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Review

Grid Integration for Electric Vehicles: A Realistic Strategy for Environmentally Friendly Mobility and Renewable Power

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Abstract: The promotion of electric vehicles (EVs) as sustainable energy sources for transportation is advocated due to global considerations such as energy consumption and environmental challenges. The recent incorporation of renewable energy sources into virtual power plants has greatly enhanced the influence of electric vehicles in the transportation industry. Vehicle grid integration offers a practical and economical method to improve energy sustainability, addressing the requirements of consumers on the user side. The effective utilisation of electric vehicles in stationary applications is highlighted by technological breakthroughs in the energy sector. The continuous advancement in science and industry is confirming the growing efficiency of electric vehicles (EVs) as virtual power plants. Nonetheless, a thorough inquiry is imperative to elucidate the principles, integration, and advancement of virtual power plants in conjunction with electric automobiles, specifically targeting academics and researchers in this field. The examination specifically emphasises the energy generation and storage components used in electric vehicles. In addition, it explores several vehicle–grid integration (VGI) configurations, such as single-stage, two-stage, and hybrid-multi-stage systems. This study also considers the various types of grid connections and the factors related to them. This detailed investigation seeks to offer insights into the various facets of incorporating electric vehicles into virtual power plants. It takes into account technology improvements, energy sustainability, and the practical ramifications for users.

Keywords: electric vehicle; grid integration; virtual power plants; vehicle-to-grid; grid-to-vehicle

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1. Introduction

In recent decades, the transportation industry has experienced a shift in its concentration towards renewable energy sources as a result of growing concerns regarding the use of fossil fuels and the degradation of the environment. In recent years, electric vehicles, which reduce their impact on the environment by reducing their dependency on conventional fuels, have acquired substantial commercial momentum and demonstrated rapid growth [1]. There has been a lot of interest in the idea of combining electric vehicles with large-scale energy storage and producing units as a viable alternative energy source. Furthermore, researchers in the energy sector urge for the efficient utilisation of electric vehicles in stationary applications due to the significant period that these systems remain idle (about 95 percent) [2]. During moments of inactivity, these systems can work as a form of power plant for electric vehicles. They can either charge the batteries of the vehicles or sell any extra electricity that is produced [3]. In both directions, the flow of electrical energy between electric vehicles, houses, and grids is made possible by the utilisation of electric vehicles as virtual generators. Because of this, the system's flexibility, efficiency, and equilibrium are all improved [4]. A virtual power station is a facility that is connected to the utility grid and is responsible for collecting energy from a variety of sources. These sources include renewable energy, power-producing facilities, and consumer groups. Through the utilisation of virtual power plants (VPPs), which are sometimes referred to as cloud-based distributed power plants, it is possible to combine and control all of the components of a complicated power plant that are responsible for producing and storing energy effectively. Virtual power plants are made up of a large number of electric vehicles, decentralised energy sources, and extra energy storage devices that are connected to the grid. These structures will experience fewer disruptions due to transmission/distribution line issues and offer users more reliable energy services compared to conventional power plants [5].

1.1. Motivation

Integrating electric vehicles into VPPs, in addition to dispersed energy sources, offers benefits to both parties involved. Integrating electric vehicles with VPPs aids in stabilising the electricity demand. Electric vehicles can offset the rise in immediate electricity usage within a structure, hence reducing the additional electrical energy drawn from the power grid. Integrating electric vehicles with the power grid as a customised power device mitigates the issues arising from the grid and customer interface. In addition, integrating electric vehicles into a residential area's electricity demand management offers adaptability to the power system and aids in mitigating imbalances [6]. Incorporating electric vehicles as VPPs involves sending power via EVs to the power lines at the most opportune moments, which offers numerous advantages in addition to recharging the power units in the system [7]. The notion of utilising the power grid to charge electric vehicles is known as the grid-to-vehicle (G2V) process [8]. However, employing converter interfaces that can function in both unidirectional or bidirectional fashion, electric vehicles integrated as virtual power plants can supply electricity to the utility grid [9]. Vehicle-to-grid (V2G) structures are those that are linked to electric vehicles and can supply electricity to the grid [10]. In addition to providing electricity to consumer loads connected to the grid, the V2G mode for operation may stabilise the features of the electrical grid [11]. In addition, some structures have no connection to the grid and operate independently in standalone mode [12]. Furthermore, EVs are employed as VPPs in various capacities and configurations, each with its concepts. Nevertheless, the fundamental characteristic shared by all proposals is the utilisation of electric vehicles as a supplementary energy unit to fulfil the demand for electrical power [13].

1.2. Literature Review

Multiple studies in the literature illustrate the popularity, feasibility, and benefits of utilising EVs as VPPs for supplying alternative energy. Numerous review studies have been conducted to analyse the prevalence and research subjects within the associated discipline. Numerous scientific research provides evidence of the current popularity of the connected subject. A substantial amount of scientific review publications in the current research highlights the importance of utilising EVs as alternative sources of energy. However, the majority of these studies highlight the significance of utilising electric vehicles as additional sources of energy. These studies discuss various aspects such as energy management techniques, obstacles, the impact of power quality on the arrangement, standards, operational modes, optimisation efficiency, and the financial gains associated with EVs functioning as VPPs. The authors in reference [14] specifically examine the energy management techniques utilised in vehicle–grid integration systems, with a focus on the issues associated with this field. The researchers present information concerning the standards for electric vehicles, the charging topologies, and the challenges that are associated with vehicle-to-grid integration systems. The authors in [15] provide an overview of the many energy management strategies that have been implemented to reduce the risks associated with the incorporation of electric vehicles into the power grid. In [16], the dependability of an EV system is analysed to understand the impact on power networks in terms of the quality of the power. Also, it offers an explanation of the voltage levels that are required for electrical connections, such as those that are utilised for the purpose of charging batteries. As well as the effects that electric vehicles have on the dependability of the system, the authors analyse the effects that electric vehicles have on power networks in terms of the quality of the power that is produced by the grid. It offers an explanation of the voltage levels that are required for electrical connections, such as those that are utilised for the purpose of charging batteries.

