling. Recently many technologies have developed such as dc fast charging stations which takes less than 20 min to recharge the vehicle [34]. A well-established charging station that equips advanced control techniques necessitates the growth of Electric vehicles. In view of developing a charging station one must note the adverse impacts of Electric Power grid. Due to the high power taken from Electric grid, there are various impacts created in the distribution network that includes voltage fluctuations, issues during peak time,

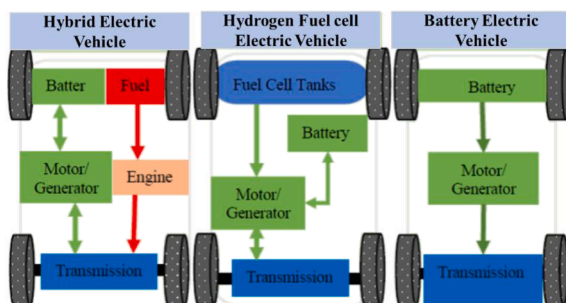


Fig. 1. Variants of Transportation in E-Mobility.

**Table 1**  
Overview of Transportation in E-Mobility.

S. No	Parameters	Conventional Vehicle	Battery Electric Vehicle	Hydrogen Fuel cell Electric Vehicle	Hybrid Electric Vehicle
1	Main Source	Petrol/Diesel	Battery	Hydrogen and Fuel Cell Stacks	Petrol/Diesel + Battery
2	Propulsion System	Internal Combustion Engine (ICE)	Electric motor drive with connected systems	Electric motor drive with connected systems	ICE + Electric motor drive
3	Refuelling System	Petrol/Diesel	Charging System	Charging System	Charging System + Petrol/Diesel
4	Advantages	More refuelling stations are available, Range is good,	Higher Efficiency, Remote Charging, Minimal Noise, Zero Emission	Good Efficiency, Low charge time, Minimal Noise, Zero Emission	Good Efficiency, Flexible to operate in low charge conditions, Low noise.
5	Disadvantages	More Noise, Higher in generating the emissions, Running cost is high	Range limitation, Charging Time is more, Charging Infrastructure, Still updating the technology.	Poor in technology due to lack of infrastructure, Capital cost is high	Technology Complex, Exhibits minimal emission,

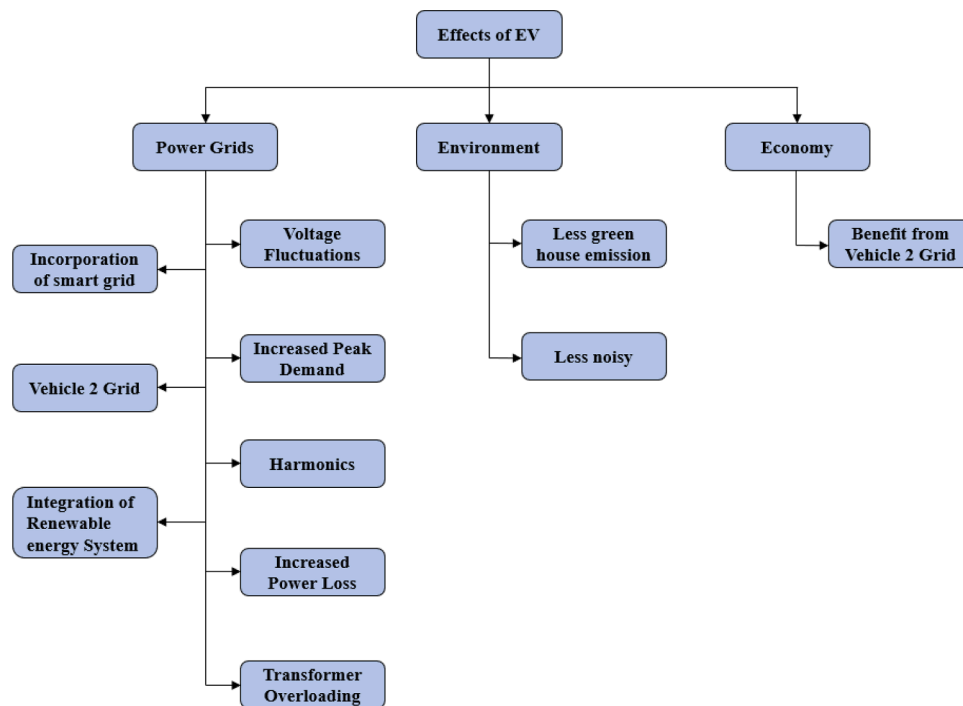


Fig. 2. Outline of the effects of Electric Vehicles [85].

**Table 2**  
Various levels of charging modes.

Different Conditions	Power Levels		
	Level-1	Level-2	Level-3
Grid Voltage	120/230 V <sub>AC</sub> and 12 A to 16 A	208/430 V <sub>AC</sub> and 15 A to 80 A	308 to 600 V <sub>AC</sub> or V <sub>DC</sub> and max 400 A
Power Range	<3 kW	<20 kW	>50 kW
Approximate Charging Time	17 h	8 h	<30 min
Grid Supply Type	1-Phase	1-Phase or 3-Phase	3-Phase
Charging Type	Slow Charge	Semi-fast charge	Fast Charging
Battery Capacity	20 kWh	20 kWh	20 kWh
EV Charging Use	Residential charger	Commercial spaces such as malls, offices etc.,	EV Charging Station required

increased power losses, Transformer loading problems [35,36]. In view of minimizing the adverse effect of electric power grid while designing the EVCS, one must incorporate various renewable energy technologies such as solar, wind and other sources. Electrical energy can be stored during excess production of electricity and inexpensive (especially from

**Table 3**  
Latest Electric Vehicles and its specifications in the country India [84].

Electric Vehicle	Battery Capacity (kWh)	Battery type	Home charging	Direct Current fast charging	Range (km)
Hyundai Kona	39.2	Lithium-Polymer	6 h 10 min	57 min	452
MG ZS EV	44.5	Lithium-ion	16 h	50 min	340
Tata Nexon EV 2020	30.2	Lithium-ion	8.5 h	60 min	312
Tata Tigor EV 2019	21.5	Lithium-ion	11.5 h	2 h	213
Mahindra e-Verito	18.55	Lithium-ion	11.5 h	1 h 30 min	140
Mahindra e2o	15	Lithium-ion	7 h 20 min	1 h 35 min	140

renewable energy sources) or when there is less demand and it should be further returned to the grid especially during high electricity prices. In order to facilitate this Battery Energy Storage Systems are used.

