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A Comprehensive Review on Electrical Vehicle Charging Infrastructure Configuration Based on Renewable Energy Resources

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Abstract: **At present, the limited existence of fossil fuels and the environmental issues over greenhouse gas emissions have been directly affected by the transition from conventional vehicles to electric vehicles (EVs). The electrification of transportation systems and the growing demand for EVs have prompted recent researchers to investigate the possible solution for electric vehicle charging stations (EVCSs). However, there are numerous challenges faced when implementing EVs at large scale including stability issues in the grid.**

Therefore, it is necessary to balance electricity production and EV charging to guarantee and preserve secure constant grid operation. The problem with EVs is that they can disturb the demand side and cause grid overload; this condition can result in a decrease in both power quality and grid stability. Hence, to address the above challenges considering also stochastic and variable nature of renewable energy sources and loads, this paper presents a comprehensive review of EV charging infrastructures (EVCI) that could ensure optimum operation and enhance grid support. It has been found that networked EVCIs are expected to offer technical and economic benefits to charging station owners, customers, grid/utility, and other stakeholders.

An overview of power management strategy in EVCIs with renewable energy resources integration, energy storage, energy management system, energy trading, control, modes of operation, and artificial intelligence as energy coordination in EVCI for optimal reliability has been evaluated.

Keywords: **Electric vehicle (EVs); EV charging infrastructure; EV battery chargers; control and power management; grid impact.**

1. INTRODUCTION

Electrification has become a major factor in social development, economic growth, and environmental contribution. Electrification is also projected to be increased in the transport sector focusing on the energy transition towards a zero-carbon emission economy. However, charging the EV from the power grid places an additional load on the utility, especially during high-demand hours. Therefore, prompting the charge of renewable energy sources is one method to mitigate the grid's negative impact [1]. The use of these clean energy sources is meant to reduce negative environmental consequences while also increasing the overall efficiency of the charging system. To increase the penetration of renewable energies in the power grid, there is a need to expand the transmission and distribution system to allow the sharing of resources where required. Another solution is to change the power generation system from being centralized, with a few large power plants to a distributed power generation system, particularly in the distribution grid. It is now practical to install PV-Wind hybrid systems with power ratings of several kilowatts in the residential power distribution system as at charging stations. In this way, the consumers are becoming the prosumers as they can produce parts for all their energy needs.

It is from that concept that, in smart grid includes the deployment of electrification in the transport sector, with the introduction of electric vehicles (EV). When the EVs are charged by the electric power outputs of renewable energy sources, the GHG emissions can be reduced and hence climate change can be mitigated. Moreover, EV batteries have the potential to mitigate the power intermittency from renewable resources, as they can be considered as mobile storage units connected to the distribution grid. However, such implementation requires innovative and smart power control strategies that can actively control the charging and discharging of the EV batteries, while at the same time using a part of the energies of the EV batteries to mitigate the intermittency of renewable energy sources output and to help buffer the fluctuation of the individual household load demand and in a small way help to balance the generation and the load demand of the power grid.

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2. DISTRIBUTED ENERGY RESOURCES

2.1 An overview

Distributed energy resources (DERs) are small-scale electricity supply or demand resources that are interconnected to the electric grid as shown in Figure 1 and they are power generation resources that are usually located close to load centers and can be used individually or collectively to provide value to the grid. These distributed generation resources, if installed in the right place and the right size, can include many economic and technical benefits, such as reducing power losses, improving power quality, improving reliability, eliminating distribution density, and causing economic benefits for the power grid [2].

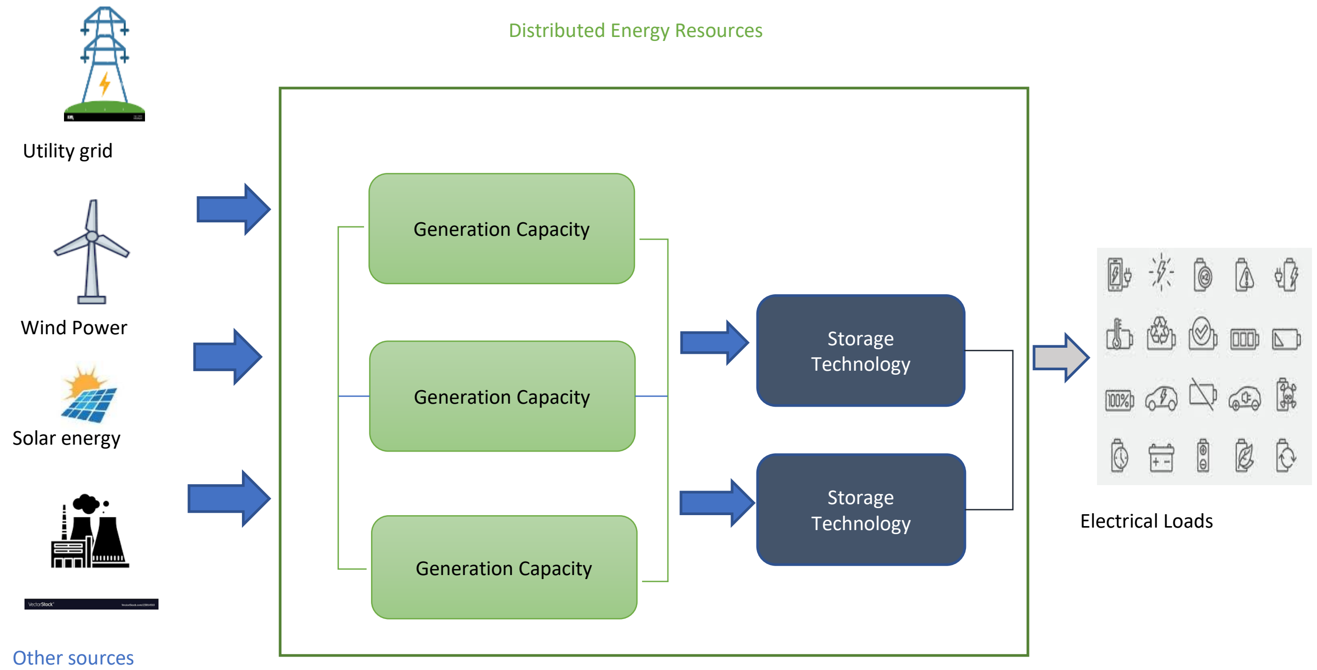

Figure 1: Structure of a DER system

2.2 Power Sharing Theory in DER

To investigate the distribution of active and reactive powers by distributed generation sources and power distribution equations, the equivalent circuit of a distributed generation source is considered according to Figure 2. In this equivalent circuit, the distributed generation source is modeled with an alternating voltage source that is connected to the AC bus via a Z-impedance supply line and supplies the load. The power transferred from the distributed generation source to the ac bus is as follows:

$$S = P + jQ \tag{1}$$

$$S = \bar{E}I^* = E\angle\left[\frac{E}{Z}\angle(\theta-\delta) - \frac{V}{Z}\angle\theta\right] = \frac{E^2}{Z}\angle\theta - \frac{EV}{Z}\angle(\theta+\delta) \tag{2}$$

$$P = \frac{E^2}{Z}Cos\theta - \frac{EV}{Z}Cos(\theta+\delta) = \frac{(E^2 - EVCos\delta)Cos\theta}{Z} + \frac{EVsin\theta sin\delta}{Z} \tag{3}$$

$$Q = \frac{E^2}{Z}Sin\theta - \frac{EV}{Z}Sin(\theta+\delta) = \frac{(E^2 - EVCos\delta)Sin\theta}{Z} - \frac{EVsin\theta sin\delta}{Z} \tag{4}$$