Within the scope of the research presented in [17], the needs for electric vehicles, the infrastructure for charging, and the impact of the quality of the electricity on the power system are all taken into consideration. Specifically, this article discusses the obstacles and difficulties that are involved with the technology of vehicle-to-grid, specifically in terms of the methodology for optimising facilities, the environmental ramifications, and the policy surrounding energy [18]. The research presented in [19] lightly focuses on the challenges and obstacles that are related to car-to-grid systems. These difficulties and obstructions are essentially associated with the deterioration of batteries, the demand profile of electric vehicles, the influence of saturation levels, the effects of charging on distributed networks, and the implications on distribution parameters. This article lightly focuses on the challenges and obstacles that are related to car-to-grid systems. The authors in [20] also analyse the difficulties that are linked with the concept of vehicle-to-grid. These difficulties include the deterioration of batteries, the effects on distribution devices, the costs of investments, and the energy losses. The authors in reference [21] analyse the effects that the usage of vehicle-to-grid technology has on distribution systems, with a particular emphasis on the environmental benefits that the grid receives, the provision of extra services, the support and rebalancing of renewable energy, and the impact on distribution equipment.

The research on operation modes and norms includes a review study that highlights the significance of various business models. These models encompass car producers, battery producers, motorists, suppliers of energy, gearbox and distribution system managers, vessels, aggregators of mobility service providers, independent clean energy providers, and transit system operators [22]. This study provides clarification on the factors that influence the economic success of V2G installations. The criteria for goals, marketing, technical challenges, expenses, and oversight explain the distinct factors that influence the financial results of the systems [23]. The study described in [24] is driven by the effects of electric vehicles on the smart grid, existing laws, and the integration of EVs with the smart grid's capabilities. This study examines the consequences of smart grid capacity for load on the quality of electricity, financial markets, and the natural world. This paper discusses the requirements for communication and charging structures of electric vehicles when they are used as virtual power plants. There are a variety of subjects that are covered, including power electronics converters, operation methods, plug designs, and the direction of energy flow [25]. This work examines the operational modes of a few VGI topologies and also presents experimental findings to illustrate the energy flow in these systems [26]. The authors in [27] provide detailed information on the power interaction types, scheduling approaches, and analytical principles of electric vehicles when they are used as VPPs. The authors in [28] explore the ideas of vehicle-to-home (V2H), vehicle-to-vehicle (V2V), and V2G operations, as well as the modelling of local electrical equipment, electrical interactions, and battery technologies. The researchers provide a thorough analysis of the categorisation of charging systems and reversible converters employed in the integration of electric vehicles into VPPs [29].

In prior research, investigators in [30] examine the structure, optimisation techniques, benefits, and challenges of using VGI technology for EVs as virtual power plants. These include the high expenditure cost, social obstacles, and optimisation objectives. The authors in [31] provide a systematic evaluation that examines the social effects of V2G structures on the environment, society, and human factors. The authors in reference [28] explore the potential and difficulties associated with utilising electric vehicles for VPP applications. The authors in [32] present a comprehensive analysis of the financial advantages of V2G technology for power production firms, network operators, EV aggregators and customers. The authors in [33] provide an analysis of auxiliary service potentials, together with an assessment of potential repercussions and future market penetration capabilities in the relevant field. In addition, [34] provides an analysis of the future implications of V2G technology, focusing on its impact on technical grid efficiency, different types of electric utilities, socio-environmental considerations, potential cost savings, and environmental expectations.

1.3. Contribution

Current research indicates a lack of comprehensive review papers that thoroughly cover the systematic integration, operational aspects, and advancements in vehicle-to-grid technology. In addition, the published review studies on the utilisation of electric vehicles as VPPs do not provide detailed explanations of the integration principles, interface buildings, and the product's commercial and future issues. Hence, it is imperative to commit resources to address every aspect of the networks whereby VPPs are connected to electric vehicles to provide guidance and uncover the demands of the relevant region. Hence, the primary objective of this study is to elucidate various virtual power plant configurations associated with electric vehicles, the interface mechanisms between EVs and utility grids, and the prospective advancements in this sector. This is accomplished by conducting a comprehensive literature review and highlighting the essential research needs.

The present study examines previous research in the field of utilising electric vehicle VPPs. It aims to illustrate the essential structures of system integration and offer comprehensive guidance to academics for future investigations. In contrast to previous review studies, this work provides a detailed analysis of the integration principles of electric vehicles as VPPs. The structures under investigation are categorised into four primary sections: independent operation, performance connected to the power grid, transition functioning, and operation assisted by the power grid. Following that, the interaction architectures of VPPs that are linked to electric vehicles are thoroughly elucidated about EV concepts, stage-based categorisation, and grid connection. The examination of electric vehicles is divided into two distinct groups in order to accomplish this goal. These categories are vehicles that utilise energy-generating systems (EGSs) and cars that depend on energy storage systems (ESSs), as shown in Figure 1. In the course of the investigation, electronic converter interfaces are investigated and classified into three distinct categories: hybrid stages, two-stage, and single-stage designs. The grid-connection component encompasses several aspects such as grid classifications, physical connectivity challenges, and adherence to grid regulations. In addition, comprehensive information is provided on international research initiatives and commercial subjects to demonstrate the present state of electric vehicles as VPPs. The current analysis additionally emphasises future directions for virtual power plants linked with electric vehicles. This study also examines and presents future factors such as charging techniques, intelligent technology, and technical difficulties as summarised in Figure 2.