#### 4.1. Optimization techniques

Optimization is done for determining the optimal location and thereby sizing of a charging station. Optimization is the process of minimizing or maximizing a particular function for obtaining best possible solution for a given problem under defined set of constraints. In order to facilitate the design of an EVCS, suitable optimization algorithm is necessary. Optimization for charging station has mainly four steps such as to identify appropriate location [37,38], charging the vehicle by using energy management approach and choosing an appropriate optimization technique based on the objective [39]. Various Optimization techniques are used for the effective design of charging stations which are as followed:

- 1 Game theory [40,41].
- 2 Ant Colony Optimization [42].
- 3 Learnable Partheno-Genetic Algorithm [43].
- 4 Gravitational Search Algorithm [44].
- 5 Genetic Algorithm [45].
- 6 Mixed Integer linear programming [46].
- 7 Differential evolution.
- 8 Multi-Agent Particle Swarm Optimization [47].

In view of having an optimal design for charging station, it is essential to determine the design variable which is to be optimized. With reference to the literature [48], it can be identified that determining the size of charging station, number of vehicles in the charging station, state of the charge of battery, estimation of number of chargers to be placed in the station, energy storage system's capacity, power of converters are essential parameters in the optimization.

#### 4.2. Configurations for the design of electric vehicle charging station

Due to the increasing demand for Electric vehicles, there are large advances in the charging stations. In view of promoting the charging station it is essential to find the optimum location and sizing of charging station. In view of this various technologies and algorithms are developed. The different configurations of charging stations are categorized based on the utilization of power.

- 1 Battery Swapping Technology.
- 2 Charging Station utilizing only grid power.
- 3 Charging Station utilizing grid power and Energy Storage System.
- 4 Charging station utilizing grid power and Renewable energy.
- 5 Charging Station utilizing grid power, Renewable energy and Energy Storage System.
- 6 Off-grid Charging Station.

##### 4.2.1. Battery swapping technology (BST)

Exchanging the completely depleted battery or nearly depleted battery of electric vehicles with a fully charged battery is known as Battery swapping. Due to the rapid deployment of Electric vehicles, there needs an urge to develop Battery swap stations. Optimum models for battery swap stations in the distribution systems are developed in [26]. A modified differential evolution algorithm is used for solving the proposed method. In order to attain optimal operation in the Battery Swapping Stations, many optimization techniques are proposed in [27, 28].

By adopting the BST, the life of the battery packs will increase due to slow charging and it generates the revenue to fleet owners in longer run. The integration with grid or RESS (wind, solar and other modes of charging) is easier due to less complexity. The main drawback of BST is it can be adopted for less kWh due to heavy weight of the packing technology, huge stock is required which is high capital investment and charging infrastructure is required.

##### 4.2.2. Charging station utilizing only grid power

Due to the rapid rise in the electric vehicle market, there needs an urge to develop DC Fast charging stations. DC Fast charging stations are similar to petroleum stations where charging of electric vehicle is done within a few minutes. It is considered as the fastest charging mode. A careful planning in the design of charging station is essential to regulate the increasing demand of power taken from grid. Fig. 3 represents an outline of charging station utilizing only grid power. Sizing of charging station for Plug-in Electric vehicle is done using Markovian Demand Characterization in [49]. Here, optimal sizing of waiting spaces and chargers are determined based on the demand for charging.

The extension of this work can be carried out considering distributed generators, Power distribution network and transportation network. The improvement of voltage profile and reduction in network losses is performed in [50]. A modified primal-dual interior point algorithm (MPDIPA) is used to solve the optimal problem aiming to decrease the cost of the charging station. The factors such as traffic conditions, demand for charging is referred to be considered in the future. Minimization of total cost of charging station is also done in [34]. The cost of the land, charging cost, losses in the grid and vehicle due to the travel are also included here. A Mixed Integer Non-Linear (MINLP) optimization is done for appropriate placement of charging station and sizing. This is then solved by Genetic Algorithm. In order to support the long distance travel, it is essential to design location and capacity of charging station [51]. The optimization is done under a fixed budget constraint solved by a customized neighborhood search strategy. The extension of this work can be carried out using multiple charging facilities. Optimal allocation of fast charging stations are performed using Binary Firefly Algorithm(BFA) in [52].

The objective of the proposed algorithm focuses on minimization of cost with respect to transportation energy loss (TEL), substation energy loss (SEL) and build-up (BU) cost due to charging of EV. In the literature [53], Grid Partition Method and Genetic Algorithm is used for planning charging station for EV. Here the solution obtained is a local optimum rather than a global optimum solution.

##### 4.2.3. Charging station utilizing grid power and energy storage system

The increasing demand for electrical power in the charging stations is a great threat faced by distribution network. Therefore, increasing demand for electrical energy necessitate the need for Energy Storage Systems [54]. Fig. 4 represents a charging station utilizing grid power and Energy storage system. Energy Storage System (ESS) not only enhances distribution network performance but also station cost. Implementation of ESS in a fast charging station is done as a prototype [55]. A LabVIEW (visual programming language) control interface is also implemented. Optimum size of a fast charging station storage system is determined by [56].

