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Review on optimal planning and operation of charging stations for electric vehicles

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ABSTRACT

Several factors need to be taken into account while planning the locations of electric vehicle charging stations. The thoughtful design and arrangement of charging stations, as a crucial component of the infrastructure supporting electric vehicles, is essential for the advancement of these kinds of vehicles. However, a number of intricate aspects, including policy economics, charging demand, user comfort when charging, and traffic circumstances, influence the design and arrangement of charging stations. With the goal to uncover competing interests and opportunities for collaboration in the operation and development of charging infrastructure, this study intends to assist researchers and technology developers in investigating cutting-edge techniques from the viewpoint of each constituent. Additionally, only a strong electric vehicle charging station (EVCS) infrastructure may provide some of the answers to the most basic EV concerns, like EV cost and range. The literature claims that several sorts of techniques, objective functions, and constraints for issue formulation have been used by the scholars. In addition, sensitivity analysis, vehicle to grid strategy, integration of distributed generation, charging kinds, objective functions, restrictions, EV load modelling, uncertainty, and optimization methodologies are examined for the most recent research publications. Discussions occur as well regarding the effects of the EV load on the distribution network, the environment, and the economy.

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1. INTRODUCTION

The market penetration of electric cars (EVs) as an environmentally friendly option has increased due to growing global concerns about environmental degradation and global warming. The increasing demand for in EV usage necessitates the development of ecological charging infrastructure. Because the driving range of EVs is restricted and depends on a number of factors [1], [2]. In terms of mobility and transportation, internal combustion engine vehicles (ICEVs) may soon be replaced by EVs [3]. In the distribution network, the erratic installation of EV charging stations presents a number of technical and financial challenges. Large voltage fluctuations, poor power quality, and harmonic injection are among the several technical problems [4], [5]. The number of EVs has increased since the turn of the twenty-first century, but there are still a lot of barriers preventing EV use on a broad scale. Some of the main obstacles to the widespread use of EVs are advancements in battery technology, a lack of charging stations, a lack of suitable infrastructure for charging, incorrect station sating, and inconsistent charging inside the stations [6], [7]. In this review, the following factors to be considered as opportunities, problems, and challenges related to electric vehicles, charging effects, EV charging technology connects an EVs system to the grid, optimal planning of charging infrastructure, optimal placement of charging station, performance optimization using heuristic algorithm, evaluation of EV charging infrastructure based on renewable energy, evaluation of EV impacts, complications with EV integration regarding power quality, current grid integration solution for EVs.

The literature survey on the optimal planning and operation of EV charging stations and their impacts on the grid highlights several key findings. Effective site selection, diverse charging technologies, accurate demand forecasting, and user-centric design are critical for optimal infrastructure deployment. Grid impacts include challenges in stability and reliability due to new demand patterns, necessitating advanced load management and infrastructure upgrades. Integration of renewable energy sources with charging stations offers environmental benefits, while economic and policy considerations play a significant role in financial viability. Overall, strategic planning and innovative technologies are essential to enhance grid resilience and support EV adoption.

2. OPPORTUNITIES, PROBLEMS, AND CHALLENGES RELATED TO ELECTRIC VEHICLES AND ITS CHARGING INFRASTRUCTURE

The demand for EVs is currently rising, which has resulted in a number of issues that people are actively working to resolve in order to lessen. Apart from the difficulties related to electric vehicles, there are also new prospects that are crucial for the advancement of any country. Figure 1 presents the opportunities and problems related to electric vehicles [8].

The goal of the EV charging challenge is to raise awareness of the various challenges that have impeded the popularity of EVs, such as infrastructure, cost, and driving range [9]. Several obstacles have been identified in the literature [10].

- Not all EV models support every kind of charging, and not every EV charging station offers every kind of charge. Users thus have difficulty locating infrastructure or stations that are appropriate for charging.
- There is currently no recognized standard for charging infrastructure device makers. It differs depending on the nation. When everyone adheres to the same standard, charging device costs decrease.
- At the moment, charging stations are primarily found in cities and are not found on highways.
- A lot of land is needed for a charging station with renewable integration, which is not possible in a city. However, this configuration is ideal for a highway location, where a lot of vacant land may be readily available.
- The charging station's layout is unique. Consumers encounter the issue because IC engine vehicles have the same refueling stations; nevertheless, if a standard platform for charging is developed, EV adoption will rise.

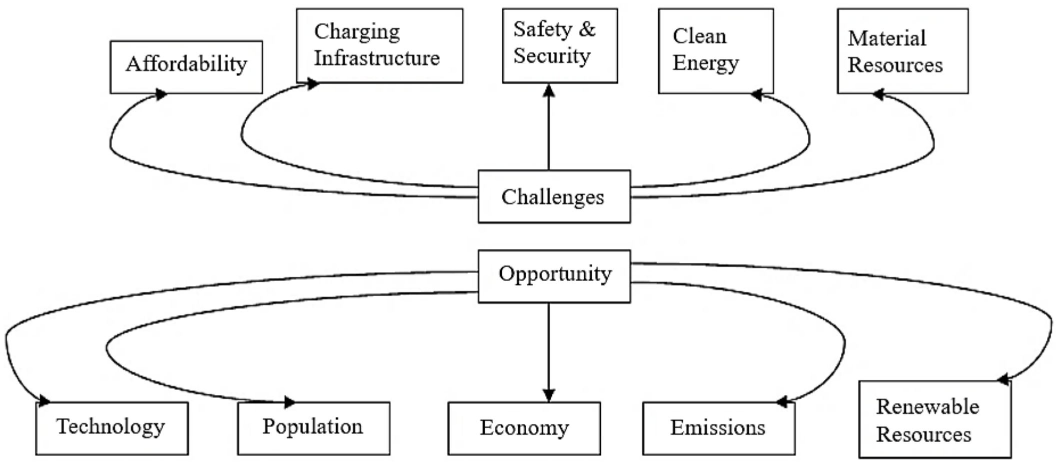

Figure 1. Opportunities and problems related to electric vehicles

3. CHARGING EFFECTS OF ELECTRIC VEHICLES

Significant issues and concerns regarding the stability and functionality of electrical grids are brought about by the growing use of electric vehicles (EVs). Due to the significant infrastructure needed for charging, EVs have a significant impact on power quality, voltage stability, and grid operations as a whole. Important problems that might put stress on power networks include voltage deviations, harmonic distortions in both voltage and current, and the possibility of overloading current distribution systems. Furthermore, these changing demands may result in increased consumption and stress on distribution grid components like transformers and circuit breakers. A number of factors, including as an increase of EV adoption, charging trends, and grid resilience, are crucial in determining the magnitude of these effects. The charging effects involving electric vehicles are shown in Figure 2.

- Stability of voltage: The capacity of the system to sustain the steady state voltage of all system buses following a disturbance from a specific initial operating point is known as voltage stability [11].
- Deviation in voltage: When EV load increases relative to the primary distribution system, voltage fluctuation mostly happens on the secondary distribution system. The discrepancy between nominal and actual voltage is known as voltage deviation. $VD = V_n – V_a$. Nominal voltage is V_n and actual voltage is equal to V_a [12], [13].
- Improve the maximum load: The grid is under increased stress during periods of most significant load, which reduces the reserve margin [14]. Examine the effects of charging in various scenarios, such as unregulated home charging and charging during off-peak hours on the distribution network [15].
- Issue with power quality: The nonlinear nature of the EV charging load is caused by a power quality issue within the system. Certain power quality issues, such as voltage sag, exist.
- Harmonic distortion of the voltage and current: Signal whose frequency is the reference signal's integral multiple in a power system, harmonic distortion arises from nonlinear loads or devices [16].
- Impact on the components of distribution: Upon reviewing numerous research articles, it has been shown that unregulated charging at a high penetration level has a very negative effect on the distribution system elements [17].
- Various elements influencing grid study results: Varying levels of penetration; appropriate load scheduling; appropriate system planning; diverse system configurations; equipment ratings; and the choice of power and distribution transformers.
- System failures: As more EV charging stations are added to the grid, load demand will rise. The system's loss rises in tandem with an increase in the load and current flows via the feeder [18].