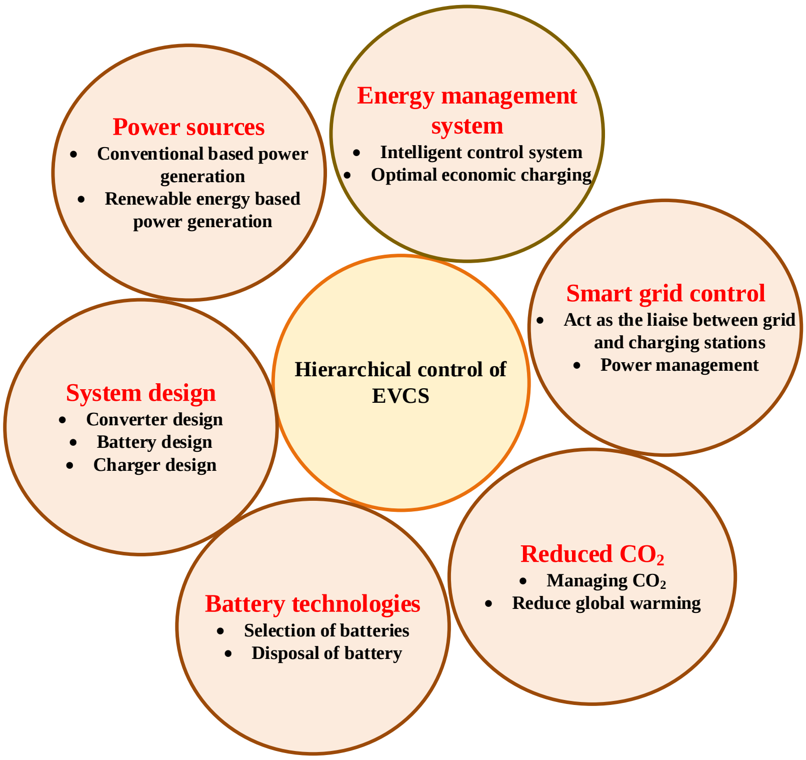

Figure 1. Energy storage and control system.

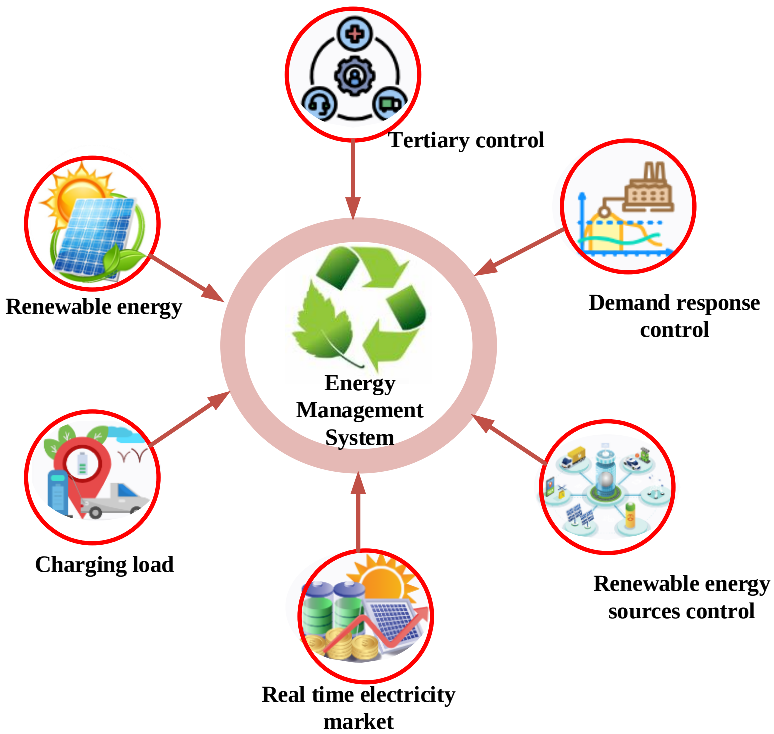

Figure 2. Various factors influencing charging system.

2. Hierarchical Structure of EV Charging Stations' System Operation

The electric vehicle charging station acts as a go-between for the people who utilise electric vehicles and the local power system [35]. By utilising a significant number of electric vehicles, it can provide additional amenities for the local electrical system and control the local charging demand, which results in a reduction in the overall costs of operation [36]. On the other hand, achieving the least cost and balance of power amongst several components concurrently while under an unpredictable charging load continues to be a difficult task [37]. By considering customers' and operator's viewpoints, it is anticipated that the electric vehicle charging station will accomplish the following goals, beginning with the lower-level control and progressing through the upper-level energy administration system [38,39].

- Output control involves the regulation of voltage and current in different converters. It is necessary to guarantee that these values closely follow the target values and that any oscillations are effectively suppressed.
- Power quality management refers to the capacity to uphold the necessary charging voltage and current for electric vehicle batteries, while minimising any adverse effects on the power system, such as limiting peak power and harmonic pollution.
- The capacity to maintain the operational balance, which includes maintaining a constant AC frequency and rectifier bus voltage, while also maintaining the ability to accommodate changes in load and generation is termed as power system stability.
- The capacity to meet the charging demand of consumers within a restricted time frame and to achieve the lowest possible costs without negatively impacting the happiness of users is what we mean when we talk about energy management and economic dispatch.
- One definition of ancillary service is the capacity to supply the local grid with either active or reactive power supporting.

There are a variety of time frames and levels of significance associated with the objectives. In most cases, it is essential to have a hierarchical management system of the electric vehicle charging facility in order to obtain the desired results. This is because hierarchical control can provide control targets that are not connected to one another, and each objective can be accomplished at a distinct control hierarchy according to the hierarchy level. Figure 3 provides an illustration of a representation of a hierarchical control system that is conventional and consists of three layers.