The main objective carried out in the proposed method is to reduce storage system cost and thereby cost of the charging station. Simulations were carried out using MATLAB-Simulink. A control strategy was implemented along with a flywheel energy storage system (FESS) in [57]. Aiming to sustain the continuous charging process of the battery FESS is incorporated. The proposal was validated by a lab-scale prototype. A simulation model has been introduced to find the optimal design of ESS in [58]. It is estimated that lithium-ion batteries will be a prominent energy storage technology by 2025. Computational programming was done using Python programming. Deployment of fast charging stations are also implemented for battery bus systems in [59]. The model suggests that energy storage systems are a real solution for the growing demand for charging. The suggested model is a mixed integer linear programming model and solved using a CPLEX solver on a Dell computer.

##### 4.2.4. Charging station utilizing grid power and renewable energy

Rapid deployment of electric vehicles has led to increasing demand for electrical energy. Aiming to meet the surplus energy demand,

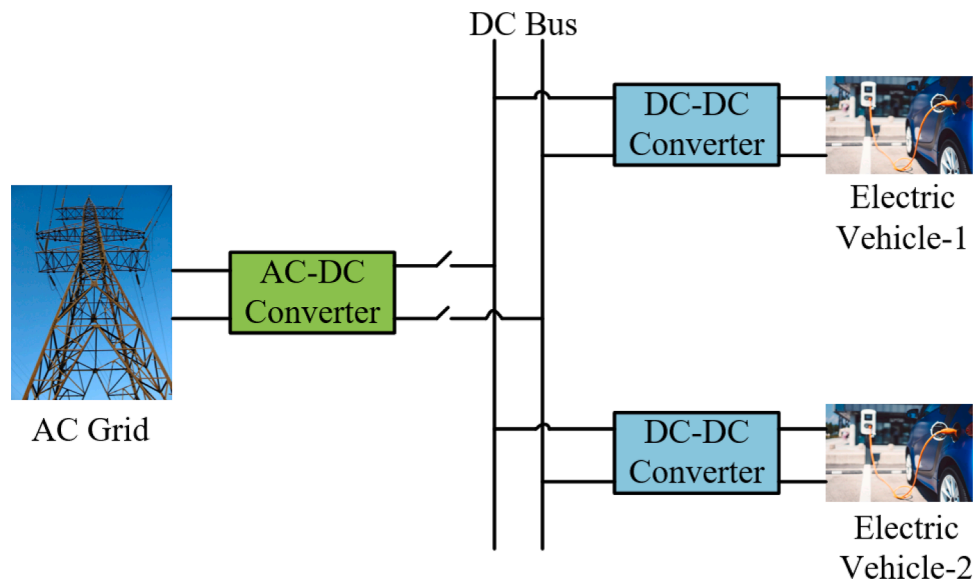


Fig. 3. Charging Station utilizing only grid power.

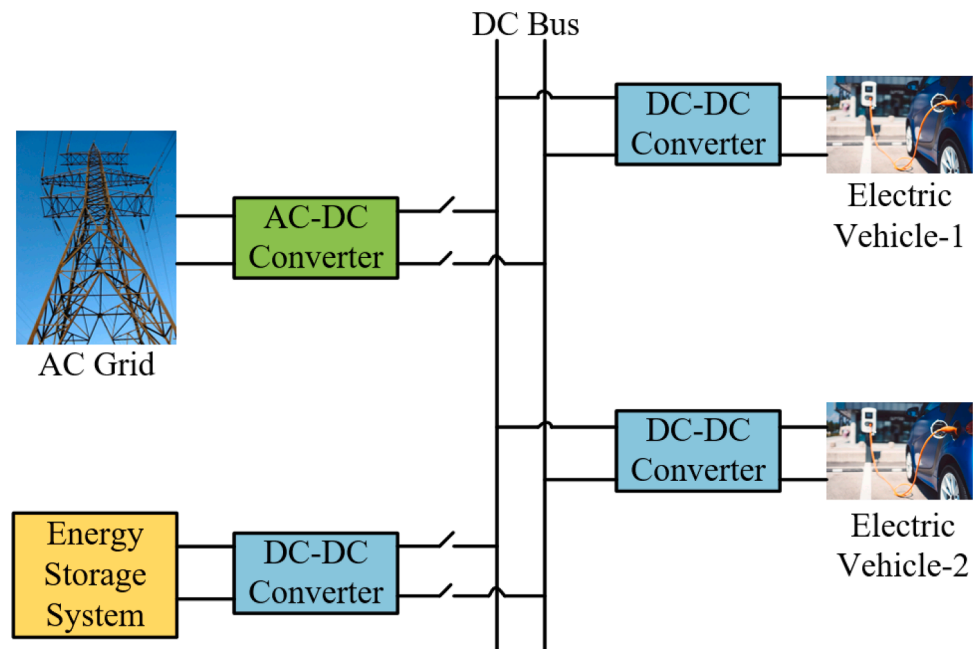


Fig. 4. Charging Station utilizing grid power and Energy Storage System [ESS].

utilization of renewable energy sources along with grid power are needed for the design of charging station. Fig. 5 represents a charging station utilizing grid power and renewable energy. Aiming for an optimum and quality exchange of power, Fast EV Charging stations are integrated with grid in [60]. Here a solar Photovoltaic (PV) generation system is integrated with the fast charging station for an Energy Management Strategy.

An optimum energy management is obtained by incorporating solar PV and thereby reducing the losses. Simulations were carried out using MATLAB-Simulink. In addition to sizing and placing of charging stations, it is also focused on sizing and placement of distributed generations, shunt capacitors by using Grasshopper optimization Algorithm [GOA] in [61]. This improves the power factor of the substation and thereby reduces the losses. Fast converging properties of GOA over Genetic Algorithm [GA] over Particle Swarm Optimization [PSO] is also

analyzed. An optimal static scheduling scheme for charging is proposed in [62]. Particle Swarm Optimization is used for the proposed method and later compared with Priority Algorithms for its significance.