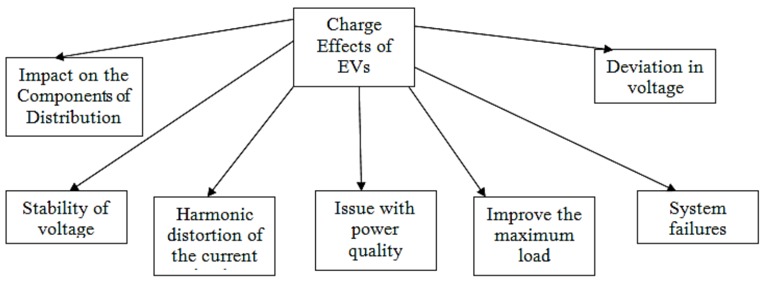

Figure 2. Charging effects involving electric vehicles

4. EV CHARGING TECHNOLOGY INTEGRATION TO THE GRID

As indicated in Table 1, EV charging technology connects an electric vehicle (EV) system to the grid, which can be divided into three tiers for AC and DC power. A number of workgroups, including the International Electromechanical Commission (IEC), the Society for Automotive Engineers (SAE), and CHAdeMO standards, have demonstrated their efficacy in developing EV charging standards [19]-[21]. Charger installation, charging level, energy source, and cable kinds are all factors that can be used to classify EV chargers [22]. EV battery charger architectures, grouped according to their unique features [23]. The different types of charging categories are also impacting on the operation of charging infrastructure.

In order ensure effective and dependable energy transfer to electric vehicles, EV charging technology is a sophisticated system that combines several components. It entails choosing the best installation configuration, controlling the flow of electricity from the grid or renewable energy sources, and coordinating with the necessary charging level to satisfy vehicle requirements. The installation process considers a number of factors, including the energy source, whether it be solar power or traditional grid electricity, the charging level, which specifies the charging speed (level 1, level 2, or DC fast charging), and the connector type, which establishes compatibility with various vehicle models. In order to maximize power transfer based on the particular needs of the infrastructure and vehicle, the procedure also incorporates multiple charger steps:

i) In accordance with power flow: Depending on which way the power is flowing, the EV charger can be unidirectional or bidirectional. EVs are charged using unidirectional charges, and they are discharged using bidirectional chargers. Vehicle-to-grid (V2G) applications, in which the electricity stored in the EV battery is used to feed power back into the grid, can be implemented with bidirectional chargers [24].

ii) Considering the installation of the charger: The on-board charger is located within the electric vehicle. When an electric vehicle (EV) is being charged off-board, the charger is placed in a certain spot to make connecting and power transfer easier. While the off-board charging method is renowned for its rapid charging capabilities, the on-board charging approach is usually characterized by a slower charging rate [25].

iii) Depending on the energy source: (a) AC chargers: The most costly and time-consuming kind of on-board charger is usually the AC charger. They have a limited power output; thus, they can only be used to charge cars with a specific capacity. (b) DC chargers are substantially less expensive and usually offer faster charging periods than AC chargers. They are usually more powerful, so they can charge cars with larger batteries. However, they are not flexible, and they might not be compatible with every type of vehicle.

iv) According to the charging level: EV chargers can be divided into three groups according to the amount of power they offer. Level 1, level 2, and level 3 are the names given to these categories. When charging an electric vehicle (EV) overnight, it is usually done in a garage using a level 1 charger, which charges at a slower rate than a regular household outlet. Level 2 charging is usually considered the standard method for both private and public facilities, requiring a 240-volt outlet. Three-phase systems are typically developed for public and commercial uses, such as petrol stations that use DC quick charging and level 3. A wide range of locations, including petrol stations, parking garages, shopping centers, hotels, rest areas, movie theatres, and restaurants, provide public level 2 and level 3 chargers. As the standard procedure for both public and private establishments [26], [27].

v) According to connector type: Electric vehicle charging outlets, plugs, and connectors are essential components of the infrastructure needed for EV charging. To recharge an electric vehicle's battery, a wide range of plugs and sockets are available; these differ based on the charging station, the nation, and the EV's manufacturer [28].

vi) Various charger stages: Single-phase or three-phase power flows with unidirectional or bidirectional power flows are available for electric vehicle charging devices. In public EV charging stations, three-phase chargers are used for quicker charging, while single-phase chargers are usually used for indoor or home charging applications [29].

Table 1. EV charging categories based on SAE standard

Type	AC			DC		
Charging speed	Slow	Semi-fast	Fast	Fast charging		
Level	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
Max V	120 VAC	240 VAC	-	200-500 VDC	200-500 VDC	200-600 VDC
Max I	12 A	16 A	-	80 A	200 A	400 A
Max P	2 kW	20 kW	>20 kW	40 kW	100 kW	240 kW
On/off board	On-board	On-board	-	Off-board	Off-board	Off-board
Grid connectivity	1-phase	1 or 3 phase	-	3-phase	3-phase	3-phase
Charging time	17 h	1.2 h	-	1.2 h	20 min	< 20 min
Connectors	J 1772	J 1772	to be ascertained	J 1772 combo	J 1772 combo	J 1772 combo

5. OPTIMAL PLANNING OF CHARGING INFRASTRUCTURE

Planning for charging infrastructure is difficult because of the country's disorganized road system, unpredictable traffic patterns, and clogged electrical grid. It was split into distinct sub-plans for the purpose of administering the entire plan [30]. The government places, the airport, the private locations, and the government firms comprised the sub-plans. A small number of organizations are chosen for the initial phase of the strategy in order to install EV stations on their property. These companies are: NITI Aayog, the Indian government (such as the North and South Block, Nirman Bhawan, and Udyog Bhawan), government-affiliated companies (GAIL, NTPC, Rural Electrification Corporation, Indian Oil, India Post), the DLF Mall of India (optional, requires discussion with the property owner), the National Highway Authority of India, and the Airports Authority of India should all be mentioned [31]. Because electric cars produce zero or extremely low exhaust emissions and produce significantly less noise, they contribute significantly to better traffic conditions and a healthier living environment [32], [33]. For the purpose of facilitating the adoption of electrically powered vehicles and promoting the use of affordable, clean electrical energy from the grid and renewable energy resources, the creation of an electric vehicle charging station and its ideal location are crucial [34], [35].

As illustrated in Figure 3, EV technologies can be divided into two primary components: electric propulsion systems and EV charging systems [36]. When driving, the electric propulsion system of an EV system provides the energy needed for the EV motor. The formula E = V*Q can be used to calculate the energy stored in an EV battery by multiplying the battery's voltage by its capacity [37], [38].

Optimal placement of charging station: Algorithm using cost, voltage level, maximum and minimum levels of active and reactive power, power balance equation, and the limit of charging station as objective functions for charging infrastructure planning. Every grid's cumulative score was computed. Additionally, each grid was given a rank determined by the total score. Furthermore, the grids with high rankings are likely to be the best places to locate EV stations [39].

A good charging station placement model should include the following qualities: The parameters of the distribution and transport networks must be considered by the model. The model needs to be able to account for the financial aspects of setting up charging stations. The model needs to account for the convenience of EV drivers. The distribution network's security must be taken into account by the model. Less computing power should be required for the model to generate the output planning outcomes [40].

Figure 4 presents a methodical perspective of the charging station installation. The choice of the test network where charging stations are to be installed is the first stage in solving the charging station placement challenge. Next, the parameters needed to calculate the best locations and quantity of charging stations are established. As a result, constraints and goal functions are established, and optimization is then carried out [41].