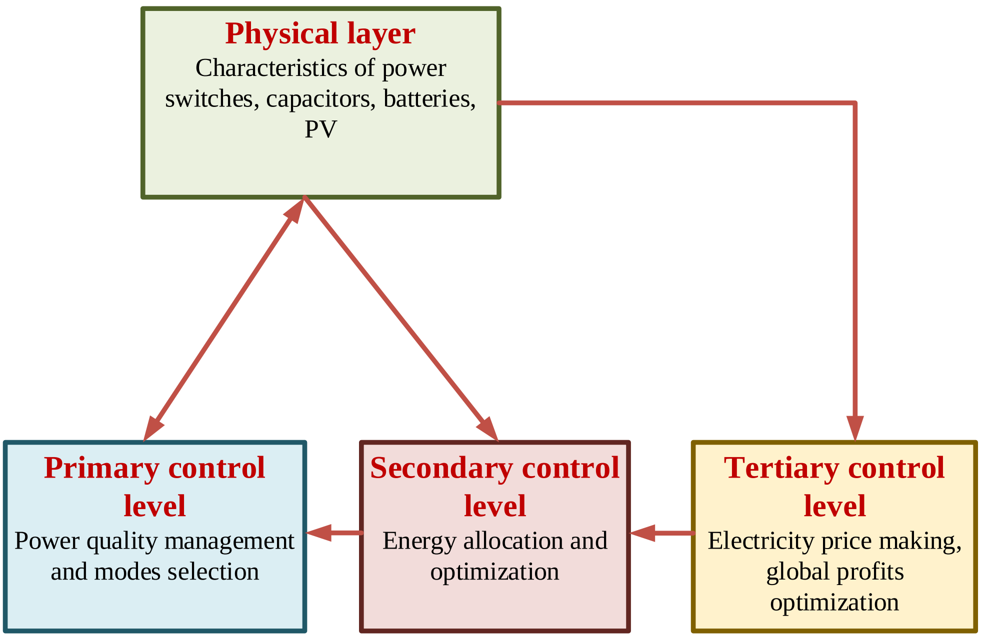

Figure 3. Typical hierarchical control system.

2.1. Tertiary Control System

The most advanced level of control in the management hierarchy is referred to as tertiary control. This control level is in charge of establishing long-term points of reference in compliance with the constraints of the major power grid. Therefore, it is responsible for this obligation. However, despite the fact that it is possible to think of it as part of the main grid, it is not entirely included in the micro-grid system. For the purpose of achieving the overall active/reactive management of electricity, it is the role of the tertiary controller to manage the various micro-grid systems. It is the responsibility of tertiary control, which is the top tier in the oversight hierarchy, to develop long-term reference points. Requirements and characteristics of the primary electrical system were taken into consideration when establishing these reference points. In order to accomplish this, it is necessary to take into consideration a variety of elements, including overall grid stability, load demand estimates, and major energy management measures. The majority of the time, it operates within a time range of a few minutes, and its primary function is to provide control signals to the second-level controller of a variety of microgrid systems. Furthermore, it is possible for the tertiary controller to create the mechanism for the dynamic price of power or further game-theoretic procedures in order to encourage the microgrid systems that participate in demand-side control over energy [40–43].

2.2. Secondary Control System

In the context of the control system for electric vehicles, the energy management system (EMS) is the abbreviation for the second control level. Under conditions of fluctuating charging demand and a dynamic market for the price of power, the EMS is responsible for guaranteeing that the operations are safe, trustworthy, and cost-effective without compromising safety or reliability. Due to the presence of a number of constraints, such as charging load limit, the degree of satisfaction experienced by electric vehicle users, and charging rate management, this task is practically tough. As a result, the secondary control acts on a time scale that is significantly slower in comparison to the primary level. A more extended time step allows for sufficient time to be allocated to the complex calculation that occurs during the optimisation process. It is also possible to lower the amount of bandwidth that is required for interaction among all of the parts of the system.

In order to establish the best methods for electric vehicle charging stations (EVCSs), it is necessary to solve the specified function objectives using a variety of optimisation approaches. When this occurs, the energy management system (EMS) is able to provide the set points, also known as references, of the primary controller. Finally, once the main controller has carried out the actions that have been established by the EMS, it is possible to accomplish certain objectives. These functions include the reduction in operation costs, the minimisation of recharging load variation, and other similar tasks. Among the many concerns of the EMS in an EVCS, the most important one is economic functioning. At the moment, the primary instruments that can be utilised to significantly reduce the costs of running a business are the variable price of power, the adjustable charging load for electric vehicles, and the marketplace for supplemental services. Additionally, in order to create additional money, the EMS can potentially make use of the local generating units as well as the local energy storage system [44,45].

Additionally, the EMS has the capability to reduce power quality issues, such as irregularities in voltage and frequency over extended periods of time. In order to be more explicit, the frequency and voltage imbalance that takes place at the point of common coupling between the grid and the charging station for electric vehicles is a serious challenge. In order to accommodate significant fluctuations in frequency and voltage, it is necessary to implement power management solutions that are appropriate [46,47]. A compensator that operates by a fuel cell is presented in [48] as a means of injecting power into the grid in such a way that the power conversion converter (PCC) voltage is able to remain balanced and include no harmonic fluctuations. In [49], it was suggested that a supercapacitor should be placed on the DC bus in order to accomplish the imbalance in voltage correction.

2.3. Primary Control System

The first level is the principal control, which is responsible for defining the rapid responses for the immediate dynamics. A closed system of control is created on the basis of the electrical signals that have been measured. If the requirements for reliability and power balance are satisfied, the output can adhere to the settings that are given by the higher command level in an array of operation modes. This is the case provided that the conditions are satisfied. In addition to this, the primary control has the capability of utilising the local energy storage system (ESS) in order to achieve consistency in the output. It is possible to employ the ESS as a power buffer to keep the bus frequency and voltage balanced in the event that the electric vehicle charging load experiences significant fluctuations. In addition to establishing a connection with the energy storage system that is located nearby, the grid-tied connection power conversion can also be utilised in order to achieve a balance between the frequency and voltage of the bus. As an illustration, droop controllers are utilised in an AC electric car charging station in order to keep the AC bus stable without the need to fulfil any communication requirements. This is carried out in order to preserve the stability of the AC bus [50].