A micro grid concept is also carried out for reducing the load from the grid and charging cost by properly transferring the EV loads. Aiming for reduction in power loss, charging cost and strengthening the voltage stability a Differential Evolution Algorithm is used in [63]. Similarly, an optimal placement and sizing of Renewable Energy Sources and Electric Vehicle charging stations simultaneously is done using hybrid optimization technique such as Genetic Algorithm –Particle Swarm Optimization (GA-PSO) in [64]. This methodology reduces losses, voltage deviations and cost by using Electric vehicles as active power sources. Even though incorporation of renewable energy sources along with grid power in the charging stations reduces the burden in the distribution network, a storage system is essential especially during peak times.

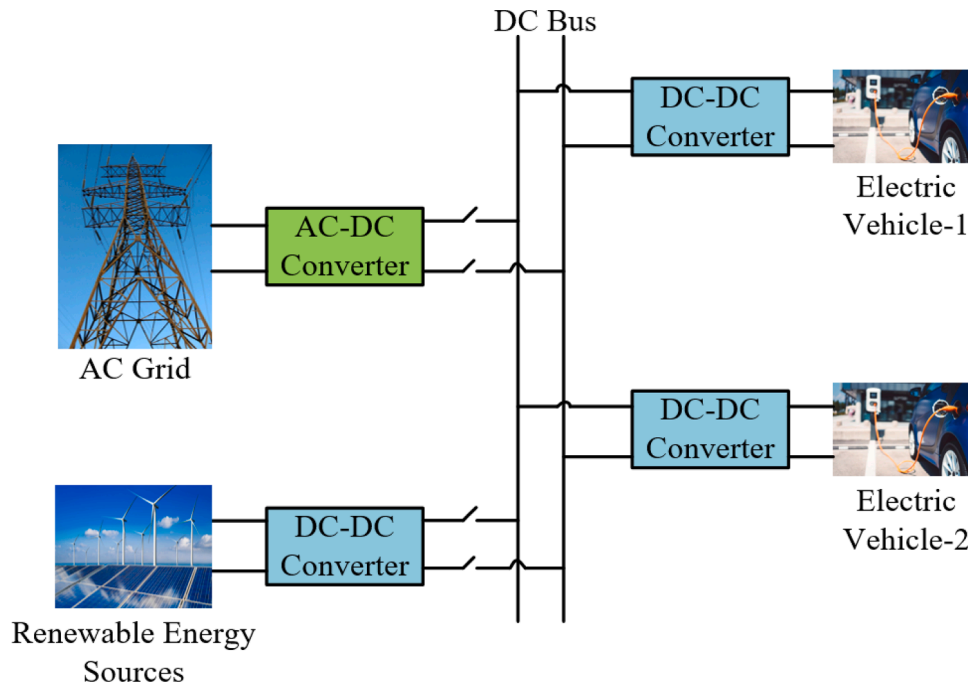


Fig. 5. Charging station utilizing grid power and Renewable energyTop of Form.

4.2.5. Charging station utilizing grid power, renewable energy and energy storage system (ESS)

The increasing demand for electrical energy in the charging stations will affect the performance of grid. Therefore, it is essential to incorporate renewable energy sources along with the charging station to support the grid by providing additional power especially during peak

times. ESS are installed in the charging stations to store and release the energy thereby balancing the issues faced from power grid. Installations of Energy Storage Systems in the charging stations helps to decrease the uncertainty in renewable energy power generation. Batteries are mainly used as storage systems.

Fig. 6 represents a charging station utilizing grid power, renewable

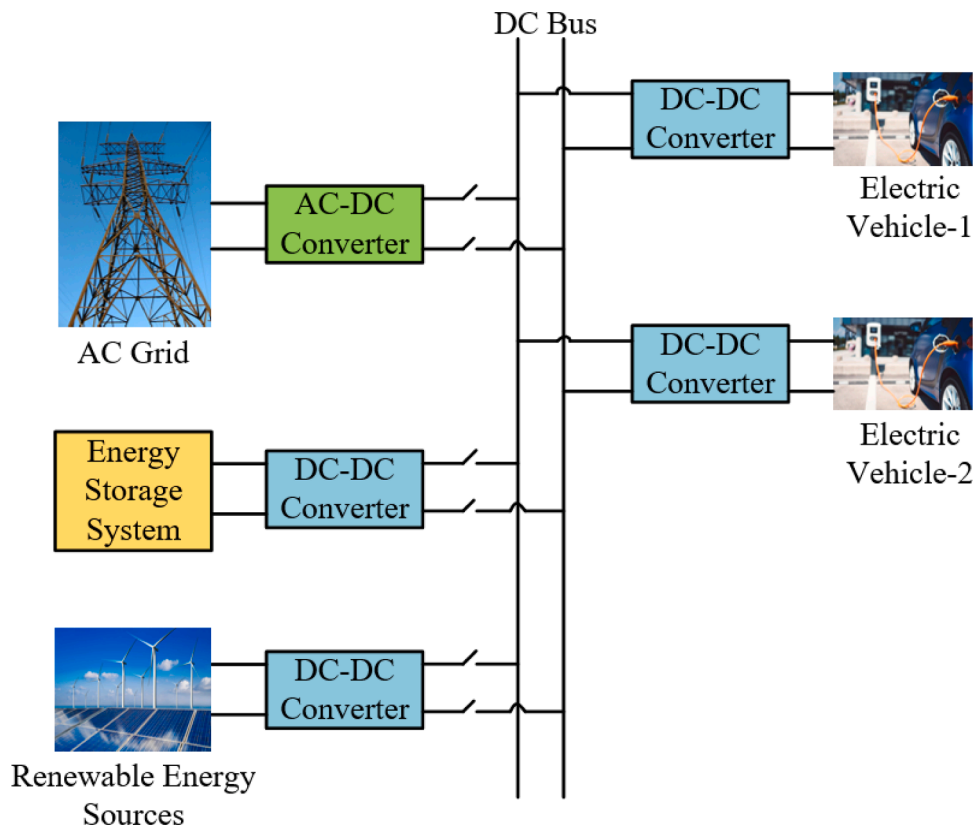


Fig. 6. Charging Station utilizing grid power, Renewable energy and Energy Storage System (ESS).