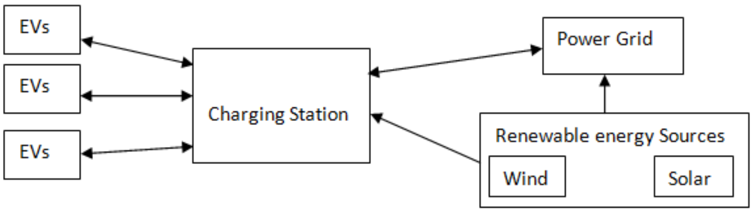

Figure 3. Charging infrastructure plan [36]

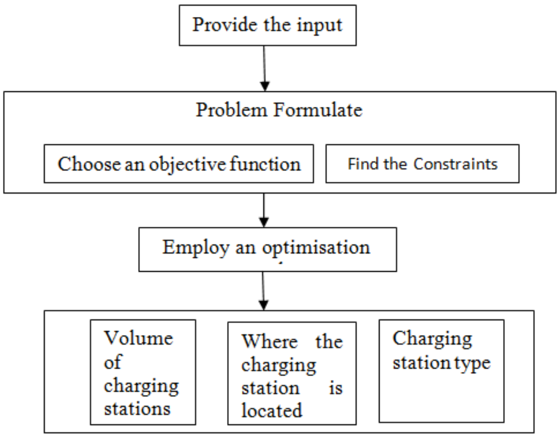

Figure 4. The steps involved in placing a charging station

6. HEURISTIC ALGORITHM BASED CHARGING INFRASTRUCTURE OPTIMISATION TECHNIQUES

The many heuristic algorithm targets established by capping the total expenses incurred when the charging station is required by the client. An optimization algorithm is an iterative process that compares several solutions until the best one is identified. The ideal location for a charging station can be determined using several kinds of optimization strategies as shown in Figure 5. The following algorithms, which are covered in this article [42].

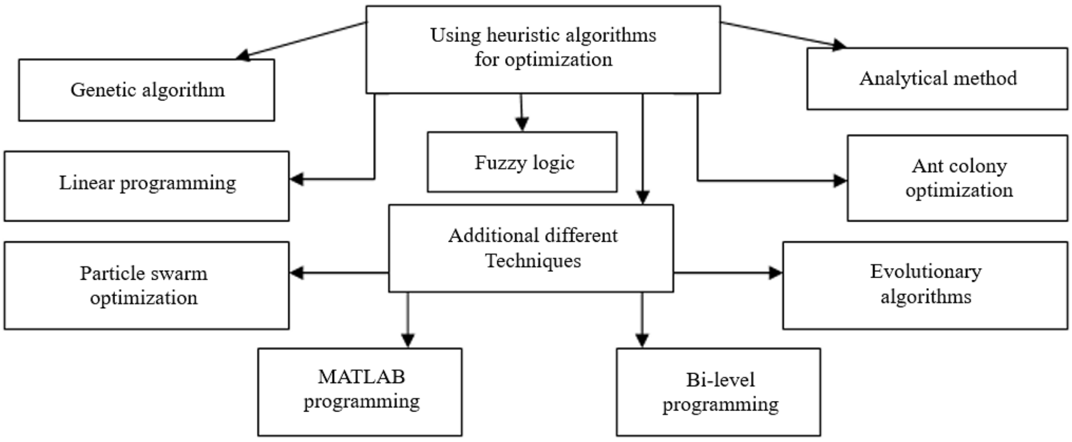

Figure 5. Different heuristic algorithms for optimization

Genetic algorithm: This program determines the best location for charging stations and establishes an efficient infrastructure for charging by drawing inspiration from Darwin's theory of evolution and the process of natural selection [43]. This method is employed, and the algorithm incorporates artificial intelligence and machine learning ideas. The advancement of DBN has made it possible to employ a genetic algorithm for automatic fault diagnostics in the electric charging station [44]. It is able to identify the best result within a certain search space. Genetic algorithms are primarily utilized in urban areas with higher traffic densities to reduce transportation expenses [45]. This method treats the charging station's power handling capabilities and traffic density as limitations. Predicting the population density, per capita car ownership, and the proportion of electric vehicles can yield the total number of electric vehicles, assuming that the square of a small area is known, in accordance with the theory of preservation of the regional transport flow of electric vehicles in the areas [46].

The cost incurred by clients on the path to the charging station is included in the total expenses taken into account in this work (C1), the cost of the electricity used en route to the destination charging station (C2) and the price of creating the desired power, which is the population's control (C3). These can be explained using (1)-(3).

$$C1 = A \times n\, \Sigma\, i = 1[(x - ai)2 + (y - bi)2]1/2 \quad (1)$$

$$C2 = G \times P \times n\, \Sigma\, i = 1[(x - ai)2 + (y - bi)2]1/2 \quad (2)$$

$$C3 = R \times P \times n\, \Sigma\, i = 1[(x - ai)2 + (y - bi)2]1/2 \quad (3)$$

The sum of the costs makes up the total expenses (C), as in (4).

$$C = [A + (G + R)P]n\, \Sigma\, i = 1[(x - ai)2 + (y - bi)2]1/2 = C1 + C2 + C3 \quad (4)$$

Whereby A is the user's average cost per kilometer, G is the cost of producing one kWh of electricity, P is an electric vehicle's power consumption per kilometer, and R is the cost of pollution control for kWh production. The coordinates of the charging stations are x and y, while the settlements are ai and bi. The algorithm's objective is to reduce the overall cost of charging. Given that A, G, R, and P are constants, minimizing the overall cost is equivalent to minimizing the total distance between communities and charging stations. The longitudes and latitudes of towns and charging stations are used to identify them, and the Haversine formula is used to determine the distances between them.

$$a = sin2\left(\frac{\varphi 2 - \varphi 1}{2}\right) + cos1cos\varphi 2sin2\left(\frac{\lambda 2 - \lambda 1}{2}\right)$$
$$c = 2Atan2(\sqrt{}a, \sqrt{}1 - a)$$
$$D = R \cdot c$$

Where R is the radius of the earth, φ is latitude, and λ is longitude. D is the total distance between settlements and the nearest charging station [47].

Analytical method: This approach involves formulating the problem while maintaining a range of market and technical parameters as variables. It then uses a variety of mathematical techniques, including differential equations, linear differential equations, Gauss Seidel iterations, and Gauss elimination methods, among others, to determine where the charging station should be placed [48], [49]. With this stochastic strategy, data optimization is required on a regular basis. This methodology provides an algorithmic and methodical way to locate the charging station in the most advantageous location while optimizing the transportation and distribution restrictions and optimizing earnings [50], [51].

Ant colony optimization technique (ACO): This method is highly prevalent for placing the charging station in the best possible location. By using this method, the electric charging station will be able to better schedule its loads based on the actual demand for charging. Using heuristic data and an algorithm that calculates the least amount of time and money needed to charge an EV while evaluating various limitations; this technique is employed as a smart charging strategy for electric vehicle routing [52]-[54].

Linear programming: An optimization method for a system of linear constraints and a linear objective function is called linear programming. The quantity that has to be optimized is defined by an objective function, and the aim of linear programming is to determine the values of the variables that maximize or minimize the objective function. Using this method, the overall expenditures can be reduced by accounting for the costs of land, transportation, and other expenses. This method can also be used to maximize energy efficiency, which is a crucial factor in choosing the best place for a charging station [55].

Adaptive systems and fuzzy logic: The charging station's renewable energy source is integrated with it, and the electric vehicle's power flow from several sources is managed by an effective fuzzy logic system. Fuzzy logic can be applied in order to accomplish the vehicle to grid capability. Due to its adaptive nature, fuzzy logic offers a wide range of membership function alternatives that can be modified to meet supply and demand needs [56]. Energy conversion from wind energy systems can make use of artificial neuro-fuzzy logic and progressive fuzzy logic [57]-[60]. Additional different techniques: i) optimization of particle swarms, ii) algorithms that evolve, and iii) the bi-level programming technique and MATLAB programming [61], [62].