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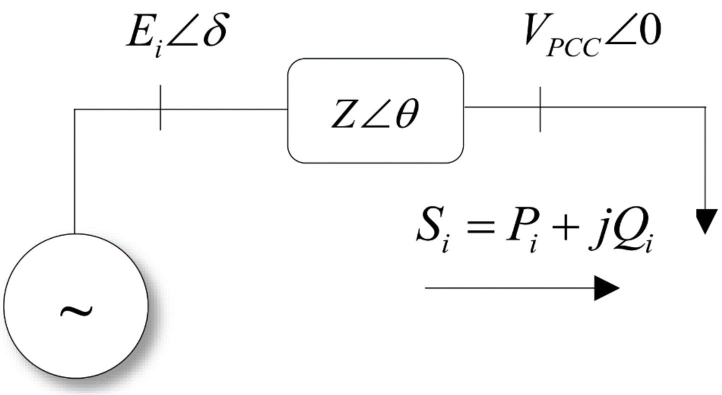
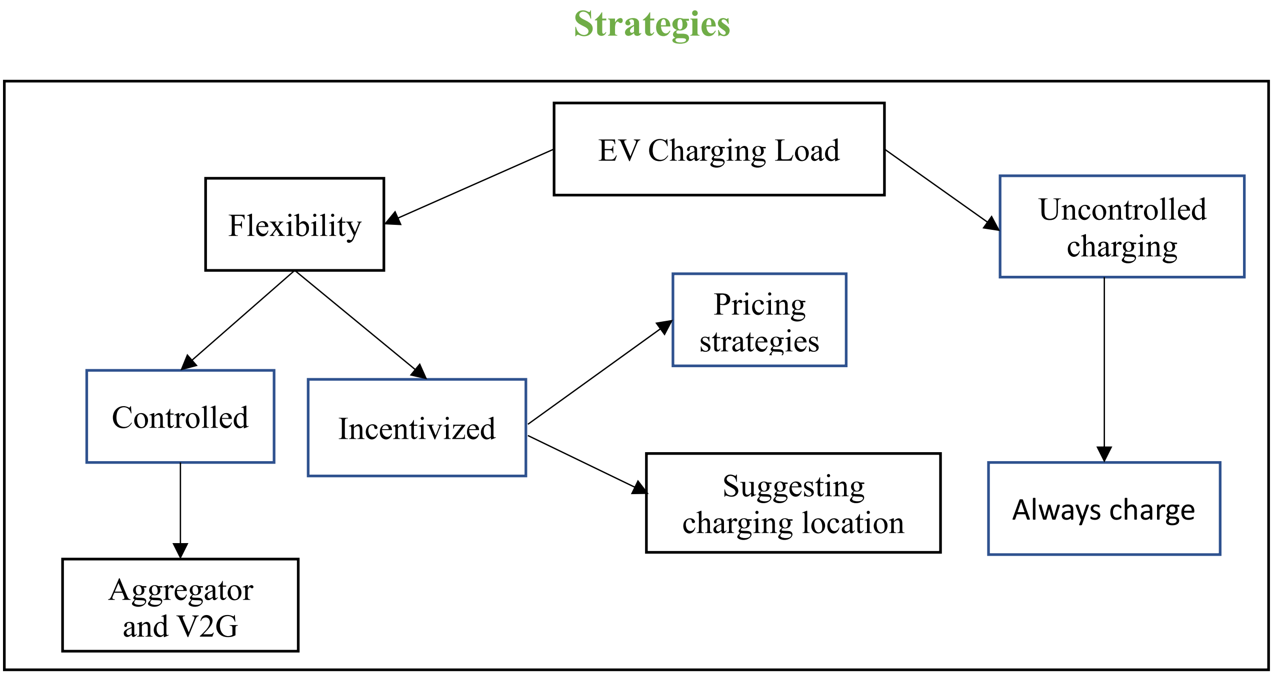


Figure 2: Single-line diagram of the power system [3].

3. EVC LOAD STRATEGIES

Electricity distribution occurs such that at any point in time and space, the consumption has to be equal to the production to avoid severe consequences such as blackouts. A significant rise in the number of EVs in circulation leads to an increase in electricity demand which could cause such a blackout if the balance in the grid is not effectively maintained. Therefore, EVs have an important role to play in maintaining this balance [3]. The purpose of this section is to explore the different aims and strategies required to overcome the potential difficulties caused by increased EV penetration. Figure 3 summarizes these aims and strategies. Incentivized flexibility and controlled flexibility are used to achieve specific aims while uncontrolled charging lets the market decide the prioritization of these aims. Load flattening and load balancing are the most common aims found in the literature and they are the focus of the following paragraphs.



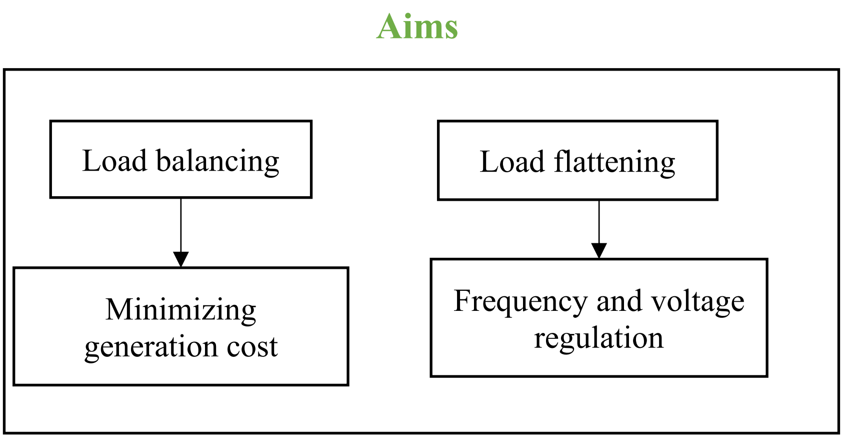


Figure 3: Strategies and aims for handling integration of Electric Vehicle (EV) load

3.1 Load Flattening

While some studies show minimal impact of EVs on peak load, the consensus in the field is that the grid will not be able to sustain its operations with the projected demand from EVs. One of the first articles dealing with the impact of EVs on load management was written in 1983 [4]. In this article, EVs were suggested as a way to minimize the overall grid load factor *f*. This factor is defined as the ratio of the average load (L) over the maximum load in a given period:

$$f = \frac{avg\ (L)}{\max\ (L)} \tag{5}$$

The maximization of this quantity results in a more efficient distribution of resources over time. The article proposed that using off-peak recharging of EVs will significantly increase the load factor. This means shifting the EV demand to times when the rest of the demand is low (e.g., nighttime) to flatten the load curve. The flexibility analysis produced in [5] suggests that it is possible to shift the EV charging to the afternoon and night valleys for different clusters of users without changing their behaviors. This could lead to peak reduction and load factor maximization with little change to users' requirements and lifestyles [6].

Articles [7] such as strived to estimate the benefits of this kind of controlled or incentivized EV charging. However, these articles do not always account for potential mistakes in load forecasting, therefore the benefits calculated could be inaccurate. Hence, it is critical to improve EV load forecasting models to alleviate the risk of unrealistic optimization schedules for maximizing the load factor.