energy and Energy storage system. Integration of charging station with grid and wind energy which is solved using GAMS(General Algebraic Modelling System) tool box is done in [65]. The station contains slow, medium and fast chargers. The proposed method contains a storage system in which 85% of its energy can be discharged in an hour. Since solar energy have more uncertainties and variations compared to wind energy, the proposed method suggests to model solar energy in future. Design of fast charging station incorporating renewable energy sources and storage systems are performed using Genetic Algorithm [66,67]. With reference to the literature it can be concluded that incorporation of renewable energy sources along with storage systems lessen the high impact on the grid. But it needs a large investment for the implementation. EVCS is designed with slow, medium and fast chargers in [68].

The station contains Battery Energy storage system, diesel generator and solar panels. In future environmental pollutions, hydrogen and fuel cell vehicles, effects on upstream electric network can be incorporated in the model. An efficient design of charging station for optimal power management is performed using MATLAB/Simulink [69]. In the proposed method EVCS is integrated with solar energy and Battery Energy Storage System. The charging of battery electric vehicles at work places in Netherlands is investigated using solar energy [70]. It was estimated that usage of a small storage system of 10 kWh decreased the energy exchange from the grid by 25%. The outcome from this literature reveals that it was not so effective during winter season. In order to minimize the lifecycle cost, optimal design of EVCS is done considering environmental emissions [71]. Architecture of Charging Station design is done using HOMER Software. The method highlights that the usage of solar energy with ESS based isolated EVCS could have more benefits through grid connectivity.

An optimal sizing of a stand-alone micro grid with renewable energy sources and storage systems is done in [72]. The proposed design is done using Simulink Design Optimization [SDO]. The proposed method provide energy for charging electric and fuel cell vehicles. The main gap in the proposed method is that very few algorithms can be used with SDO. A DC micro grid set up is incorporated for fully electric and plug-in hybrid vehicles in [73]. The proposed architecture incorporates vehicle to grid operations, renewable energy sources and energy storage system. ESS plays a vital role in reducing the impact from the grid. In addition to this hierarchical energy management is adopted for real time application in [74].

Monte Carlo simulation is adopted to deal with uncertainties, Genetic Algorithm is used for optimization, Renewable energy, ESS and charging stations are considered for a new expansion model in [75]. Here, K-means clustering algorithm is used which is solved in Matlab programming. The proposed work can be improved in the future by considering the possibility that Electric vehicle can inject power into the network when unused. A combination of multi agent system and particle swarm optimization known as multi-agent particle swarm optimization (MAPSO) is proposed for optimization of grid connected renewable energy sources, energy storage and EVCS in [47]. The results confirmed that it has more accuracy and convergence speed when compared with Particle Swarm Optimization (PSO) and it minimizes the Cost of Electricity [COE]. An optimum energy management approach is proposed for the minimal intake of grid power and storage of PV energy in [76]. The model is simulated in Matlab/Simulink. A prototype model was also developed and experimented in the laboratory. Optimal operation model of PV assisted charging station is built in [77].

The model is solved by Particle Swarm optimization model. It is observed that through the appropriate coordination of Electric vehicles, PV power generation units and energy storage devices, optimum performance of charging station can be achieved. In [78] modelling of EVCS expansion is proposed using a hybrid algorithm combining Sample Average Approximation and Progressive Hedging Algorithm. It is recommended that different conditions of state-of-charge (SOC), traffic patterns, variations in electric power could be included in the future

expansion of this proposed model. Integration of renewable energy sources along with ESS with grid can store energy coming from renewable energy sources and also can feedback to grid when required. Utilization of renewable energy sources reduces the impact of high power taken from the grid especially during the peak times.

#### 4.2.6. Off-grid charging station

Off-grid charging stations are powered from distributed energy sources rather than utility grid. Therefore, one must give utmost care in the design and implementation of off-grid charging stations. An optimal Algorithm to design and implement off-grid charging station for electric and fuel cell vehicles is proposed in [79]. The uncertainty in the parameters as well as design of charging station is done by stochastic programming. Diesel generator is also included in the charging station thereby reduction of cost by 15%. Implementation of renewable energy systems in an off-grid EVCS for a villages is proposed by [80].

The proposed strategy uses wind energy, solar energy and an ESS to prevent the usage of diesel generators. However, there are several factors that one must encounter in order to propose a charging station utilizing renewable energy. A charging station consisting of renewable energy sources and fuel cell system for plug-in hybrid electric vehicles is proposed in [81]. Fuel cell system act as the storage device instead of batteries in the charging station. A microcontroller MC68HC11E9 programming is utilized here. In future, a grid tied version of proposed charging station is recommended. A solar charging station for electric vehicles incorporating storage backup is modelled in [82]. The proposed charging station is environment friendly. A micro grid connected with renewable energy sources is proposed for electric vehicle charging stations in [83]. The main focus is to reduce the power flow issues faced in United Kingdom national transmission system. The proposed method is simulated using MATLAB-Simulink tool boxes. Even though these technologies are more environmentally friendly compared to other techniques, while designing these charging stations one must consider the availability of the resources in order to meet the increasing demand for electric supply for the charging stations. The Table 4 describes the merits and demerits of various EV Charging Configurations.