7. EVALUATION OF RENEWABLE ENERGY BASED EV CHARGING INFRASTRUCTURE

Renewable energy-based EV charging infrastructure is a rapidly emerging technology that is revolutionizing the way our transportation networks are powered. By charging EVs using sustainable energy sources like solar, wind, and hydro power, we can reduce our dependency on fossil fuels and battle climate change. The application of this technology has the potential to improve public health, reduce air pollution, and open up new business opportunities. It is vital to evaluate the current systems and technologies in use before carrying out a study of EV charging infrastructure that makes use of renewable energy sources. Many considerations, including possible improvements in public health, lower carbon emissions, increased economic activity, and lower fuel usage, are taken into account by this method. Improved public safety, enhanced energy security, and more job possibilities should all be considered in the assessment. The difficulties associated with putting in place EV charging infrastructure that is dependent on renewable energy sources should also be taken into account by the inquiry [63]-[65]:

i) Advantages for the environment: Clean electricity is produced by hydropower, wind, and solar energy. By using renewable energy for EV charging, the transportation sector can reduce its carbon footprint and contribute to the fight against climate change.
ii) Energy self-sufficiency and durability: Imports of fossil fuels are decreased by the abundance and home production of renewable energy sources. Energy independence and resistance to disruptions in the fossil fuel supply chain can be increased by incorporating renewable energy into EV charging infrastructure.
iii) Savings on expenses: The cost of renewable energy is getting close to that of energy sources derived from fossil fuels. Time-of-use pricing and net metering can help consumers save money when charging EVs with renewable energy.
iv) Demand control and stability of the grid: Infrastructure for EV charging powered by renewable energy contributes to demand stabilization and reduction. Power supply and demand are optimized by planned or subsidized EV charging during periods of peak renewable energy generation.

8. EVALUATION OF EV IMPACTS ON GRID

The implications of electric vehicles (EVs) on society, the environment, and the economy have been the subject of extensive research in recent years. Nonetheless, the integration of EVs with the grid is one of the most recent trends in the current scenario impact evaluations. This evaluation should take into account the effects that e-vehicles have on the environment, the economy, and the electric grid, both directly and indirectly [66]. Among the environmental advantages are less reliance on foreign oil, improved energy security, decreased noise and air pollution, and decreased greenhouse gas emissions. Some of the societal effects include better public health, more accessible public transportation, and increased economic opportunities. Some of the economic effects include reduced fuel prices, more money invested in EV infrastructure, an improved trade balance, and faster economic growth [67]-[69]:

i) Economic repercussions: Due to their superior efficiency over traditional gasoline-powered vehicles and their ecologically friendly features, electric vehicles (EVs) have seen an enormous increase in popularity. Due to recent developments in battery technology, the expansion of the infrastructure for charging EVs, and the rising global demand from consumers, EVs have become increasingly popular globally [70]. Due to their constant power needs to satisfy daily recharge demands; EVs significantly strain the electrical system. Fuel and capacity costs for the production of electricity will rise as a result of the anticipated increase in demand for power. Furthermore, at times of peak demand, maintaining the grid becomes more difficult. One benefit is that EVs may be charged using renewable energy, which has benefits for the environment and the economy. Owners of electric vehicles (EVs) enjoy numerous benefits, which are mainly related to the exceptional effectiveness of electric motors and their very inexpensive power source. Because of this, these cars have lower running costs, making them a more cost-effective choice for buyers [71].

ii) Effects on the environment: In this situation, EVs and electrical grids must establish a relationship. Furthermore, by utilizing dependable and clean energy sources, the adoption of EVs within a vehicle-to-grid (V2G) ecosystem improves a society's resilience and sustainability. With less reliance on fossil fuels, the development of EV technology could significantly contribute to the creation of a more sustainable global environment [72], [73]. There are numerous environmental advantages of combining electric vehicles (EVs) with renewable energy sources (RESs). The implementation of a sustainable energy revolution is contingent upon the utilization of V2G technology.
   - Favorable effects: Because they don't require engine oil, EVs are better for the environment. EV brake pads are designed differently to prevent "corrosion, crumbling and failing early" and the associated high maintenance costs. EV makers have historically prioritized the use of recyclable and biodegradable components. EV chargers powered by renewable energy emit fewer emissions than petrol stations. Unlike petrol stations, charging stations can maintain "fuel" close by.
   - Adverse effects: Water scarcity, pollution, and habitat degradation are caused by the production of EV batteries; Extraction of battery metals such as cobalt, nickel, and lithium requires a lot of energy. Usually, these minerals are extracted in areas with poor environmental regulations; EV batteries were not designed with recycling in mind, however recycling-facilitating technology is advancing quickly; Premature tire wear is caused by the weight and torque of EVs. Pollution increases when tires are purchased more frequently.

iii) EV Integration's effect on the grid: The introduction of EVs into the electric system can result in grid instability because of variations in electricity supply and demand brought on by EV changes. The challenges of integrating EVs, include grid congestion, power quality problems, higher energy losses, and the requirement for more efficient charging methods. It then goes over possible fixes, including as smart charging, energy storage, and load control, to enhance grid stability and lower the cost of EV integration. Lastly, the difficulties that need to be addressed on a technological, financial, and regulatory level in order to facilitate the affordable and reliable integration of electric vehicles into the grid are discussed [74]-[78].
   - Grid stability affected by EV integration: EVs behave differently from traditional loads when charging from the grid due to their non-linear load behavior. The power system may be under stress as a result of this. The unpredictability of EV charging sites, times, and durations makes the estimate of this new load's behavior much more challenging. If a large number of EVs are charging at once, there may be questions about the power system's stability [79]-[81]. When compared to traditional loads, EV charging presents unique load characteristics. The region, amount of penetration, and duration of EV charging may all impact how stable the grid's voltage is after EV integration [82]. The unresolved issues surrounding the EV connection site, penetration level, and connection and disconnection times increase the load demand. Consequently, there may be a risk to the frequency stability of the grid [83]. An EV load has quite different features from regular loads. More so than regular system loads, the characteristics of negative exponential EV loads have an impact on the oscillatory stability of the power system [84]. EVs have the potential to significantly raise grid demand, particularly during peak charging times. The quantity of EVs, how they are charged, and the infrastructure for charging them all influence peak load rise. Peak electricity demand is predicted to rise when EVs are widely used [85]. Electrical infrastructure depends on transformers, and EV charging can accelerate the ageing of these components. Increased demand for EV charging may result in higher costs for transformer replacement or maintenance. A case study that looked at how EV charging influenced transformer ageing was conducted in a city where EV use is common [86].

The quality of power produced by the power system may be impacted by the incorporation of EVs. Many studies have been conducted on the consequences of EV integration, with a focus on power quality attributes in particular. Voltage profile, voltage imbalance, power losses, and harmonics are some of these features. The amount of EVs overall, system characteristics, charging characteristics, and other aspects all affect how power quality affects EV grid integration [87], [88]. Voltage swings are mostly dependent on the degree of integration and charging pace of EVs. Both the rate of charging and the number of individuals charged have an increasing effect. Voltage imbalance is more affected by the growing usage of single-phase charging for EVs. The grid voltage stability could be caused by it. More power is lost in single-phase and unregulated EV charging systems. Distribution transformer overloading and power losses are caused by increased EV penetration. The effect of electric vehicle penetration on harmonics is dependent on the penetration level and increases as the penetration level and charging rate increase. Furthermore, harmonics rise as a result of uncontrolled EV charging. There is a noticeable shift in frequency mismatch as a result of the integration and penetration of several EVs. The numerous EVs charging in an unorganized manner cause the grid to become imbalanced in frequency [89], [90].

9. CURRENT GRID INTEGRATION SOLUTION FOR EV's

There are multiple benefits to grid stability from the incorporation of EVs. For the grid's frequency and voltage support, the EVs must be carefully inserted into and used inside the system. The grid's stability in terms of voltage and frequency is negatively impacted by improper use of EVs [91].