3.2 Load Balancing

The behavior of a large-scale EV charging facility can affect the public electric grid in a complex way. However, in the case of distribution grids with sufficient capacity, it can be assumed that the selected sizing, which determines the peak power of the station, guarantees that the activities in the charging station do not expose the public grid operation. Therefore, many countries with climate-related commitments are aiming to increase the share of renewables in their energy mix. However, the main drawback of renewable energies is their intermittent delivery of supply. Indeed, solar panels and wind farms are highly weather-dependent. In this context, EVs can adequately balance the energy coming from renewable power plants. This strategy consists of considering multiple EVs acting as a large battery or electricity storage system which can be discharged back into the grid when weather conditions do not allow renewable power plants to produce enough energy [8].

Although V2G has many advantages, one drawback is that it reduces battery lifetime by adding unnecessary cycles of charge and discharge to the vehicle [9]. Furthermore, this strategy requires the existence of global and local communication and monitoring channels which do not exist yet. These channels are necessary for the development of EVs in general and particularly for V2G and load balancing [10]. Finally, to ensure effective communication, EV load models are critical as they can reduce uncertainty and minimize contradicting signals from what is expected and what is observed by operations management.

4. EV CHARGING INFRASTRUCTURES

4.1 Analysis of Renewable-Energy-Based EV Charging Station

EV charging infrastructure based on renewable energy is a quickly developing technology that is transforming how we power our transportation networks. We can reduce our reliance on fossil fuels and contribute to the fight against climate change by using renewable energy sources like solar, wind, and hydropower to charge EVs. The implementation of this technology holds promise in augmenting public health, mitigating air pollution, and creating novel avenues for commercial enterprise. Before analyzing EV charging infrastructure that utilizes renewable energy sources, it is necessary to first assess the existing systems and technologies that are currently employed. This necessitates a comprehensive study of the available charging options, their associated prices, and their environmental impact. The research should also think about where the market is now and where it could go in the future [11].

Table 1 explains the analysis conducted on EV charging infrastructure, specifically focusing on the various energy sources utilization. The assessment offers a comprehensive overview of the current state of the technology as well as its potential for future advancements. This information can be utilized by policymakers and other stakeholders to make informed decisions regarding the implementation of this technology [12].

Table 1: A review of different charging stations proposed by different authors

Ref no	**Micro grid type**	**On Board Storage System**	**Resources**	**Charging Types**	**Control Strategy**	**V2G/ V2V**	**Pros**	**Cons**	
[13]	DC	Not Available	Wind, utility grid	Off-board	Energy management	Yes	High-efficiency, bidirectional power flow.	Dependent on weath and grid.	
[14]	DC	Available	Solar; utility grid	On-board	Power flow management	Yes	System computation time and efficiency are improved by the suggested strategies.	System efficiency in dynamic environments are challenging.	
[15]	DC	Not Available	Solar and wind, Fuel cell, utility grid	Off-board	Genetic algorithm (GA)	Yes	This facilitates the planning of EV charging station parking.	No experimental validation is available.	
[16]	AC	Available	Diesel generators, Solar, utility grid	On-board	Load demand	Yes	Continuous power provided by backup generators.	Charger conversion requirement	
[17]	DC	Available	Diesel generator, utility grid, PV, and Battery	Charging station	Co-ordinated control	Yes	Operating in both islanded and grid-connected mode in an efficient manner.	Variable dynamic condition results sho challenges.	
[18]	AC	Available	Diesel generator, utility grid, Solar	On-board	Load demand	Yes	Continuous power provided by backup generators	Charger conversion requirements	
[19]	Hybrid	Available	PV and Wind, utility grid	On-board	Power control	No	A charging converter with a high power density.	Grid stabilization is difficult due to de	
[20]	AC	Available	Utility grid	Off-board	Power control strategies	No	Infrastructure for fast charging is accessible.	Increased conversion losses due to the AC distribution network.	
[21]	Hybrid	Available	PV, utility grid	Off-board	PV and DC link power	Yes	Maximizes PV usage and boost grid reliability with V2G technologies.	High initial costs and more dependence on RES.	

4.2 Energy Management Techniques in EVCS

The following section presents a compilation of dominant energy management techniques employed in EV charging systems:

- Demand Response (DR): Demand response systems enable the synchronized charging of EVs by the requirements of the electrical grid and the amount of electricity being utilized. Charging can be effectively managed through various methods, such as implementing scheduled charges during off-peak hours or adjusting charging patterns based on signals received from the grid operator. Utilizing this approach during non-peak periods enables users to leverage reduced electricity expenses while simultaneously contributing to grid stability [22].

    - The term "demand response" refers to a broad category of measures taken to lower electricity demand (peak demand) and prevent a blackout. Utility providers and industrial and household customers alike will need to take part.
- Smart meters and smart grids can help utilities track consumption and identify peak demand.
- Consumers can reduce peak demand by turning off lights, air conditioning, and other electrical products and machinery.
- Time-of-Use (TOU) Pricing: The time-of-use (TOU) pricing model provides different electricity costs at different times of the day. Customers are advised to utilize charging stations for their EVs during periods of the day characterized by reduced electricity demand. This is because charging stations can take advantage of lower rates offered during off-peak hours. The proposed plan aims to mitigate the peak load on the system and enhance energy efficiency simultaneously [23].

- Vehicle-to-Grid (V2G) Integration: Vehicle-to-grid (V2G) technology facilitates the exchange of power in both directions between EVs and the power grid. Consequently, the energy that is stored within the batteries of EVs can be harnessed to supply power to adjacent residential and commercial establishments. The electrical energy stored in the battery of an EV can be utilized for non-vehicular applications, such as providing power to residential or commercial buildings, or even feeding it back into the grid during periods of high demand. In both scenarios, this facilitates grid maintenance and promotes the integration of renewable energy sources [24].
- Smart Charging Algorithms: Smart charging algorithms are designed to optimize the charging process by considering various factors. These factors include the cost of electricity, the demand on the grid, and the preferences of the user. To achieve energy optimization, cost reduction, and grid stability preservation, the algorithms have the potential to modify the charge rate, introduce charging delays, or prioritize charging for vehicles [25].
- Grid Integration and Load Management: The integration of EV charging infrastructure with grid management systems enables the monitoring and control of the charging demand for EVs. Load management techniques are employed to ensure the even distribution of the charging load among the available charging stations while adhering to the capacity limitations of the grid. This is crucial for maintaining optimal charging efficiency and preventing the overloading of the grid [26].
- Renewable Energy Integration: The compatibility of EV charging infrastructure with various renewable energy sources, such as solar or wind power, can be achieved. The technologies mentioned above can effectively prioritize the charging process during periods characterized by significant levels of generation from renewable energy sources. By optimizing the utilization of renewable energy sources, we can effectively decrease our dependence on the power grid. This approach enables us to maximize the benefits of renewable energy while minimizing our reliance on conventional energy sources [27].
- Energy Storage Integration: The utilization of energy storage devices in EV charging enhances the adaptability and stability of the grid. Energy storage systems hold great potential in their capacity to store excess renewable energy or grid electricity during periods of low demand. This stored energy can then be discharged during times of peak demand or utilized for charging the EVs. Implementing enhanced control over the electrical current, this feature is expected to alleviate the strain on the system and enhance overall efficiency [28].
    - The implementation of energy management techniques facilitates the optimization of energy resource utilization and reduction of grid impact and enables the seamless integration of EV charging with renewable energy sources and grid infrastructure. Although there are multiple papers available that discuss the different energy management systems (EMSs) used in EVs, the research literature in this area is still relatively new. The significance of EMS technology is underscored by EVs and the diverse charging infrastructures they require. Table 2 presents an analysis of energy management techniques that have been developed and implemented by different researchers.