## 5. Results and discussion

This section discusses the overall outlook of the review study. In view of developing a pollution free environment, EV is considered as a promising forthcoming option. There is a tremendous increase in the development of electric vehicles in order to promote a pollution free environment. Development of various charging stations are in progress for meeting the increasing demand for power. There are different options in which electric vehicle can be charged. In view of developing a public charging station, level 3 charging mode, which is also termed as DC fast charging is the best option for charging within short time duration. It can be implemented in public charging stations similar to petrol/diesel stations. Level 3 charging mode can be implemented in the electric vehicle charging stations in order to charge the vehicles within short time. It usually requires high power circuits for charging. It gives a solution concerned with range anxiety of electric vehicles.

The various factors that can be noted for building up an effective charging station.

### 5.1. Identification of optimal location

It is essential to have an optimal location for building an effective fast charging station. One must consider the availability of uninterrupted grid power, land cost, environmental factors for the selection of an apt location for the charging station. It is also noted that placing a charging station should be done in such a way that electric vehicles can be easily accessed to the charging station [37]. Travelling behavior of the electric vehicle should also be taken into account in consideration of suitable location for the charging station [38]. Charging station utilizing only



**Table 4**  
Overview of EV charging configurations.

EV Configurations	Merits	Demerits
Battery Swapping Technology	<ul style="list-style-type: none"> <li>Life of the battery packs will increase.</li> <li>Feet owners will get benefited in longer run.</li> <li>Waiting time is less.</li> </ul>	<ul style="list-style-type: none"> <li>Initial cost is high to setup.</li> <li>Charging Infrastructure is required.</li> <li>The global OEM's need to standardize the battery voltage, energy density and formfactors.</li> </ul>
Charging Station utilizing only grid power.	<ul style="list-style-type: none"> <li>Running cost will be less.</li> <li>It can be helpful in peak load levelling.</li> <li>Easy in operation.</li> </ul>	<ul style="list-style-type: none"> <li>Overloading the grid.</li> <li>Charging infrastructure is required with high capital cost.</li> </ul>
Charging Station utilizing grid power and Energy Storage System.	<ul style="list-style-type: none"> <li>Flexible in operating when failure occurs.</li> <li>ESS will give benefits to the owners.</li> </ul>	<ul style="list-style-type: none"> <li>Complex in system.</li> <li>Integration with grid is a major drawback.</li> <li>Capital investment is high.</li> </ul>
Charging station utilizing grid power and Renewable energy.	<ul style="list-style-type: none"> <li>Renewable Energy Station will generate the revenue.</li> </ul>	<ul style="list-style-type: none"> <li>Capital investment is high.</li> <li>Implement new/novel efficient algorithms which it increases cost of the system.</li> </ul>
Charging Station utilizing grid power, Renewable energy and Energy Storage System.	<ul style="list-style-type: none"> <li>Running cost is too low.</li> <li>Helpful to charge multiple sources at a time.</li> </ul>	<ul style="list-style-type: none"> <li>Complex in operation.</li> <li>Designing the system with effective control algorithms will requires more capital investment.</li> <li>Finding a faulty a system is difficulty.</li> </ul>
Off-grid Charging Station	<ul style="list-style-type: none"> <li>It doesn't depend on the grid power.</li> <li>It can be implemented anywhere from remote places.</li> </ul>	<ul style="list-style-type: none"> <li>Remote grids are overloaded, need to monitor simultaneously.</li> </ul>

grid power creates various impacts in the distribution network [25]. Therefore, it is essential to incorporate Renewable energy sources along with the charging station. Integration of Battery Energy Storage Systems helps in reducing the uncertainty associated with renewable energy sources. In order to determine suitable location for charging station, it is worthwhile to note the availability of renewable energy sources. The variations associated with renewable energy sources should be analyzed for the location of charging station.

### 5.2. Grid connected, renewable energy-based charging station

The various configurations of the charging station which is categorized based on the power utilized can be studied in Section 4. The large-scale deployment of electric vehicles leads to the development of well-equipped charging station. Due to the penetration of the increasing number of electric vehicles, there is an urge to extract more power from the grid for the EVCS. Therefore, a careful analysis in the design of charging station is essential to meet the increasing demand for power needed for charging the electric vehicles. Energy Storage Systems play a vital role in storing excess energy and release the energy when there is excess demand. Therefore, it is essential to incorporate battery energy storage systems along with the charging station. Table 5 summarizes the review aspects analyzed in Grid connected charging station.

Due to the tremendous increase in the development of electric vehicles, there is a huge demand for electrical energy to meet the charging demand for electric vehicles. Integrating charging station with renewable energy sources such as solar, wind etc. lessen the impact of high power taken from the grid. Implementing energy storage systems in the charging station provides a solution for the uncertainty in the renewable

**Table 5**  
Summary of the review aspects analyzed in Grid connected charging station.

Refs.	Highlights	Future Scope
[49, 53]	<ul style="list-style-type: none"> <li>Optimal number of chargers, waiting spaces in the fast charging stations are found out.</li> </ul>	<ul style="list-style-type: none"> <li>Inclusion of Distributed generators, Power distribution network and transportation network.</li> </ul>
[50]	<ul style="list-style-type: none"> <li>Minimize total cost associated with charging station.</li> </ul>	<ul style="list-style-type: none"> <li>Considering traffic pattern, charging demand of the electric vehicles.</li> </ul>
[50, 34, 52]	<ul style="list-style-type: none"> <li>Reduces network losses.</li> <li>Considers travel loss, land cost.</li> </ul>	<ul style="list-style-type: none"> <li>Uncertainty in the input parameters should be analyzed.</li> </ul>
[51]	<ul style="list-style-type: none"> <li>Solves large problem.</li> <li>5% optimality gap.</li> </ul>	<ul style="list-style-type: none"> <li>The uncertainty in charging behaviors should be estimated in the design model.</li> </ul>
[55]	<ul style="list-style-type: none"> <li>Peak shaving functions implemented.</li> </ul>	<ul style="list-style-type: none"> <li>More complex power system can be used for the analysis.</li> </ul>

energy power production. In order to integrate renewable energy along with grid connected charging station, it is essential to find out an appropriate location where renewable energy is abundant in nature. An appropriate energy management system should be maintained to have an optimal design of charging station. Table 6 analysis the review aspects carried out in grid connected charging station along with renewable energy.