A combination of smart charging, smart grid infrastructure, and advanced EV-charging management systems enable optimal charging schedules, real-time monitoring, and energy distribution; vehicle-to-grid (V2G) technology allows EVs to return excess energy to the grid, enhancing grid resilience; and the integration of renewable energy sources and state-of-the-art power electronics further supports sustainable and cost-effective energy use throughout the system. As the number of electric vehicles (EVs) increases, it is essential to integrate EVs into the grid in order to ensure efficient energy management and stability.

- Smart charging: This invention maximizes EV charging procedures to prevent overloading the power system. It makes it possible to plan EV charging at off-peak times or in accordance with the availability of renewable energy.
- Smart grid: Using information and communication technology, smart grids are designed to automatically detect, monitor, and control the flow of energy between power providers and end users. EVs can be charged and discharged in a smart grid in a coordinated manner that permits the integration of renewable energy sources like solar and wind power into the system [92].
- EV-charging management systems: By optimizing the quantity of energy that electric vehicles (EVs) take from the grid, these systems can lessen the strain on distribution networks and distribution transformers. Furthermore, contributing to the decrease in EV charging costs are these systems, which provide usage-based or dynamic pricing.
- Vehicle-to-grid (V2G): V2G technology allows EVs to supply electricity to the grid. By providing additional energy during peak hours, this benefits the grid's frequency regulation service [93].
- EV/grid interoperability standards: These guidelines can help to guarantee the safe and efficient integration of EVs into the grid. These standards may result in grid compatibility for the hardware and software used for EV charging.
- Renewable energy sources: Renewable energy sources like solar and wind power can be used to charge electric vehicles. As a result, there is less reliance on fossil fuels and less greenhouse gas pollution.
- Electric vehicle supply equipment (EVSE): By lowering the amount of power needed for EV charging, it helps reduce grid overload [94].
- Power electronics: EV-to-grid energy transfer is facilitated, regulated, and enhanced via power electronic converters. Improvements in energy flow management and appropriate EV grid integration are made possible by converter advancements [95].

10. CONCLUSION

The overview of literature offers a thorough examination of the most current advancements and difficulties pertaining to EVs and the infrastructure supporting their charging. An overview of the primary issues influencing the uptake of electric vehicles the accessibility of charging infrastructure and the availability of energy resources is provided. Depending on the charging technology and region, we go over different kinds of charging infrastructure. The ideal locations for charging stations are also reviewed in this paper, along with objective functions and optimization methods. A thorough analysis of these infrastructures is provided, along with a look ahead at them. As a result of the widespread use of electric vehicles (EVs), a number of EV structures, EV charging infrastructures, EVs powered by renewable energy sources, and grid-integrated EV systems have emerged. For multi-source EV systems, it is vital to apply a unique control approach and power management technique in order to efficiently manage the charging process.

The following is a list of some forthcoming initiatives in this field: i) Artificial intelligence can be utilized to improve the capabilities of charging stations once the notion behind them develops. Systems that charge automatically can make use of this. These systems are also capable of optimizing themselves to fit various scenarios, including operating at peak efficiency; and ii) India is experiencing a boom in renewable energy. As electric vehicle technology advances, it is essential to integrate solar photovoltaics and other renewable energy sources to meet a substantial portion of the EV's charging requirement and add additional power supply.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration. All authors contributed to the overall conceptualization and design of the review article. They worked collaboratively to define the scope and objectives of the study. The methodology was developed jointly by the authors, with each contributing their expertise in different aspects of charging station planning, operation, and optimization for electric vehicles (EVs). The validation of the findings, including models and analyses, was carried out by all authors; all authors managed the project, ensuring effective collaboration and timely completion of the review article.

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K. R. Satish	✓	✓		✓		✓				✓	✓		✓	
Arunkumar Patil	✓	✓		✓		✓	✓			✓	✓	✓	✓	
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest regarding the publication of this paper.

DATA AVAILABILITY

This review paper does not involve the use of original datasets. All data and information discussed are derived from publicly available sources and existing literature. No new data were created or analyzed in the preparation of this manuscript.

REFERENCES

[1] Y. Wu and L. Zhang, "Can the development of electric vehicles reduce the emission of air pollutants and greenhouse gases in developing countries?," *Transportation Research Part D: Transport and Environment*, vol. 51, pp. 129–145, 2017, doi: 10.1016/j.trd.2016.12.007.

[2] H. Yu and A. L. Stuart, "Impacts of compact growth and electric vehicles on future air quality and urban exposures may be mixed," *Science of The Total Environment*, vol. 576, pp. 148–158, 2017, doi: 10.1016/j.scitotenv.2016.10.079.

[3] M. H. Amini, M. P. Moghaddam, and O. Karabasoglu, "Simultaneous allocation of electric vehicles' parking lots and distributed renewable resources in smart power distribution networks," *Sustainable Cities and Society*, vol. 28, pp. 332–342, 2017, doi: 10.1016/j.scs.2016.10.006.

[4] S. Deb, K. Kalita, and P. Mahanta, "Review of impact of electric vehicle charging station on the power grid," in *2017 International Conference on Technological Advancements in Power and Energy (TAP Energy)*, Kollam, India, 2017, pp. 1–6, doi: 10.1109/TAPENERGY.2017.8397215.

[5] S. Pazouki and J. Olamaei, "The effect of heterogeneous electric vehicles with different battery capacities in parking lots on peak load of electric power distribution networks," *International Journal of Ambient Energy*, vol. 40, no. 7, pp. 734–738, Oct. 2019, doi: 10.1080/01430750.2017.1423382.

[6] J. C. Mukherjee and A. Gupta, "A review of charge scheduling of electric vehicles in smart grid," *IEEE Systems Journal*, vol. 9, no. 4, pp. 1541–1553, Dec. 2015, doi: 10.1109/JSYST.2014.2356559.

[7] E. Sortomme and M. A. El-Sharkawi, "Optimal charging strategies for unidirectional vehicle-to-grid," *IEEE Transactions on Smart Grid*, vol. 2, no. 1, pp. 131–138, Mar. 2011, doi: 10.1109/TSG.2010.2090910.

[8] B. E. Lebrouhi, Y. Khattari, B. Lamrani, M. Maaroufi, Y. Zeraouli, and T. Kousksou, "Key challenges for a large-scale development of battery electric vehicles: A comprehensive review," *Journal of Energy Storage*, vol. 44, p. 103273, Dec. 2021, doi: 10.1016/j.est.2021.103273.

[9] L. Kumar and N. A. Ravi, "Electric vehicle charging method and impact of charging and discharging on distribution system: a review," *International Journal of Electric and Hybrid Vehicles*, vol. 14, no. 1–2, pp. 87–111, 2022, doi: 10.1504/IJEHV.2022.125253.

[10] M. Kumar, K. P. Panda, R. T. Naayagi, R. Thakur, and G. Panda, "Comprehensive review of electric vehicle technology and its impacts: detailed investigation of charging infrastructure, power management, and control techniques," *Applied Sciences*, vol. 13, no. 15, p. 8919, Aug. 2023, doi: 10.3390/app13158919.

[11] D. P. Kothari and I. J. Nagrath, *Modern power system analysis*. New Delhi, India: Tata McGraw-Hill, 2003.

[12] M. K. Gray and W. G. Morsi, "Power quality assessment in distribution systems embedded with plug-in hybrid and battery electric vehicles," *IEEE Transactions on Power Systems*, vol. 30, no. 2, pp. 663–671, Mar. 2015, doi: 10.1109/TPWRS.2014.2332058.

[13] H. Ramadan, A. Ali, and C. Farkas, "Assessment of plug-in electric vehicles charging impacts on residential low voltage distribution grid in Hungary," in *2018 6th International Istanbul Smart Grids and Cities Congress and Fair (ICSG)*, IEEE, Apr. 2018, pp. 105–109, doi: 10.1109/SGCF.2018.8408952.