2.4. Physical Layer of EV Charging Station

The power grid, the gearbox network, the charging management system, and the battery charging system are the key components that make up the infrastructure for charging electric vehicles. The most significant of these components is the charging management system. The responsibility of delivering continuous electric power to the infrastructure that is used to charge electric vehicles lies with the electric grid. This is carried out in order to make the process of recharging the batteries from electric vehicles easier. It is necessary to have a charging monitoring system in order to have an adequate management of the impact on the local electrical system and to lessen the effect of the degradation of the electric vehicle batteries while they are being charged. It is also required to have an interface between the charge control system and the battery management system of the vehicle in order to avoid problems with overcharging or over discharging the battery. It is for this reason that standardisation and protocols are necessary in order to ensure that all of these devices function appropriately [51]. This project is being carried out by a number of international organisations, including the International Electrotechnical Commission (IEC), the International Organisation for Standardisation (ISO), the Society of Automotive Engineers (SAE), and the Institute of Electrical and Electronics Engineers (IEEE) [14,17,52,53]. One of these international standards and protocols was developed with the express purpose of facilitating bidirectional charging and voice-to-grid connections [54,55]. A significant connection for communication between the charging station and the central system is provided by the Open Charge station protocol, and the most recent version of this protocol has included support for vehicle-to-grid technologies [56].

The layout of the electrical structure is a significant concern for electric vehicle control systems [57]. It is possible to design an electric vehicle control system based on either an alternating-current microgrid system or a direct-current microgrid system. Both have their advantages and disadvantages [58]. A DC micro-grid type of electric car charging station is built of many DC chargers that are connected to a common DC bus, as shown in Figure 4. This form of charging station is used to charge electric vehicles. It is also possible to employ a high-power rectifier as the connecting power converter between the DC and AC grid. This is carried out in order to create a connection between the two. On the other hand, in an electric vehicle charging station that is of the AC micro-grid sort, each individual electric vehicle charger is provided with a separate rectifier that is connected to the shared AC bus, as shown in Figure 5. This helps to ensure that the charging station is suitable for charging electric vehicles.

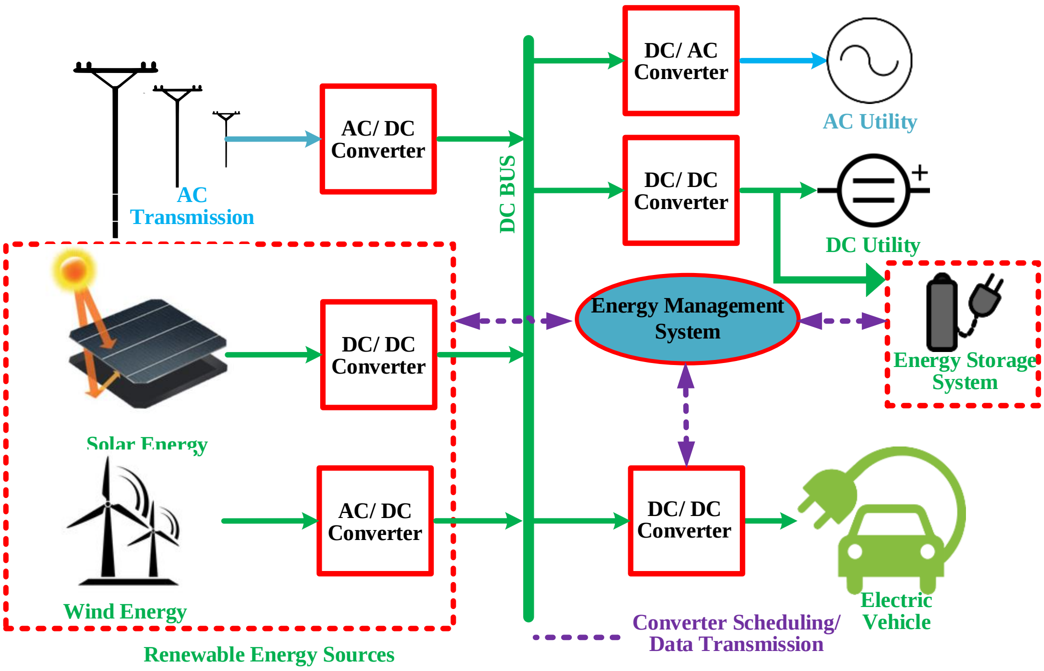

Figure 4. DC charging system.

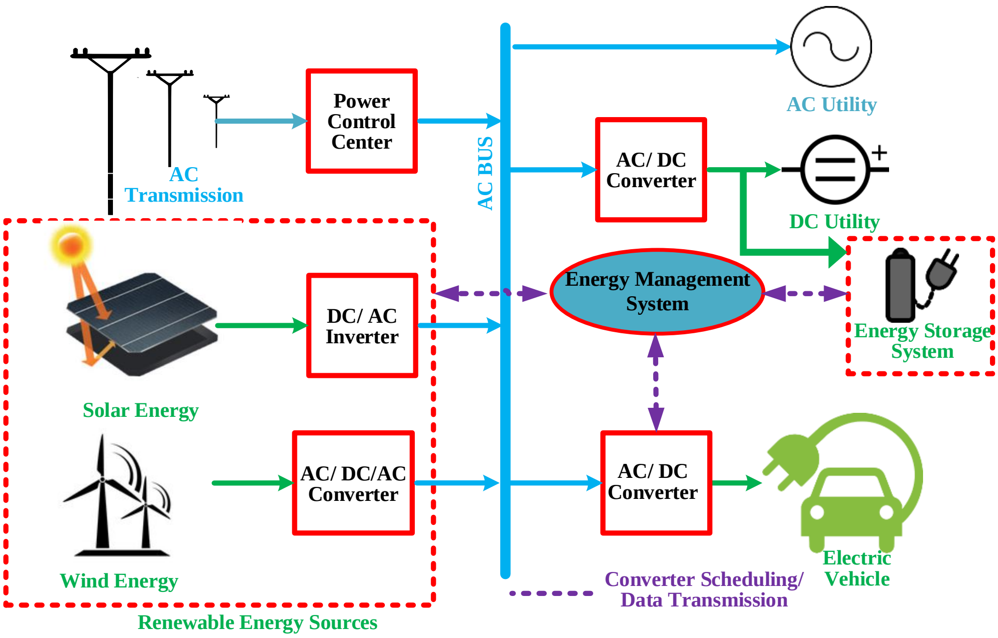

Figure 5. AC charging system.