### 5.3. Selection of optimization technique

A cost-effective charging station utilizing advanced techniques is essential for the successful implementation of charging station. Table 7 summarizes the techniques used in the design of charging station. It can be noted that Genetic Algorithm can handle complex problems and is faster in finding solutions to the problems [34,53,66,67,74]. Binary firefly Algorithm can also be used to solve large scale problems [51,52]. It can be analyzed from the literature that differential evolution algorithm requires huge computation time when compared with Genetic Algorithm-Particle Swarm Optimization hybrid Algorithm [63]. GOA and Particle Swarm Optimization are also used to solve problems regarding optimization [62,77]. It can be inferred that Multi-Agent Particle swarm optimization have more accuracy and convergence speed when compared with Particle Swarm Optimization [47]. Grasshopper optimization technique have fast converging behavior when compared with Genetic Algorithm and Particle Swarm optimization [61].

### 5.4. Energy management approach

The upcoming transport industry which solely depends on electric vehicle, construction of EVCS plays a vital role. With reference to the previous literatures focusing on design of EVCS it can be identified that in order to reduce the negative impacts from the grid, incorporation of renewable energy and storage systems are essential. An appropriate energy management is essential for maintaining optimum flow of energy among the various components in the charging station. An optimum energy management is focused based on the power flow in [60]. Renewable energy integration with the charging station reduces the dependency from the grid. Energy management of the charging station should be simulated for evaluating the station's operations [66,67]. An appropriate co-ordination between renewable energy sources, storage system, grid with the charging station is needed for the power management [69,74]. The main focus of the energy management approach is the minimal usage of grid power and maximize the usage of renewable energy [76].

**Table 6**  
Summary of the review aspects analyzed in Grid connected charging station along with Renewable energy sources.

Refs.	Highlights	Future Scope
[60, 61]	<ul style="list-style-type: none"> <li>An optimum energy management is maintained.</li> <li>Reduction of losses.</li> </ul>	<ul style="list-style-type: none"> <li>Unpredictable nature of renewable energy sources.</li> <li>Arrival and departure of large number of EVs.</li> <li>Variable market price.</li> <li>Uncertainty in input parameters.</li> </ul>
[63, 64]	<ul style="list-style-type: none"> <li>Reduction in Power loss.</li> <li>Improves voltage stability.</li> <li>Reduction of charging costs.</li> </ul>	
[66, 67]	<ul style="list-style-type: none"> <li>Incorporation of renewable energy sources along with storage systems lessen the high impact on the grid.</li> </ul>	<ul style="list-style-type: none"> <li>Investment is high.</li> </ul>
[70]	<ul style="list-style-type: none"> <li>Design of Photovoltaic system is performed.</li> <li>10 kWh local storage.</li> <li>Reduction of grid power 25%.</li> </ul>	<ul style="list-style-type: none"> <li>Solar tracking is not effective in winter.</li> </ul>
[71, 73]	<ul style="list-style-type: none"> <li>Environmental emissions are considered.</li> <li>Vehicle to grid operations, renewable energy sources and energy storage system are carried out.</li> </ul>	<ul style="list-style-type: none"> <li>High cost.</li> </ul>
[75]	<ul style="list-style-type: none"> <li>Investment needed for renewable energy sources, charging station, distribution network, energy storage system is jointly considered.</li> <li>Uncertainty associated with renewable energy sources are considered.</li> </ul>	<ul style="list-style-type: none"> <li>Electric vehicle can inject power into the network when unused.</li> </ul>
[78]	<ul style="list-style-type: none"> <li>Solves large size problems in a bounded time.</li> </ul>	<ul style="list-style-type: none"> <li>Variations in the state-of-charge, traffic patterns and electric power should be analyzed in the future.</li> </ul>

**Table 7**  
Summary of Techniques used in the Design of EVCS.

Configurations for the design of EVCS	Techniques/Optimization methods used
Utilizing only grid power.	Markovian Demand Characterization, Modified primal-dual interior point algorithm, Genetic Algorithm, Customized neighborhood search strategy, Grid Partition method, Binary Firefly Algorithm.
Utilizing grid power and ESS	Mathematical modeling, Python programming, mixed integer linear programming model, Visual programming language
Utilizing grid power and Renewable energy	Mathematical modeling, Grasshopper optimization Algorithm, Particle Swarm Optimization, Priority Algorithm, Differential Evolution Algorithm, Genetic Algorithm –Particle Swarm Optimization.
Utilizing grid power, Renewable energy and ESS	Multi-Agent Particle Swarm Optimization, Mixed integer linear programming, Genetic Algorithm, Stochastic programming, Mathematical modeling, K-means clustering Algorithm, Particle Swarm optimization, Sample Average Approximation and Progressive Hedging Algorithm.
Off-grid Charging Station	Stochastic Optimization Programming, Microcontroller programming, Mathematical modeling

5.5. Off-grid mode

In order to have an environment friendly charging station one can address off-grid charging mode. Off-grid charging mode doesn't depend on grid power. Off-grid charging station can be implemented in remote units. But one must give utmost care for meeting the increasing demand for electrical energy. Section 4.2.6 addresses off-grid charging mode. Here charging station regarding off-grid mode is discussed. Off-grid mode can be implemented where abundant amount of renewable energy is available. But uncertainty of renewable energy production is one of the key concerns.