[14] W. Jian, L. Zhizhen, W. Kuihua, W. Feng, and Z. Yi, "Impact of plug-in hybrid electric vehicles on power distribution networks," in *2011 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT)*, IEEE, Jul. 2011, pp. 1618–1622, doi: 10.1109/DRPT.2011.5994156.

[15] Y. Fan, C. Guo, P. Hou, and Z. Tang, "Impact of electric vehicle charging on power load based on TOU price," *Energy and Power Engineering*, vol. 5, no. 4, pp. 1347–1351, 2013, doi: 10.4236/epe.2013.54B255.

[16] R. C. Dugan, M. F. McGranaghan, S. Santoso, and H. W. Beaty, *Electrical power systems quality*, 2nd ed. New York, NY, USA: McGraw-Hill, 2004.

[17] S. Habib, M. M. Khan, F. Abbas, L. Sang, M. U. Shahid, and H. Tang, "A comprehensive study of implemented international standards, technical challenges, impacts and prospects for electric vehicles," *IEEE Access*, vol. 6, pp. 13866–13890, 2018, doi: 10.1109/ACCESS.2018.2812303.

[18] L. P. Fernandez, T. G. S. Roman, R. Cossent, C. M. Domingo, and P. Frias, "Assessment of the impact of plug-in electric vehicles on distribution networks," *IEEE Transactions on Power Systems*, vol. 26, no. 1, pp. 206–213, Feb. 2011, doi: 10.1109/TPWRS.2010.2049133.

[19] S. Rahman, I. A. Khan, A. A. Khan, A. Mallik, and M. F. Nadeem, "Comprehensive review & impact analysis of integrating projected electric vehicle charging load to the existing low voltage distribution system," *Renewable and Sustainable Energy Reviews*, vol. 153, p. 111756, Jan. 2022, doi: 10.1016/j.rser.2021.111756.

[20] S. M. N., Y. Maruthi, P. B. Bobba, and S. Vuddanti, "A case study on wired and wireless charger standards in India for electric vehicle application," *E3S Web of Conferences*, vol. 87, p. 01017, Feb. 2019, doi: 10.1051/e3sconf/20198701017.

[21] J. Kumar K., S. Kumar, and N. V. S., "Standards for electric vehicle charging stations in India: A review," *Energy Storage*, vol. 4, no. 1, p. e261, Feb. 2022, doi: 10.1002/est2.261.

[22] M. R. Khalid, I. A. Khan, S. Hameed, M. S. J. Asghar, and J. Ro, "A comprehensive review on structural topologies, power levels, energy storage systems, and standards for electric vehicle charging stations and their impacts on grid," *IEEE Access*, vol. 9, pp. 128069–128094, 2021, doi: 10.1109/ACCESS.2021.3112189.

[23] A. Bahrami, "EV charging definitions, modes, levels, communication protocols and applied standards," *Changes 1*, pp. 1–10, 2020.

[24] S. Habib, M. M. Khan, F. Abbas, and H. Tang, "Assessment of electric vehicles concerning impacts, charging infrastructure with unidirectional and bidirectional chargers, and power flow comparisons," *International Journal of Energy Research*, vol. 42, no. 11, pp. 3416–3441, Sep. 2018, doi: 10.1002/er.4033.

[25] A. Moradewicz, "On/off - board chargers for electric vehicles," *Przegląd Elektrotechniczny*, vol. 1, no. 2, pp. 136–139, Feb. 2019, doi: 10.15199/48.2019.02.30.

[26] M. Khalid, F. Ahmad, B. K. Panigrahi, and L. Al-Fagih, "A comprehensive review on advanced charging topologies and methodologies for electric vehicle battery," *Journal of Energy Storage*, vol. 53, p. 105084, Sep. 2022, doi: 10.1016/j.est.2022.105084.

[27] G. F. Savari *et al.*, "Assessment of charging technologies, infrastructure and charging station recommendation schemes of electric vehicles: A review," *Ain Shams Engineering Journal*, vol. 14, no. 4, p. 101938, Apr. 2023, doi: 10.1016/j.asej.2022.101938.

[28] K. Chamberlain and S. Al-Majeed, "Standardisation of UK electric vehicle charging protocol, payment and charge point connection," *World Electric Vehicle Journal*, vol. 12, no. 2, p. 63, Apr. 2021, doi: 10.3390/wevj12020063.

[29] N. Blasuttigh, H. Beiranvand, T. Pereira, and M. Liserre, "Comparative study of single-phase and three-phase DAB for EV charging application," in *2022 24th European Conference on Power Electronics and Applications (EPE'22 ECCE Europe)*, 2022, pp. 1–9.

[30] I. Ullah, J. Zheng, A. Jamal, M. Zahid, M. Almoshageh, and M. Safdar, "Electric vehicles charging infrastructure planning: a review," *International Journal of Green Energy*, vol. 21, no. 7, pp. 1710–1728, May 2024, doi: 10.1080/15435075.2023.2259975.

[31] H. Fathabadi, "Novel stand-alone, completely autonomous and renewable energy based charging station for charging plug-in hybrid electric vehicles (PHEVs)," *Applied Energy*, vol. 260, p. 114194, Feb. 2020, doi: 10.1016/j.apenergy.2019.114194.

[32] H. Gavranović, A. Barut, G. Ertek, O. B. Yüzbaşıoğlu, O. Pekpostalcı, and Ö. Tombuş, "Optimizing the electric charge station network of EŞARJ," *Procedia Computer Science*, vol. 31, pp. 15–21, 2014, doi: 10.1016/j.procs.2014.05.240.

[33] F. Sanchez-Sutil, J. C. Hernández, and C. Tobajas, "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," *Electric Power Systems Research*, vol. 122, pp. 104–118, May 2015, doi: 10.1016/j.epsr.2015.01.003.

[34] Y. A. Alhazmi, H. A. Mostafa, and M. M. A. Salama, "Optimal allocation for electric vehicle charging stations using trip success ratio," *International Journal of Electrical Power & Energy Systems*, vol. 91, pp. 101–116, 2017, doi: 10.1016/j.ijepes.2017.03.009.

[35] V. A. Martínez and A. Sumper, "Planning and operation objectives of public electric vehicle charging infrastructures: A review," *Energies*, vol. 16, no. 14, p. 5431, Jul. 2023, doi: 10.3390/en16145431.

[36] Q. Chen and K. A. Folly, "Application of artificial intelligence for EV charging and discharging scheduling and dynamic pricing: A review," *Energies*, vol. 16, no. 1, p. 146, 2023, doi: 10.3390/en16010146.

[37] S. Goel, R. Sharma, and A. K. Rathore, "A review on barrier and challenges of electric vehicle in India and vehicle to grid optimisation," *Transportation Engineering*, vol. 4, p. 100057, Jun. 2021, doi: 10.1016/j.treng.2021.100057.

[38] B. Singh, M. Tripathi, S. Maithil, and V. Gupta, "A review on the integration of electric vehicles into the power grid and its impact on the energy infrastructure in India," in *2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM)*, IEEE, May 2023, pp. 1–6, doi: 10.1109/RESEM57584.2023.10236371.

[39] S. Mishra *et al.*, "A comprehensive review on developments in electric vehicle charging station infrastructure and present scenario of India," *Sustainability*, vol. 13, no. 4, p. 2396, Feb. 2021, doi: 10.3390/su13042396.

[40] S. Deb, K. Tammi, K. Kalita, and P. Mahanta, "Review of recent trends in charging infrastructure planning for electric vehicles," *WIREs Energy and Environment*, vol. 7, no. 6, p. e306, Nov. 2018, doi: 10.1002/wene.306.