When compared to the AC-EVCS, the AC/DC converter stages in DC power plants can be reduced in quantity [35]. The battery of an electric vehicle, the sources of clean energy, and the local energy storage system are all examples of DC load/sources. This is the reason why this is the case [59,60]. Specifically, this is due to the fact that the DC bus may have been naturally associated with sources of renewable energy. The DC charger may offer a cheaper and more effective method of integrating DC power and energy from renewable sources into the local grid [61]. This is because the DC charging stations have fewer converting stages than other types of charging facility.

On the other hand, the lower recharging power of AC chargers can bring about other benefits, including lower production costs [35]. Consequently, air conditioning charging stations have become the most desired option for public recharging terminals [62].

Additionally, there are additional benefits that are linked with charging stations for air conditioning, such as the accessibility to mature air conditioning technology and charging devices on the market [35]. Although this is the case, the AC charger is capable of delivering an aggregate recharging power of up to 19.2 kW, which indicates that it is suited for applications that require a long charging procedure [63].

2.5. Intelligent EV Charging Algorithms

Critical remarks on charging algorithms are listed in Table 1. It was ascertained whether the optimisation tasks were characterised as single- or multi-objective. Single-objective optimisation aims to optimise a single criterion, whereas multi-objective optimisation involves the simultaneous optimisation of multiple conflicting objectives [64]. The aims for integrating electric vehicles may encompass minimising charging expenses, mitigating grid congestion, and optimising the utilisation of renewable energy [65]. The performance of various genetic algorithms in optimising tasks was evaluated. Genetic algorithms exhibit variability in encoding systems, selection mechanisms, crossover and mutation operators, and termination criteria [66]. The usefulness of popular genetic algorithms was assessed, such as the Simple Genetic Algorithm (SGA), Genetic Programming (GP), Differential Evolution (DE), and Genetic Algorithm with Elitism, in handling specific challenges linked to electric car integration [67].

The measures employed to assess the efficacy of each algorithm were determined. Possible metrics to consider are the rate at which convergence occurs, the quality of the solution, the ability to handle unexpected situations, and the ability to scale up [68]. It was examined whether these algorithms were contrasted with conventional optimisation techniques, heuristics, or alternative evolutionary algorithms to offer a more comprehensive viewpoint [69]. The No Free Lunch Theorem asserts that there does not exist a universal optimisation algorithm that can be applied to all problems [70]. The selection of the genetic algorithm over other optimisation techniques was driven by the unique features of the electric car integration problem [71]. Practical instances and examples where such genetic algorithms were utilised for the integration of electric vehicles were examined. The difficulties encountered were evaluated and the algorithms' performance in real-world situations was evaluated [72].

The many methods used to adjust or modify the parameters of genetic algorithms were examined. Optimal parameter settings can have a substantial impact on the performance of these algorithms [73]. It is crucial to investigate the sensitivity of the results to various parameter configurations. It was examined whether there was an exploration of hybrid methodologies, integrating genetic algorithms with other optimisation approaches or machine learning methods [74]. Hybrid methodologies can occasionally improve the overall efficiency of optimisation.

Table 1. Critical remarks on charging algorithm.

Ref	Algorithm	Charging Type	Remarks
[75]	Multistage stochastic	Fast	Figure out the selection of charging stations for planning period.
[76]	Genetic Algorithm	Plug in	This study's goals include locating charging stations in the best spot, lowering customers' concerns about range anxiety, and minimising the costs of ownership.
[77]	Optimisation-based method that puts stations in the right place	Fast	This study adds a new constraint that is based on the process of building corridors and two new goal functions.

Table 1. *Cont.*

Ref	Algorithm	Charging Type	Remarks
[78]	A computer-based model for finding the best place for a public charging station	Public charging	In this study, a simulation–optimisation model is used to figure out where chargers for electric cars should be placed so that private EVs can use them most efficiently.
[79]	Genetic Algorithm	Fast	Through the lens of price and demand elasticity, this study looks at the location issues that come up with fast-charging stations when there is input from network congestion.
[80]	Multistage stochastic	Fast	Figure out the selection of charging stations for planning period.

3. Electric Vehicle Integration with the Utility Grid

In the most recent era, the transportation industry and the electric power industry have become inextricably linked to one another. Electric utilities have seen significant interruptions as a result of the widespread adoption of electric transport and transport systems [80]. On the other hand, electric vehicles have not only brought about substantial difficulties for the electricity system, but they have also brought about significant advantages. The electric vehicle grid integration (EVGI) has traditionally been considered to be the most important component of the process of charging the battery of an electric car [37]. Electric vehicles can significantly contribute to the grid by providing services like harmonic elimination, reactive power supply, peak demand shaving, and other similar services [81]. These services are facilitated by intelligent energy management in the electric vehicle environment. To achieve these objectives, EVGI needs to have a strong foundation in both its technical and business operations. Within the context of the development of technology, the community is responsible for the management of the distribution, generation, and regulation of energy. Furthermore, the technical process integrates low-level management strategies that merge and synchronise the administration of communication networks and electrical networks [82]. On the other hand, business operations include a variety of domains, including power generation, transmission, distribution, and retailers, which are also known as load-serving organisations, as well as customers who charge their EVs at charging stations [35]. In order to incorporate electric vehicles on a greater scale into the system, it is necessary to have a regulatory agency that specialises in EV aggregation. In order to maximise business prospects within the electricity industry, electric vehicle aggregators typically combine electric vehicles according to the preferences of their owners [83]. By themselves, electric vehicles make a contribution to the industry that is insignificant and inefficient; however, this contribution can be increased if EVs and EV collectors collaborate.

3.1. Modalities of the Electricity Interface between Electric Vehicles and the Grid

Electric vehicles are charged either by an uncoordinated or synchronised power exchange between electrical grids and electric vehicles [84]. Numerous EVs operate in charging modes that are not synchronised, regardless of the performance of the gearbox or the utilisation status of the vehicle [85]. This has a substantial impact on the quality and reliability of the vehicle. For the purpose of controlling a large number of electric vehicles within the existing control system, the synchronised V2G mode is currently being developed [86].