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Ref. No.	Energy Source	Objective	Energy Management Techniques	Review and Comments
[29]	Solar & wind	study a wind-solar hybrid energy charging station designed and optimized via HOMER software.	Adaptive real-time dynamic programming	The optimal solution for the hybrid system consists of 44.4% wind energy and 55.6% solar energy and the annual electricity production is 843150 kWh with the 0.064 $/kWh production cost. Grid interoperability is neglected and no networked system
[30]	Wind	Co-ordinated scheduling approach for optimizing wind power absorption while taking thermal generator.	Parameter adaptive differential evaluation algorithm	Established coordinated scheduling of EV charging using wind power system absorption and reduced the charging cost and GHG emission. However, it only considers the wind power system and does not consider hybrid renewable energy resources and networked systems.
[31]	Utility grid	Examine the public distribution network in terms of harmonic distortion percentage increase due to EV charging station penetration.	Mixed integer non-linear programming	Results show that a large EVCS should be connected to a dedicated 11 kV feeder. It can be realized for up to a 5 MW EVCS plant as per QEWC standards. No RES integration and no interconnection system
[32]	Utility grid	To determine optimal locations and sizes of PEVFCSs.	Mixed-integer linear programming	The proposed model finds the optimal location and capacity of PEVFCSs in such a way that, in addition to reducing the travel time of PEVs to reach a PEVFCS and reducing waiting time to get charging service in Transportation and Distribution Networks. RES and networked systems are not considered
[33]	Battery technology, utility grid	Revise the advances of EVs regarding battery technology trends, and charging methods, as well as new research challenges and open opportunities	Intelligent energy management	Areas to be improved are the use of new battery technologies or manufacturing processes, improvement and optimization of the charging process, the use of communications and AI in electric vehicles for improving mobility, and efficient use of the charging infrastructure. No proposal about networked EVCS, and use of RES
[34]	PV, ESS, and grid	Optimize a grid-connected solar-powered electric EV charging station.	Intelligent energy management	This approach optimizes the utilization of photovoltaic (PV) power for EV charging while minimizing the potential impact of energy exchange on the electrical grid. The inclusion of the vehicle-to-grid technique is not accounted for in the comprehensive analysis.
[35]		Propose a hybrid decentralized robust optimization-stochastic programming (DRO-SP) model based on the alternating direction method of multipliers to coordinate the management of entities	Hybrid distributed robust optimization-stochastic programming (DRO-SP)	Results show that the robust LMPs rise when the entities purchase electricity and decrease when the EVAGG sells electricity to the wholesale market to reach the worst-case realization of the locational marginal price (LMP) uncertainties. Use of EVCS based on RES, and interconnection system
[36]	PV, Grid	Find the best combination of the control parameters of a voltage source inverter that integrates a PV power system with an EV charging station through a common grid-connected ac-bus	Salp Swarm Optimization	The outcomes show that the proposed control design can reduce the fluctuation of the dc-bus voltage by around 50%, the total harmonic distortion of voltage by 40%, and current by 64% compared to the analytical-based design, which makes the system compatible with the requirements defined by the IEEE 1547 international standard. Networked system and hybrid optimization techniques are missing

Table 2: Analysis of energy management techniques by different researchers.

4.3 Energy Trading for EV Charging Station

Energy trading with EVs allows for the elimination of maximum peak demand for EV charges while also saving money and profiting all parties involved. Because EVs perform as loads during charging, ESSs when stationary, and distributed energy sources when discharging. To absorb environmental energy, energy production is frequently used at the consumer's location.

When production exceeds demand, excess energy is stored in batteries, leased to convenient consumers, or injected into the local grid. Energy trading is a cost-effective approach to relieve strain on the local grid even while making money. Energy trading is used to offer excess power to the grid or to sell these products to local users, charging stations, or communities. Energy trade is categorized based on the buyer. (1) Feed-in tariff; (2) peer-to-peer (P2P). Consumers may inject excess energy into the grid through feed-in tariffs, whereas prosumers could fully engage in the energy-sharing market through P2P energy trading [37]. The entire energy trading procedure is usually controlled by a central entity that is in charge of the energy market.

Nevertheless, there is no centralized control structure in P2P energy trading; instead, it is spread in the form of community-based and entirely decentralized control [38]. The sustainability of energy trading is dependent on the availability of prosumers and the reliability of distributed generation. EVs are intended primarily to be a cost-effective and ecologically friendly mode of transportation, but they also have the capacity to store a significant quantity of energy.

Authors in [39] created an EV-to-EV energy market based on auctions. The market is steered by a central auctioneer, who uses a primitive auction procedure to determine energy prices repeatedly. It proposes an autonomous energy trading market operated by a fog computing-based administrator [40]. An online double auction technique for P2P energy trading among electric vehicles that contains anonymous methods to address the problem of trade participants' identification and position leaking [41].

EVs are a worthy contender for energy transfer because of their dynamic nature. Utility vehicle energy trading, in which EVs are utilized to transfer energy to usefulness elements, is yet another promising strategy that benefits EVs. Estimating demands, scheduling generation, and simulating the energy trade system can all benefit from stochastic energy forecasting.

To manage the charge/discharge operation of EVs, various strategies have been studied, as well as grid control with incentives and time-varying charges provided by the power grid. Korea Electric Power Corporation (KEPCO) is responsible for all energy transactions between customers and prosumers [42]. Furthermore, there are many relevant operational gains for utilities, including lower reliance on the electrical grid, reduced transmission losses, enhanced efficiency, and energy request supply. Because they include the distribution of energy from the grid to consumers, energy trading schemes demand a great deal of attention. In a smart grid, robust energy management strategies and energy trading policies for EVs are critical.

The aggregator uses the mathematical framework [43] to try to match the best prosumers with the best consumers to achieve the lowest operating costs while meeting consumer energy demand and charging station limits. Furthermore, widespread adoption of electric vehicles may cause existing power grid stations to become overburdened necessitating the development of more efficient vehicle-grid combination and energy-trading strategies. Existing energy trading systems have made use of knowledge and communication technologies (ICT) to conduct energy trading among EVs. The surplus energy of an EV battery is estimated and sold back to the electric vehicle or grid station using an ICT-based energy trading platform. Most ICT-based systems, on the other hand, are centralized, highly decentralized, unsecured, secretive, and unreliable [44].

It has the potential to improve the efficiency, transparency, and dependability of EV energy trading processes. Furthermore, EVs can use ICT-based systems to (a) compute battery discharge rate, (b) locate reputable energy CS, (c) approximate energy requests through off-peak hours, and (d) estimate energy demand during peak hours. (d) Determine the shortest distance between the energy CSs at the sender and the receiver, (e) excess electricity is available to customers or grid station, and (f) calculate the price of power in a specific region throughout off-peak hours [45]. Furthermore, because blockchain data and transactions are available publicly to all, the blockchain provides increased transparency to energy trading members of the network. Therefore, Peer-to-grid (P2G) is a traditional way of energy trading where microgrids can only trade with the main grid. However, peer-to-peer (P2P) is a multidirectional way of energy trading that enables microgrids to act as the prosumers and do energy trading with the neighboring prosumers, consumers, and the main grid as shown in Figure 4.