[41] P. P. Singh, F. Wen, I. Palu, S. Sachan, and S. Deb, "Electric vehicles charging infrastructure demand and deployment: Challenges and solutions," *Energies*, vol. 16, no. 1, p. 7, Dec. 2022, doi: 10.3390/en16010007.

[42] M. Suhail, I. Akhtar, and S. Kirmani, "Objective functions and infrastructure for optimal placement of electrical vehicle charging station: A comprehensive survey," *IETE Journal of Research*, vol. 69, no. 8, pp. 5250–5260, Sep. 2023, doi: 10.1080/03772063.2021.1959425.

[43] L. Jiacheng and L. Lei, "A hybrid genetic algorithm based on information entropy and game theory," *IEEE Access*, vol. 8, pp. 36602–36611, 2020, doi: 10.1109/ACCESS.2020.2971060.

[44] S. Fu, F. Cai, and W. Wang, "Fault diagnosis of photovoltaic array based on SE-ResNet," *Journal of Physics: Conference Series*, vol. 1682, no. 1, p. 012004, Nov. 2020, doi: 10.1088/1742-6596/1682/1/012004.

[45] A. Jafari, T. Khalili, E. Babaei, and A. Bidram, "A hybrid optimization technique using exchange market and genetic algorithms," *IEEE Access*, vol. 8, pp. 2417–2427, 2020, doi: 10.1109/ACCESS.2019.2962153.

[46] G. Zhou, Z. Zhu, and S. Luo, "Location optimization of electric vehicle charging stations: Based on cost model and genetic algorithm," *Energy*, vol. 247, p. 123437, May 2022, doi: 10.1016/j.energy.2022.123437.

[47] S. S. Chougule, "Charging infrastructure in India," Savitribai Phule Pune University, Pune, India, 2020, doi: 10.13140/RG.2.2.13527.09126.

[48] C. Luo, Y.-F. Huang, and V. Gupta, "Placement of EV charging stations--balancing benefits among multiple entities," *IEEE Transactions on Smart Grid*, vol. 8, no. 2, pp. 759–768, 2017, doi: 10.1109/TSG.2015.2508740.

[49] Y. Liu and K. Sun, "Solving power system differential algebraic equations using differential transformation," *IEEE Transactions on Power Systems*, vol. 35, no. 3, pp. 2289–2299, May 2020, doi: 10.1109/TPWRS.2019.2945512.

[50] L. Galleani and L. Cohen, "The Wigner distribution for ordinary linear differential equations and wave equations," in *Proceedings of the Tenth IEEE Workshop on Statistical Signal and Array Processing (Cat. No.00TH8496)*, IEEE, 2000, pp. 589–593, doi: 10.1109/SSAP.2000.870193.

[51] J. Guo, Y. Xie, and F. G. Canavero, "Gauss–seidel iterative solution of electromagnetic pulse coupling to three-conductor transmission lines," *IEEE Transactions on Electromagnetic Compatibility*, vol. 57, no. 2, pp. 292–298, Apr. 2015, doi: 10.1109/TEMC.2014.2374173.

[52] Z. Ding, Y. Lu, L. Zhang, W.-J. Lee, and D. Chen, "A stochastic resource-planning scheme for PHEV charging station considering energy portfolio optimization and price-responsive demand," *IEEE Transactions on Industry Applications*, vol. 54, no. 6, pp. 5590–5598, Nov. 2018, doi: 10.1109/TIA.2018.2851205.

[53] Y. Yang, Y. Zhang, and X. Meng, "A data-driven approach for optimizing the EV charging stations network," *IEEE Access*, vol. 8, pp. 118572–118592, 2020, doi: 10.1109/ACCESS.2020.3004715.

[54] M. Mavrovouniotis, G. Ellinas, and M. Polycarpou, "Electric vehicle charging scheduling using ant colony system," in *2019 IEEE Congress on Evolutionary Computation (CEC)*, IEEE, Jun. 2019, pp. 2581–2588, doi: 10.1109/CEC.2019.8789989.

[55] Z. Moghaddam, I. Ahmad, D. Habibi, and Q. V. Phung, "Smart charging strategy for electric vehicle charging stations," *IEEE Transactions on Transportation Electrification*, vol. 4, no. 1, pp. 76–88, Mar. 2018, doi: 10.1109/TTE.2017.2753403.

[56] S. Deb, K. Tammi, X.-Z. Gao, K. Kalita, and P. Mahanta, "A hybrid multi-objective chicken swarm optimization and teaching learning based algorithm for charging station placement problem," *IEEE Access*, vol. 8, pp. 92573–92590, 2020, doi: 10.1109/ACCESS.2020.2994298.

[57] X. Wang, C. Yuen, N. U. Hassan, N. An, and W. Wu, "Electric vehicle charging station placement for urban public bus systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 1, pp. 128–139, Jan. 2017, doi: 10.1109/TITS.2016.2563166.

[58] S. Hussain, M. A. Ahmed, and Y.-C. Kim, "Efficient power management algorithm based on fuzzy logic inference for electric vehicles parking lot," *IEEE Access*, vol. 7, pp. 65467–65485, 2019, doi: 10.1109/ACCESS.2019.2917297.

[59] K. Chaudhari, A. Ukil, K. N. Kumar, U. Manandhar, and S. K. Kollimalla, "Hybrid optimization for economic deployment of ESS in PV-integrated EV charging stations," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 1, pp. 106–116, Jan. 2018, doi: 10.1109/TII.2017.2713481.

[60] H. Ko, S. Pack, and V. C. M. Leung, "Mobility-aware vehicle-to-grid control algorithm in microgrids," *IEEE Transactions on Intelligent Transportation Systems*, vol. 19, no. 7, pp. 2165–2174, Jul. 2018, doi: 10.1109/TITS.2018.2816935.

[61] M. Elsisi, M.-Q. Tran, K. Mahmoud, M. Lehtonen, and M. M. F. Darwish, "Robust design of ANFIS-based blade pitch controller for wind energy conversion systems against wind speed fluctuations," *IEEE Access*, vol. 9, pp. 37894–37904, 2021, doi: 10.1109/ACCESS.2021.3063053.

[62] A. Raghavan, P. Maan, and A. K. B. Shenoy, "Optimization of day-ahead energy storage system scheduling in microgrid using genetic algorithm and particle swarm optimization," *IEEE Access*, vol. 8, pp. 173068–173078, 2020, doi: 10.1109/ACCESS.2020.3025673.

[63] B. Zeng, H. Dong, F. Xu, and M. Zeng, "Bilevel programming approach for optimal planning design of EV charging station," *IEEE Transactions on Industry Applications*, vol. 56, no. 3, pp. 2314–2323, May 2020, doi: 10.1109/TIA.2020.2973189.

[64] K. Jithin, P. P. Haridev, N. Mayadevi, R. P. Harikumar, and V. P. Mini, "A review on challenges in DC microgrid planning and implementation," *Journal of Modern Power Systems and Clean Energy*, vol. 11, no. 5, pp. 1375–1395, 2023, doi: 10.35833/MPCE.2022.000053.