In the development of an adaptive charging and discharging mechanism for electric vehicles, there has been no advancement. The flow of electricity among the grid and plug-in electric vehicles is depicted in Figure 6 for both uncontrolled charging and V2G modes. On the other hand, power is transferred in both directions, meaning that it goes through the grid to autonomous vehicles and vice versa [33]. The power flow orientation consists of three distinct modes, as evidenced by Table 2. Below is an enumeration of the commonalities and distinctions of each mode.

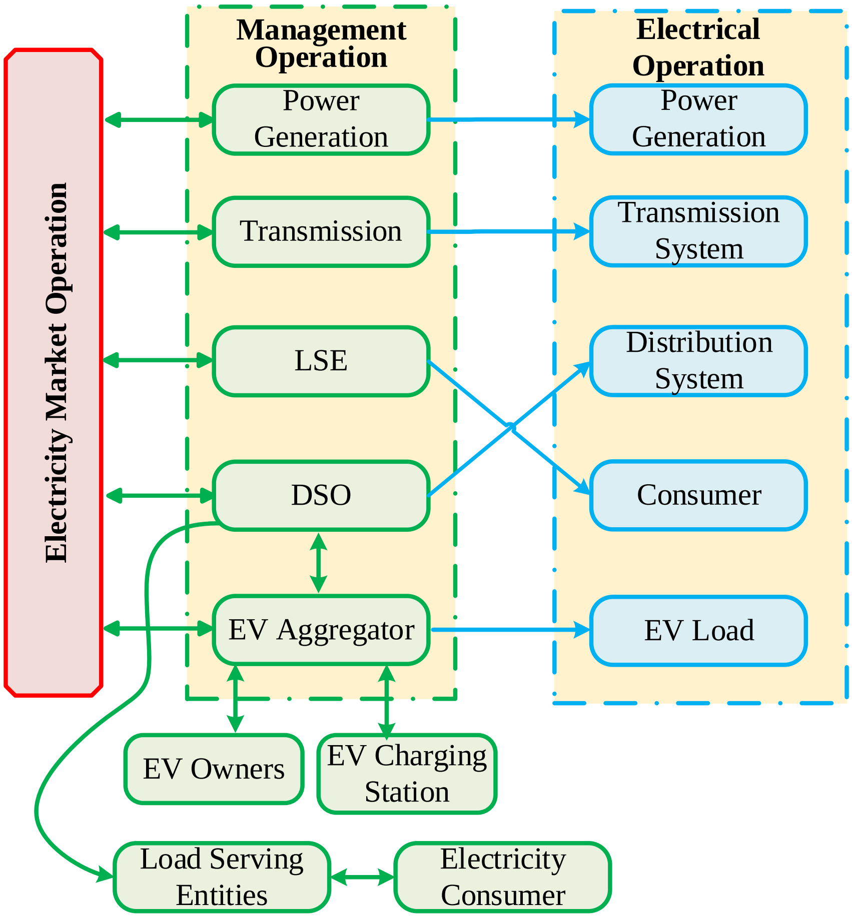

Figure 6. Flow of electricity among the grid and plug-in electric vehicles.

Table 2. Power flow in different modes.

Modes of Operation	Power Flow	Charging/Discharging
Uncontrolled charging	G2V	Regular, unintelligent, and unregulated
Unidirectional charging	G2V	Intelligent, coordinate, and controlled
Bidirectional	V2G and G2V	Intelligent, coordinate, and controlled

3.2. The Importance of Using Sustainable Energy

The primary sources of carbon dioxide emissions are power plants that generate energy and manufacturing facilities in the transportation sector [87]. The risks to both human health and the environment have reached a level that is extremely hazardous [88]. Using renewable energy sources can help reduce the effects of global warming while also encouraging environmental protection. Furthermore, the creation of renewable energy sources is strongly reliant on the factors that are inherent to the natural environment [89]. One of the most significant drawbacks of green energy is that they generate energy in a manner that is both unpredictable and incoherent [90]. When electric vehicles are incorporated into the power grid, they have the potential to solve the difficulties described above. When there is a lack of consistency in the generation of renewable energy, one solution to the problem is to power an electric car fleet [38]. This solves the problem of inconsistent use of renewable energy. During this interim period, they function as a source of energy that can be used to store extra electricity that is generated by sources that are renewable, keeping the source of energy from being reduced [91]. In order to make use of clean energy, electric vehicle energy storage, and connected grids, the power system can be modified to meet specific requirements [38]. Economic growth in the clean energy sector is anticipated to be bolstered by the introduction of electric automobiles. Ensuring adequate electricity storage is crucial for enhancing the safety and efficiency of electric vehicles and the power grid [92]. This is particularly relevant in the context of integrating renewable energy sources.

3.3. Integrating EVs and Their Impacts on the Grid

The impact of integrating electric cars into the grid can be classified into both adverse and advantageous aspects. In Figure 7, a more detailed outline of these is provided. Electric vehicles pose substantial issues for electrical utilities. The extensive incorporation of EVs into the supply network has a detrimental impact on the stability of the distribution grid. It is possible for there to be problems with power regulation, peak loads, and power quality degradation as a result of the overwhelming penetration of EVs into the grid [93–95]. Advanced power management approaches can be employed to tackle these challenges. The favourable effects of integrating electric vehicles are summarised in Table 3.