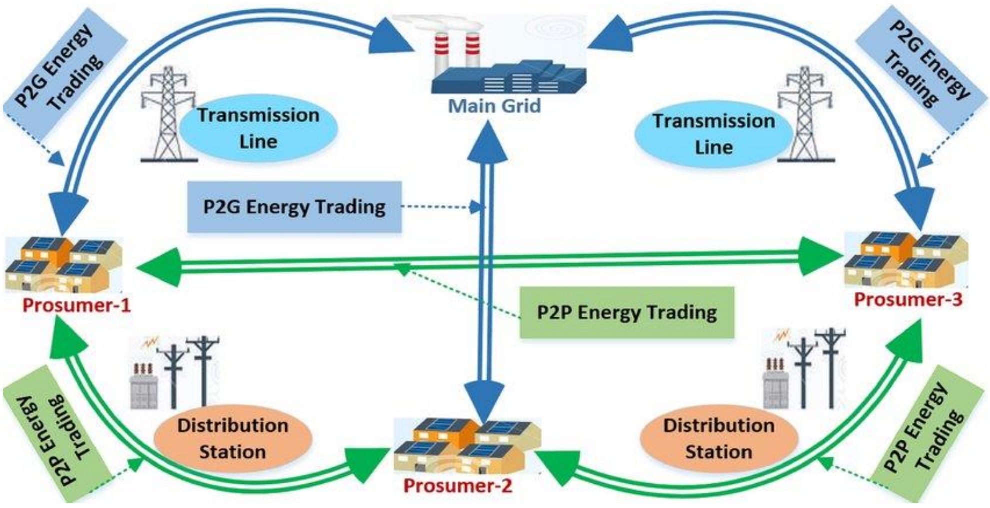

Figure 4: Energy trading schemes P2G and P2P [46]

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5. POWER GRID TECHNOLOGIES FOR INTEROPERABILITY OF EVCS

The traditional electricity grid has been facing the challenge of managing the increasing electricity consumption effectively. With the development of technology, the existing grids are transforming into a self-regulated grid called Smart Grid (SG). The SG network is an intelligent electricity grid equipped with information and communication (ICT) facilities. The SG network provides a controlled environment to coordinate EVs' charging operation [47], enable large integration of renewable energy sources and flatten their variability, and support the vehicle-to-grid (V2G) feature for grid support services including frequency tuning and load regulation. All these attributes are about smart grid technology, which sets an efficient and sustainable energy system to facilitate (1) individual customers regulating their electricity consumption against varying electricity prices and (2) utilities and grid operators monitoring and controlling their generation resources and network assets for optimized network operation [48]. The smart grid has a comprehensive charging facility including advanced metering infrastructure, which allows bidirectional communication between electricity customers and aggregators to schedule the charging/discharging activities. An aggregator is an intermediate entity that manages the communication and electricity distribution between the group of electricity users (EV charging customers) and the utility, as highlighted in Figure 5. The major role of the aggregator is between load devices and dispatchers to establish and monitor market supply and demand. In a cooperative setup, an aggregator coordinates and schedules the EV charging to minimize the overall charging cost. The EV aggregator persuades or allows the charging load to level the off-peak loading that occurs at the power grid and also improves the load curve by consuming the surplus power during the off-peak hours [49].

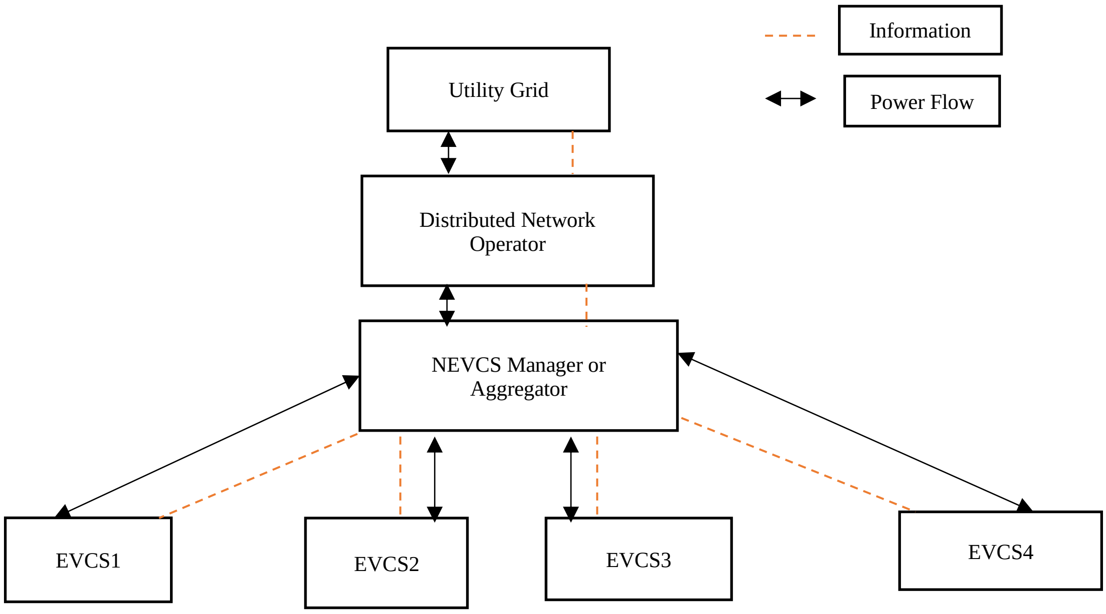

Figure 5: Interoperability of EVCS

6. CONTROL OF CHARGING INFRASTRUCTURE, MODES OF OPERATION AND EV CONNECTIVITY

6.1 Control of Charging Infrastructures

The widespread adoption of EVs has the potential to raise load demand, boost system losses, and lower grid voltage. Overloading service transformers, reducing their lifespan, and increasing system losses are all possible outcomes of the increased load demand caused by EV loads. The charging of EVs causes new load peaks that may exceed the service transformer's rated capacity, hastening the aging process. The daily expansion and contraction of the transformer can be mitigated if EVs are largely charged during off-peak hours, which is good for the transformer's life [50].

In addition to this, the increased adoption of EVs in our daily lives will give rise to numerous challenges. To address the issues, it is imperative to implement effective control techniques throughout the entire process, starting from the grid and extending to the vehicles. In an EV system, various control techniques are employed to manage different aspects of the vehicle's operation [51]. In this section, we clarify several predominant control techniques employed in EV systems.

Motor Control: EVs utilize electric motors for propulsion. Motor control techniques include:

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- ❖ Field-Oriented Control (FOC): FOC is a technique that accurately controls the torque and speed of the motor by decoupling the torque and flux components. It maximizes motor efficiency and performance.
- ❖ Direct Torque Control (DTC): DTC is a control method that directly controls the torque and flux of the motor without needing to decouple them. It provides a fast and precise control response.
- ❖ Pulse-Width Modulation (PWM): PWM is used to control the motor drive by adjusting the duty cycle of the voltage pulses applied to the motor. It regulates the motor's speed and torque output.

Battery Management System (BMS) Control: The importance of the battery management system (BMS) in ensuring the safety and protection of an EV cannot be exaggerated. The BMS is responsible for overseeing the operation of the rechargeable battery pack or individual cells, thereby exerting control over the associated electronics. By implementing this mechanism, the battery is protected from overcharging, which ensures the user's safety from potential electrocution. The BMS utilizes various control methods, which are as follows:

- ❖ State-of-Charge (SOC) Estimation: SOC estimation techniques are utilized to determine the remaining energy in a battery pack by considering various factors such as voltage, current, temperature, and additional parameters. The provided information is essential for the optimization of battery usage.
- ❖ State-of-Health (SOH) Estimation: The estimation techniques for the state of health (SOH) evaluate the condition and deterioration of the battery pack. The measurement assists in determining the remaining capacity of the battery and its power delivery capability.
- ❖ Cell Balancing: Cell-balancing techniques are implemented to ensure uniform charging and discharging of each battery cell within a pack. The prevention of cell voltage imbalances is crucial to maintain optimal battery performance and prolong its lifespan.