5.6. Future research recommendations & research gaps

As per the literature survey of this paper, future research recommendations are jotted as follows:

- Improving the V2G technology can avoid peak demand sharing in the power systems network. This can be cost beneficial to fleet owners by

selling the power. Upcoming fellow researchers have to focus more on the power electronics technology to improve the V2G's.

- As of now many literatures are focused on the grid connected EV charging stations and there are few non-conventional EV charging stations are developing. However, there is a research gap in integrating the EV charging station with non-conventional sources if this can be sorted by improving the grid integration. Moreover, the major advantage is the running cost of the electricity will scale down in longer period.
- In the present EV marketing strategies competitors offering the higher mileage's, if the researchers will consider the advancements in regenerative braking strategies.
- In recent years many optimal algorithms have been developed in finding out the optimal locations and sizing. But the efficiency of the system is decreases due to improvements are carried in conventional algorithms. If researchers will focus on artificial intelligence and machine learning based algorithms which will improve the efficiency of the overall power system network.
- If BST can be improved the lifespan of the batteries will increases by reducing the no of charge and discharge cycles.
- Researchers may focus on over current, under voltage stress and losses in transmitting the power will reduces the impact on transformers.

A total of 97 publications were referred in the review study. Fig. 7 shows the status of the referred publications year-wise. References were taken from various reputed journals with high citations. And also Fig. 7 shows that most of the referred publications were taken from the year 2019. Fig. 8 shows various categories in which the review paper is arranged. It can be seen that 50% of review paper is focused on the design aspects of EVCS. Various optimization methods and techniques are incorporated to promote the deployment of EVCS.

6. Conclusion

The review study gives an overview of electric vehicles, impacts of electric vehicles, different charging modes, and various design methods for EVCS. Here a set of publications are identified from the year 1997 to 2020 in Fig. 7. Numerous literatures were brought out in such a way that various advancements in the charging station design are identified. Charging station design can be categorized into different segments depending on the power utilized. Due to the tremendous increase in the

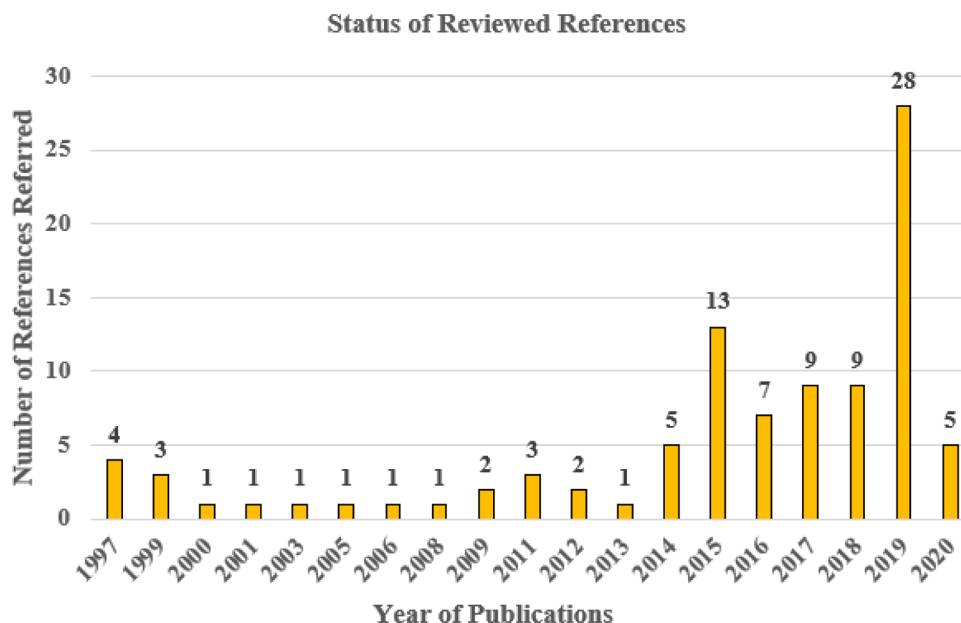


Fig. 7. Status of Reviewed References.

### Categories of Review Paper

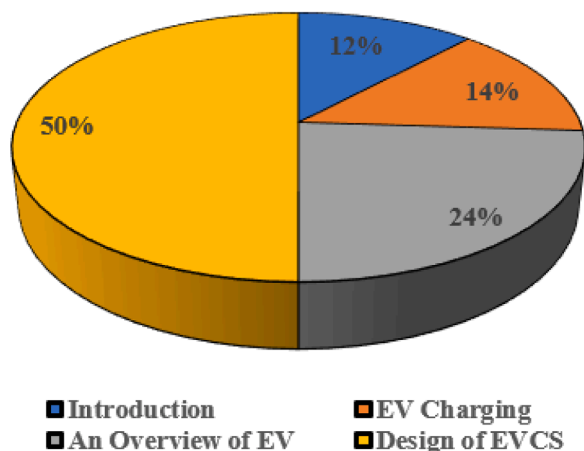


Fig. 8. Categories of Review paper.

electric vehicles, the demand for utilizing electrical energy increases. This creates a huge impact in the grid. Therefore, it is essential to incorporate renewable energy technologies with grid. Due to the uncertainties in the renewable energy, it is essential to incorporate energy storage systems. ESS can be used to store energy during excess renewable energy production and release energy when required. The major highlights of grid connected, renewable energy-based charging station, off-grid mode is analyzed in the review study. Different methodologies, optimization techniques and future scope are summarized and presented in the review study for providing an optimal design for the charging station. It can also identify that the usage of electric vehicle is directly proportional to development of charging stations. Therefore, one must give prior importance to the deployment of electric vehicles for a sustainable environment.

#### Declaration of Competing Interest

Authors having NO conflict of Interest.

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