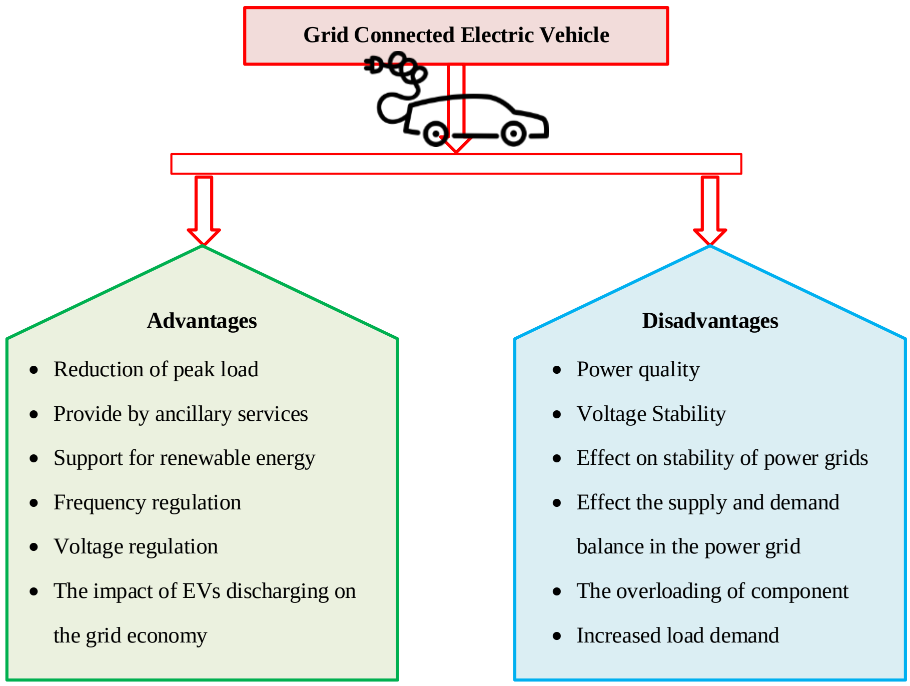

Figure 7. Impact of integrating electric cars.

Table 3. Effects of integrating electric vehicles.

Effect	Remarks
Impact on power quality	• Nature of the supply; • Over voltage; • Higher current faults; • Harmonics;
Impact on voltage stability	• High current for short durations; • Power system disturbances;
Impact on grid stability	• Unstable; • Need accurate model to determine the stability; • Intelligent algorithm is required;
Supply and demand balance	• Harmonics;
Impact on load	• More utility load; • Draws more currents.

3.4. Role of Agent in the EVGI

A self-governing programme may manipulate its behaviour by analysing the conditions of its operational surroundings. Electric power workers should be able to work on their own, be smart, make sense, and be able to learn and fit in. A non-regulated agent is a business that works in either the retail energy market or the customer energy market, or in other words, in both [96,97]. Regulated agents, albeit operating under natural monopolies, are subject to regulation based on incentives [98]. EVGI might need the help of other groups too, like charging point managers, EV suppliers–aggregators, and EV owners along with the people listed [35]. The role of EVGI agents is listed in Table 4.

Table 4. Role of EVGI agents.

Agent Titles	Remarks
Charging point managers	Charging point administrators oversee the operation of EV charging and discharging stations and serve as the ultimate consumers.
EV suppliers–aggregators	Supplies power to individuals who own electric automobiles.
Collector	Like other wholesale agents, they function in a similar manner.
EV owner	The EV load demand dictates the auxiliary services that can be offered by EVs over V2G, while the EV itself supplies the electricity for battery recharging.
Distribution	Ensures the durability and safety of the distribution network by managing the distribution grid. Ensures the overall stability and optimisation of the entire system, establishes a distribution network that is equitable and economically sustainable, and promotes a competitive energy market.
Transmission	Oversees the security of the gearbox system's operations and the acquisition of system services, particularly operational maintenance.
Load serving entity	The responsibility of selling energy to end customers lies with the suppliers or Retailer Agent, whereas the responsibility of paying distribution system operator (DSO) costs related to deregulated and other service fees lies with the DSO.
Power Generation	Ensures the generation and sale of energy at a profitable rate by submitting bids for electricity pricing in the electricity market.

3.5. EV Aggregators' Function within the EVGI

When drivers tell electric vehicle brokers how much power their cars need to charge and how long they want to be connected, the aggregators send that information to grid operators [99]. Smart metres are used as the interface for EV aggregators. In addition, electric vehicle owners can receive information from EV aggregators regarding the availability of charging stations and the cost of electricity [100]. If there are numerous aggregators operating on the market, it is in the best interest of an electric vehicle owner to choose the aggregator that is the most suitable for their needs [101]. The aggregators, in conjunction with the DSO, make projections regarding the demand for energy for the following day and also calculate their purchase and sell rates [102]. As part of their duties, the DSO is responsible for conducting an analysis and evaluation of the technical viability of demand projections [103]. After receiving a forecast that is sufficiently accurate, an aggregator is allowed to move forward with market discussions. If this occurs, the DSO will put pressure on the aggregator to make the necessary adjustments in order to guarantee its safety.

Additionally, in addition to anticipating market prices, the aggregator is responsible for predicting the behaviour and preferences of automobile owners who possess electric vehicles [101]. The duration and distance of leaving and arriving are the key causes of uncertainty, as is choice [104]. Other sources of uncertainty include location and time. When aggregators acquire electricity from the grid, the price of that electricity will be lower, and they will also be able to sell it at peak periods because they will be able to benefit from the electric vehicle storage that their customers have [105]. GENCO will be in direct competition with electrical retailers when it comes to the procurement and selling of energy. Aggregators will be in direct competition with these retailers. Furthermore, because of this method, electric vehicles are able to take part in tertiary frequency control by means of the connection that exists among the aggregators and the transmission system operator. Aggregators have the ability to negotiate with other businesses, such as parking services and battery providers, in addition to the aforementioned options [83].

4. Conclusions

Proposing the integration of electric vehicles as VPPs is seen as a promising method to achieve a balance between energy output and expenditure. Within this particular setting, electric vehicles assume a noteworthy role as alternative energy sources, serving as the sole means of mobility. Consequently, there has been a significant amount of interest in recent years in the integration of electric vehicles into the power network. This paper provides a comprehensive and up-to-date analysis of the VGI technology in the context of virtual power plants. The examination of VGI technology spans diverse domains, such as the manageability of electric vehicles, public transit systems, electrical systems, buildings, and the capacity to alleviate the adverse effects of the sporadic nature of sources of clean energy. An extensive analysis is performed on the VGI concepts and offerings, interface topologies, the global market share for electric vehicles including VGI, technological requirements for incorporating EVs into the electrical grid, and the current status of EVs as VPPs.

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