6.2 EV Charging Methods

Battery exchange, wireless charging, and conductive charging are the three main charging techniques. The conductive charging is further divided into pantograph (on-board and off-board) and overnight charging, as shown in Figure 6.

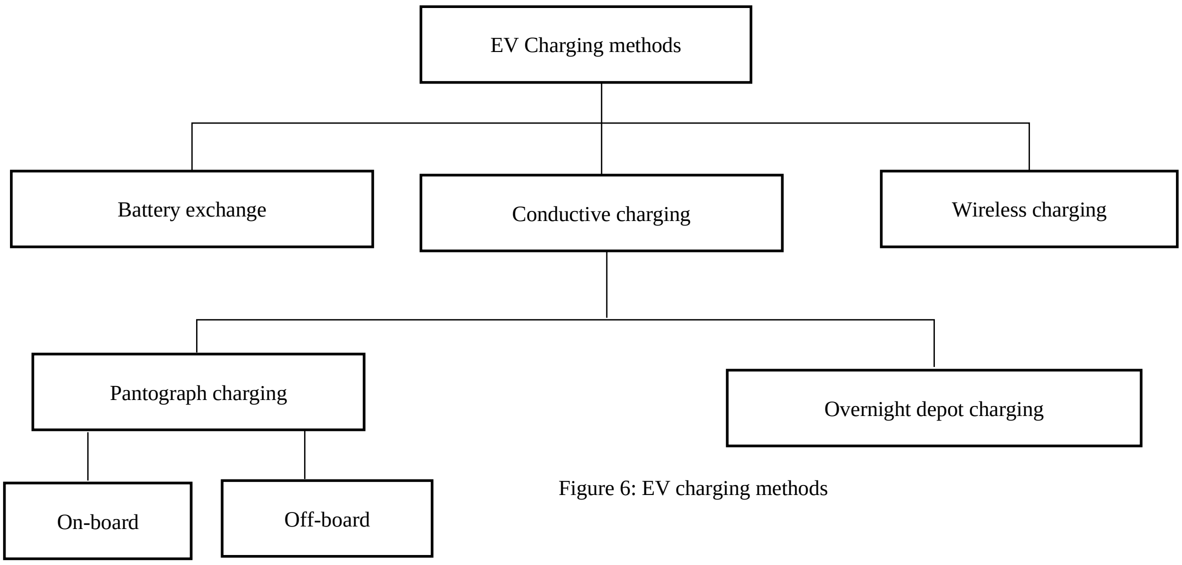

Figure 6: EV charging methods

- ❖ Battery Swap Station (BSS)

The battery swapping method is also known as "Battery Exchange", which is based on paying monthly rent for the battery to the BSS owner. The slow charging method of the BSS helps to extend the battery life [52]. It is much easier to integrate locally generated Renewable Energy Sources (RESs) such as Solar and Wind with the BSS system. One of the main advantages of this technique is the drivers do not need to get out of the vehicle and can replace the discharged battery very quickly. Moreover, the battery kept at the station can participate in the V2G (vehicle-to-grid) initiative [53]. However, due to the high monthly rental fees charged by the BSS owner, this type of EV charging technique can be costlier than the fueling of the ICE engine because the BSS owner owns the EV batteries. This technique requires multiple expensive batteries as well as a sizeable area in which to store them which may require expensive real estate in a high traffic area. Also, the station may have a particular model of the battery, but the vehicles may have different battery standards [54].

- ❖ Wireless Power Transfer (WPT)

This technology is based on electromagnetic induction and uses two coils. The primary coil is placed on the road's surface, and the secondary coil is placed inside the vehicle. Recently, WPT technology has gained attention in EV applications because

Table 3: Summary of reviews on charging method

Types	Advantages	Disadvantage	Reference	Year
BSS	Easy to integrate with the locally generated RESs. Time-saving as it is a quick battery replacement (Fully charged) Battery life as BSS as it is slow charging BSS helps utilities balance the demand and load by using the V2G facilities	Need a large stock of expensive batteries The huge investment required for both equipment and batteries Costlier because of related renting, operation, and maintenance costs Many areas needed to accommodate the batteries Different EVs have different battery standards.	[60] [61] [62]	2021 2021 2022
WPT	EV recharge it safely and conveniently No need for any standard connector No need for any standard Socket Recharge when the vehicle is in motion.	Power transfer is generally weak The range of 20 to 100 cm for efficient power Transmission The transmitter and the EV should be real-time and communication latency.	[63] [56]	2022 2021
CC	Prevent grid power overloading Provide multiple charging levels Active power support. Provide high efficiency Coordinated V2G facility Reduce the grid loss Maintain voltage level	Complex infrastructure V2G operation reduces the lifetime of the battery. Restriction to the electricity grid Fast charging causes voltage instability in the distribution system Need a standard connector/charging level Grid power overloading will occur due to uncoordinated charging	[59] [57]	2022 2020

of its ability to enable the EV to recharge safely and conveniently. Also, it does not require a standard connector (but does require a standard coupling technology) and can charge even while the vehicle is in motion [55].

However, the inductive power transfer is generally weak, and the air gap between the transmitter and receiver coils should be in the range of 20 to 100 cm for efficient power transmission. Moreover, eddy current loss is another issue in the WPT if the transmitter coil is not turned off. The information transfer between the transmitter and the EV should be real-time which means communication latency can happen [56].

- Conductive Charging (CC)

Conductive charging requires an electrical connection between the vehicle and the charging inlet and provides different charging facilities, e.g., level 1, level 2, and level 3 charging, and has high efficiency in charging due to the direct connection. The two power charging levels (Level 2, and 3) are employed for a public charging station. The first two levels (Levels 1 and 2) have less impact on the distribution system [57].

Conductive charging provides a V2G facility and reduces the grid loss, maintains voltage level, prevents grid power overloading, and active power support, and can provide reactive power compensation by using the vehicle's battery. However, level 3 has different impacts on the distribution system such as voltage deviation, reliability of the system, and transfer/power loss. It increases not only peak demand but also affects the transformer life. It also needs a complex infrastructure, limited access to the electricity grid, and a standard connector/charging level [58]. The V2G technology requires intensive communication between the grid and the vehicle. Also, the V2G operation reduces the battery lifespan of the battery due to frequent charging and discharging. The charging station types including BSS, WPT, and CC stations are summarized in Table 3. [59]

6. Impact of EV Integration on Grid Stability

Power system stability is defined as the ability of a power system to restore itself to its steady-state operational condition after experiencing a disturbance. Multiple instances of blackouts have been documented as a result of power system instability, thereby underscoring the importance of researching system stability. EVs, when charging from the grid, exhibit non-linear load behavior that differs from conventional loads. This can potentially exert stress on the power system. The estimation of the behavior of this new load is further complicated by the unpredictable characteristics of EV charging locations, times, and durations. Concerns may arise regarding the stability of the power system in the event of a substantial influx of EV charging simultaneously. The accurate modeling of EV loads is essential for conducting stability research, as load characteristics can significantly impact power system stability. Several studies have been conducted to explore different EV load models [64] [65]. Table 4 provides a clarification of the impact of integrating EVs into the power grid considering different aspects of power system stability, voltage stability, frequency stability, and oscillatory stability.