[65] P. Sharma and R. C. Naidu, "Optimization techniques for grid-connected PV with retired EV batteries in centralized charging station with challenges and future possibilities: A review," *Ain Shams Engineering Journal*, vol. 14, no. 7, p. 101985, Jul. 2023, doi: 10.1016/j.asej.2022.101985.
[66] P. Barman *et al.*, "Renewable energy integration with electric vehicle technology: A review of the existing smart charging approaches," *Renewable and Sustainable Energy Reviews*, vol. 183, p. 113518, Sep. 2023, doi: 10.1016/j.rser.2023.113518.
[67] M. Ashfaq, O. Butt, J. Selvaraj, and N. Rahim, "Assessment of electric vehicle charging infrastructure and its impact on the electric grid: A review," *International Journal of Green Energy*, vol. 18, no. 7, pp. 657–686, May 2021, doi: 10.1080/15435075.2021.1875471.
[68] C. Aichberger and G. Jungmeier, "Environmental life cycle impacts of automotive batteries based on a literature review," *Energies*, vol. 13, no. 23, p. 6345, Dec. 2020, doi: 10.3390/en13236345.
[69] A. G. Abo-Khalil *et al.*, "Electric vehicle impact on energy industry, policy, technical barriers, and power systems," *International Journal of Thermofluids*, vol. 13, p. 100134, Feb. 2022, doi: 10.1016/j.ijft.2022.100134.
[70] M. Nour, J. P. Chaves-Ávila, G. Magdy, and Á. Sánchez-Miralles, "Review of positive and negative impacts of electric vehicles charging on electric power systems," *Energies*, vol. 13, no. 18, p. 4675, Sep. 2020, doi: 10.3390/en13184675.
[71] H. Rallo, G. Benveniste, I. Gestoso, and B. Amante, "Economic analysis of the disassembling activities to the reuse of electric vehicles Li-ion batteries," *Resources, Conservation and Recycling*, vol. 159, p. 104785, Aug. 2020, doi: 10.1016/j.resconrec.2020.104785.
[72] International Electrotechnical Commission, "Electric vehicle conductive charging system-Part 1: General requirements," *IEC Standard 61851-1*, 2017.
[73] Y. Balali and S. Stegen, "Review of energy storage systems for vehicles based on technology, environmental impacts, and costs," *Renewable and Sustainable Energy Reviews*, vol. 135, p. 110185, Jan. 2021, doi: 10.1016/j.rser.2020.110185.
[74] E. Pipitone, S. Caltabellotta, and L. Occhipinti, "A life cycle environmental impact comparison between traditional, hybrid, and electric vehicles in the European context," *Sustainability*, vol. 13, no. 19, p. 10992, Oct. 2021, doi: 10.3390/su131910992.
[75] S. A. A. Rizvi, A. Xin, A. Masood, S. Iqbal, M. U. Jan, and H. Rehman, "Electric vehicles and their impacts on integration into power grid: A review," in *2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2)*, IEEE, Oct. 2018, pp. 1–6, doi: 10.1109/EI2.2018.8582069.
[76] N. Narasimhulu, M. Awasthy, R. P. de Prado, P. B. Divakarachari, and N. Himabindu, "Analysis and impacts of grid integrated photo-voltaic and electric vehicle on power quality issues," *Energies*, vol. 16, no. 2, p. 714, Jan. 2023, doi: 10.3390/en16020714.
[77] A. Tavakoli, S. Saha, M. T. Arif, M. E. Haque, N. Mendis, and A. M. T. Oo, "Impacts of grid integration of solar PV and electric vehicle on grid stability, power quality and energy economics: a review," *IET Energy Systems Integration*, vol. 2, no. 3, pp. 243–260, Sep. 2020, doi: 10.1049/iet-esi.2019.0047.
[78] G. Saldaña, J. I. San Martin, I. Zamora, F. J. Asensio, and O. Oñederra, "Electric vehicle into the grid: Charging methodologies aimed at providing ancillary services considering battery degradation," *Energies*, vol. 12, no. 12, p. 2443, Jun. 2019, doi: 10.3390/en12122443.
[79] Y. Ma *et al.*, "An overview on V2G strategies to impacts from EV integration into power system," in *2016 Chinese Control and Decision Conference (CCDC)*, 2016, pp. 2895–2900.
[80] S. Painuli, M. S. Rawat, and D. R. Rayudu, "A comprehensive review on electric vehicles operation, development and grid stability," in *2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC)*, IEEE, Apr. 2018, pp. 807–814, doi: 10.1109/PEEIC.2018.8665643.
[81] H. Das, M. Nurunnabi, M. Salem, S. Li, and M. Rahman, "Utilization of electric vehicle grid integration system for power grid ancillary services," *Energies*, vol. 15, no. 22, p. 8623, Nov. 2022, doi: 10.3390/en15228623.
[82] H. A. Khan, M. Zuhaib, and M. Rihan, "A review on voltage and frequency contingencies mitigation technologies in a grid with renewable energy integration," *Journal of The Institution of Engineers (India): Series B*, vol. 103, no. 6, pp. 2195–2205, Dec. 2022, doi: 10.1007/s40031-022-00819-2.
[83] C. H. Dharmakeerthi, N. Mithulananthan, and T. K. Saha, "Impact of electric vehicle fast charging on power system voltage stability," *International Journal of Electrical Power & Energy Systems*, vol. 57, pp. 241–249, May 2014, doi: 10.1016/j.ijepes.2013.12.005.
[84] A. Shrestha and F. Gonzalez-Longatt, "Frequency stability issues and research opportunities in converter dominated power system," *Energies*, vol. 14, no. 14, p. 4184, Jul. 2021, doi: 10.3390/en14144184.
[85] L. G. Meegahapola, S. Bu, D. P. Wadduwage, C. Y. Chung, and X. Yu, "Review on oscillatory stability in power grids with renewable energy sources: Monitoring, analysis, and control using synchrophasor technology," *IEEE Transactions on Industrial Electronics*, vol. 68, no. 1, pp. 519–531, Jan. 2021, doi: 10.1109/TIE.2020.2965455.
[86] M. M. H. Khan *et al.*, "Integration of large-scale electric vehicles into utility grid: An efficient approach for impact analysis and power quality assessment," *Sustainability*, vol. 13, no. 19, p. 10943, 2021, doi: 10.3390/su131910943.
[87] K. Qian, C. Zhou, and Y. Yuan, "Impacts of high penetration level of fully electric vehicles charging loads on the thermal ageing of power transformers," *International Journal of Electrical Power & Energy Systems*, vol. 65, pp. 102–112, Feb. 2015, doi: 10.1016/j.ijepes.2014.09.040.
[88] A. Ahmadi *et al.*, "Power quality improvement in smart grids using electric vehicles: A review," *IET Electrical Systems in Transportation*, vol. 9, no. 2, pp. 53–64, Jun. 2019, doi: 10.1049/iet-est.2018.5023.
[89] M. Shafiei and A. Ghasemi-Marzbali, "Fast-charging station for electric vehicles, challenges and issues: A comprehensive review," *Journal of Energy Storage*, vol. 49, p. 104136, May 2022, doi: 10.1016/j.est.2022.104136.
[90] A. Kazemtarghi, S. Dey, and A. Mallik, "Optimal utilization of bidirectional EVs for grid frequency support in power systems," *IEEE Transactions on Power Delivery*, vol. 38, no. 2, pp. 998–1010, Apr. 2023, doi: 10.1109/TPWRD.2022.3203654.
[91] K. Parashar, K. Verma, and S. K. Gawre, "Power quality analysis of grid connected solar powered EV charging station: A review," in *Recent Advances in Power Electronics and Drives*, 2023, pp. 259–271, doi: 10.1007/978-981-19-7728-2_19.
[92] S. S. Ravi and M. Aziz, "Utilization of electric vehicles for vehicle-to-grid services: progress and perspectives," *Energies*, vol. 15, no. 2, p. 589, Jan. 2022, doi: 10.3390/en15020589.
[93] V. Sultan, A. Aryal, H. Chang, and J. Kral, "Integration of EVs into the smart grid: A systematic literature review," *Energy Informatics*, vol. 5, p. 65, Dec. 2022, doi: 10.1186/s42162-022-00251-2.
[94] W. M. Najem, O. S. Alyozbaky, and S. M. Khudher, "Electric vehicles charging station configuration with closed loop control," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 3, pp. 2428–2439, Jun. 2023, doi: 10.11591/ijece.v13i3.pp2428-2439.
[95] K. Dhami and T. S. Saggu, "THD analysis and its mitigation using DSTATCOM integrated with EV charging station in the distribution network," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 15, no. 3, pp. 1990–1997, 2024, doi: 10.11591/ijpeds.v15.i3.pp1990-1997.

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