	Impact of EV Integration
Voltage Stability [66]	EV charging has peculiar load properties when compared to conventional loads. EV integration may have a negative effect on the stability of the grid's voltage depending on the area, level of penetration, and EV charging time.
Frequency Stability [67]	The level of load demand is raised by the unknowns around the EV connection site, penetration level, and connection and disconnection timeframes. As a result, the grid's frequency stability can be compromised. EVs can function as controlled loads and take part in frequency regulation of the grid with a faster ramp rate and ancillary services.
Oscillatory Stability [68]	When compared to traditional loads, an EV load has quite distinct properties. The properties of negative exponential EV loads affect the power system's oscillatory stability more than those of normal system loads.
Increase in Peak Load [66]	EVs can considerably increase grid demand, especially during peak charging hours. Peak load rise is affected by the number of EVs, charging behavior, and charging infrastructure. The widespread deployment of EVs is expected to increase peak electricity demand. Some reports studied the implications of EV charging on the US electricity system. EV adoption might increase nighttime peak electricity demand by 30%.
Transformer Aging [68]	Transformers are vital to electrical infrastructure, and EV charging can hasten their aging. If EV charging demand rises, transformer maintenance or replacements may cost more. A case study in a city with widespread EV use examined how EV charging affected transformer aging. Compared to sites with low EV charging demand, locations with more EVs increased transformer aging by up to 15%.

Table 4: Impact of EV Integration on Grid Stability.

7. EXISTING SOLUTION OF EV INTEGRATION WITH GRID

The integration of EVs into the grid has several positive impacts on grid stability. The EVs must be carefully placed into and utilized in the system for the frequency and voltage support of the grid. Improper utilization of EVs adversely affects the voltage and frequency stability of the grid. However, various alternative technologies and approaches are reported in the literature for the integration of EVs into the grid [69] [70]. These approaches include distributed energy resources (DERs), demand response, EV charging management, coordinated EV charging, smart charging, vehicle-to-grid technology, etc.

Some Existing Solutions of EV Integration with Grid:

- Smart Charging: This innovation optimizes the way EVs are charged to save the power grid from overload. It allows EV charging to be scheduled based on the availability of renewable energy or during off-peak hours.
- Smart Grid: Smart grids are built to automatically detect, monitor, and regulate the flow of energy between power generators and end users using information and communication technology. In smart grids, EVs can be charged and discharged in a coordinated way that also allows renewable energy sources such as solar and wind power to be integrated into the system.
- EV-Charging Management Systems: These systems can help maximize the amount of energy that EVs draw from the grid, reducing the load on distribution networks and the distribution transformer. By offering usage-based or dynamic tariffs, these systems can also help reduce the cost of EV charging.
- Demand Response: By incentivizing e-vehicle owners to charge their cars during off-peak hours (e.g., evenings), utilities can reduce peak demand. This reduces the burden on the system, provides better regulation service, and reduces the possibility of congestion in the grid.
- Vehicle-to-Grid (V2G): EVs can provide electricity to the grid according to V2G technology. Supplying extra energy during the peak hours periods helps the frequency regulation service for the grid.
- EV/Grid Interoperability Standards: The safe and effective integration of EVs into the grid can be ensured with the aid of EV/grid interoperability standards. The gear and software used for EV charging may be made compatible with the grid as a result of these standards.
- Renewable Energy Sources: EVs may be charged using renewable energy sources like solar and wind energy. This lessens the dependency on conventional energy resources and lowers greenhouse effects.

- Battery Storage: When there is a large demand for EVs, battery storage technology can be utilized to charge them. It also allows for the storage of extra renewable energy. This will result in a reduction in energy costs. The extra load can also be supplied by utilizing this battery energy storage as an ancillary service device.
- Electric Vehicle Supply Equipment (EVSE): EV supply equipment is abbreviated as EVSE. It helps minimize grid overload by reducing the amount of power consumed for EV charging.
- Power Electronics: Power electronic converters facilitate, regulate, and improve the EV-to-grid energy transfer. The advancement in converters allows suitable EV grid integration and improvement in energy flow management.

9. RELATED RESEARCH WORKS

9.1 Review of EV charging station

In this subsection, recent collaborative EV charging system research findings are presented. Areas of possible improvement (further research) are noted and lead to a research gap.

Autor in [71] has mentioned that it is necessary to install EV fast-charging stations (EVFCS) where EVs can be charged in less than 20 min in public, such as in parking lots. On the other hand, the disadvantage to EVFCS is their high-power usage, which can affect the grid. To solve this problem, renewable energy such as photovoltaic (PV), wind turbine (WT), and battery energy storage systems (BESS) must be installed in the EVFCS to mitigate the impacts on the grid. In considering the problem of the optimal pricing strategy and the charging schedule of EVCS where different schemes or methods to minimize the charging cost, [72] proposed a pricing scheme to optimize charging scheduling for EVCS, which could minimize the service dropping rate of EVCS. The optimal charging schedule for EVs was presented by [73] to minimize the charging cost and charging time.

In [74], they proposed varied charging pricing schemes to plan EV pathways by considering the charging fee, energy consumption, total time consumption, and driving distance. In their literature review, [75] found that approximately 10 optimally located fast chargers are sufficient for every 1000 EVs, but were unable to draw general conclusions based on the small amount of studies that were reviewed. [76] presented shifting peak hours demand to non-peak hours with a reduction in the average-to-peak ratio to minimize the charging cost and maximize the availability of charging capacity for EVs. The charging pricing scheme was determined to maximize total revenues and balance the profits of EVCS by using PSO. [71] has also presented the optimal design of EVFCS incorporating renewable energy sources and storage systems to maximize the profit measured by its net present value (NPV). GA was applied to find the structure of the EVFCS, consisting of the number and power of chargers, the number and type of wind generators, the installed area of PV panels, the storage system capacity, and the maximum power of the grid-connected to the station. This algorithm was also used to optimize the operation of EVFCS and find the best solution that maximizes the profit or the NPV.

In the optimal designs of EVFCS or EVCS, many methods have been proposed and applied to optimize the designs of EVFCS or EVCS and operation. Some authors attempted to solve the optimal placement problem of EVFCS or EVCS by using different metaheuristic algorithms. [77] have proposed the optimal placement of the solar-powered charging station in the IEEE 33-bus system. Chicken swarm optimization (CSO), teaching-learning-based optimization (TLBO), and Java algorithms were applied to optimally place the charging stations with multi-objective problems by considering improved voltage profile, minimum power loss, and reduced cost as the objective functions. Excessive electrical power requirements due to EVs integration, bus voltages, power loss, stability, harmonic distortion, voltage mismatch, and power efficiency could negatively affect the distribution network.

Furthermore, the addition of EVs requires more reliable electric vehicle charging station (EVCS) systems with less EV charging time. As a result, [78] has found that fast charging in the EVCSs is viable for charging an EV’s battery in 20-30 min. The multi-objective function maximizing voltage stability index, minimizing active and reactive power losses, and average voltage deviation index were considered by [79] to optimize the placement of EVCS in the IEEE 69-bus system. A hybrid bacterial foraging optimization algorithm and PSO (BFOA-PSO) technique were proposed to solve this problem. [80] applied the cuckoo search algorithm (CSA), genetic algorithm (GA), and simulated annealing algorithm (SAA) to optimize the sizing of the installed PV within EVFCS and the position of EVFCS in the IEEE 33-bus system. Additionally, an improved shark smell optimization algorithm is used to obtain the optimal location and size of the electrical energy storage system in the microgrid [81]. [82] has found that many variables influence the load on EVCSs, including weather, the number of EVs on the road, and power costs. An approach for EVCS load forecasting based on a multivariable residual correction gray model and a long short-term memory network.

In addition, different metaheuristic algorithms have been presented in many works to optimize the structures such as the number and power of chargers, sizing of renewable energy sources and BESS, and operations of EVFCS or EVCS. [83] introduced the optimal design of EVCS by considering the minimization of the lifecycle cost as the objective by using HOMER software. The optimal energy storage system (ESS) size in EVFCS was proposed by [84] to minimize the ESS cost and ensure the resilience of EVs during power outages. [85] used the multi-agent particle swarm optimization algorithm (MAPSO) to find the optimal sizing of PV and BESS and determine the charging and discharging pattern of BESS and electric exchange with the grid. The results showed that the optimal sizing of the structures and operation could minimize the electricity cost. The optimal configuration of PV and battery, and the optimal design of operation for EVCS by using improved hybrid optimization genetic algorithm (iHOGA) software version 2.4, were examined by [86]. This software was applied to design PV and battery sizing to ensure that EVCS could accommodate EVs throughout all 24 hours of the day to maximize the net present cost. [87] computed the minimum numbers of PV modules and energy storage unit batteries for PV grid-connected charging systems by using PSO to decrease the charging price and impact on the grid. However, most of the papers about the design of EVFCS or EVCS have only focused on the problem of the placement or configuration structures within EVFCS or EVCS.

Recently, with growth in the number of MGs with diverse features, the NMGs framework has been proposed. In the distribution network of a regional power system, these interconnected MGs forming NMGs are geographically near to each other. At different times of the day, different MGs have varying generation and load requirements. At any given time, the quantity of energy generated by local RES in the MGs may be higher or lower than the local demand in MGs. In the event of a power deficit, MGs obtain power from the costly utility grid. [88] proposed that the NMG architecture allows the interconnected MGs to perform energy trading /power exchange among MGs. Energy trading among MGs, allows the NMGs to optimize their economic benefits, maximize the use of DERs, reduce losses, and maximize security and reliability, and they found it is technically and economically beneficial for MGs to trade energy directly among MGs to increase the resilience and reliability.

Authors in [89] studied optimal sizing of the ESS problem for NMG. This problem is modeled as a bi-level problem, reduced to a single-level problem, and solved using mixed-integer linear programming. [90] proposed the optimal siting, sizing, type, and dispatch of DERs, including allocation of section switches, and the objective is modeled as mixed-integer linear programming and solved using MOPSO. [91] discussed the appropriate placement and size of various components in various buildings acting as smart MGs for a pilot project in Iran where sizing and siting are done to lower MG costs and losses respectively. A networked microgrid consists of multiple microgrids, where each microgrid might contain various generation resources, batteries, and residential loads. Compared to the individual microgrid configuration, a networked microgrid enjoys lower cost and emission.
A study of [92] proposed a technique of loss of power supply probability for optimum sizing of microgrids for their technical and economic analysis. Apart from different contributions to the optimization of P2P energy trading schemes, many researchers have used game theory approaches for the pricing and energy exchange with power systems [93] and a technique of multi-objective optimization is performed for the planning of clustered microgrids and networked microgrids, where different criteria for optimization are considered so that the most suitable sizes for the generation resources and batteries are found.

9.2 Review of Energy Management System

The multiple microgrids can be connected to the network at the distribution level through one or more switches. However, the switching operations to connect/disconnect individual microgrids can cause uncontrolled frequency and voltage deviations that ultimately could lead to system collapse [94]. Therefore, control measures are necessary to ensure safe and reliable operation, especially in transient periods. A distributed secondary control of interconnected microgrids using multi-agent systems and the RL algorithm is proposed in [95]. This methodology can achieve global coordination in interconnected microgrids in a distributed manner and the voltage and frequency can be controlled effectively.

A concept of voltage and frequency control for islanded multi-microgrids using adaptive NN and distributed cooperative control has been discussed in [96]. Model-based controllers were designed using Lyapunov theory and the ANN predicts the system dynamics to control the parameters. A generation capacity optimization using ANN is also proposed for the islanded operation of an incoming microgrid in a multi-microgrid [97].

The resiliency of interconnected microgrids has been studied in [98] by examining the real and predicted dynamic states of the system. Various factors like time-shifting, magnitude deviations, and other data averaging effects were considered individually and later collectively to determine the power imbalances at a unit time step. The uncertainties are quantified and eliminated in the proposed power-sharing algorithm to develop an efficient EMS.

[99] published a book and found that modeling and optimization of energy management systems for micro- and mini-grids play an important role in the fields of energy generation dispatch, system operation, protection coordination, power quality issues, and peak demand conflict with grid security. This comprehensive reference text provides an in-depth insight into these topics. This text discusses the use of meta-heuristic and artificial intelligence algorithms for developing energy management systems with energy use prediction for mini- and microgrid systems.
Hence, it is clear that in the future, AI-based solutions may be considered to understand more realistic extreme weather conditions, develop forecasting algorithms, and implement other control strategies.

10. Research Gap and Future Research

The large-scale integration of EVs in the conventional power system can lead to an increment in power demand and can therefore threaten the main grid. The integration of renewable EVCI into the local grid will minimize the total operation costs, as well together with maximize the local utilization of renewable energy, and improve the system reliability. Hence, the reviewed recent research in EVCI, potential areas of improvement have been noted as per the following listing.

A networked electrical vehicle charging infrastructure (NEVCI) based on hybrid energy should be modeled

This configuration can store energy either a surplus from renewable energy resources or from the grid during off-peak and trade with it during peak hours. The operation of these NEVCIs is expected to offer technical and economic benefits to charging station owners, customers, grid/utility, and other stakeholders as they will allow to maximizing benefits and reliability of these charging stations and the grid as well.

1. A technique of multi-objective optimization to be performed based on criteria of annual cost and energy index of reliability.

Multi-objective optimization (MOO) to be dispatched for this EVCS configuration (MGs) can achieve many benefits, such as minimized operation cost, greenhouse gas emission reduction, and enhanced reliability of service. This NEVCI should be designed in a way that the first priority of the prosumer which is each CS will be exchanging excess power or power shortage with the nearest prosumer or with any prosumer within the network to meet the requirement as this reduces stress on the utility grid. In the second priority, if the prosumers are unable to meet the power requirement, then it will do the power exchange with the main grid.

2. A deep study on developed energy management system that will coordinate the energy sharing of this NEVCI
Energy management systems are very crucial in such networked EVCI as it has more than one element, it could be either energy resources or the application of various storage technologies for optimal power sharing between each EVCS in the network or with the utility grid for efficient, reliable, and economic operation.

3. Cost analysis during energy trading both when injecting in the grid or between prosumers.
To ensure the robust performance of networked electrical vehicle charging infrastructure (NEVCI) against uncertainty, it is necessary to research a fair energy trading scheme for both prosumers and the utility grid.

4. Communications and AI application in this NEVCI
The use of artificial intelligence will help to improve the accuracy of operation to provide effective and accurate prediction control of the proposed integrated system

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