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Review on Electric Vehicles Smart Charging: Solutions, Strategies, Technologies and Challenges

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ABSTRACT

Due to their environmental friendliness and capacity to reduce/absorb excess power from renewable energy sources, Electric Vehicles (EVs) will play a critical role in energy systems during the coming years. Researchers and businesses all over the world are currently concentrating heavily on EV smart charging (EVSC) solutions to adequately meet the demand for EV charging while minimising their harmful impacts on the power grid. To overcome these obstacles, efficient EVSC techniques and technologies are needed. The advantages and difficulties of the EVSC process are discussed in this study from several viewpoints. It is described how EV aggregators fit into EVSC, as well as the goals and infrastructure needed to put EVSC into practise. Also evaluated are the EVSC integrated energy systems, which include buildings, houses and integrated energy systems, then the advanced green charging techniques to maximise EVs environmental benefits. According to the literature analysis, EVSC is effective in lowering grid operating costs by 10%, renewable curtailment costs by 40% and charging prices by 30%. The study provides crucial conclusions and suggestions that can be useful to scholars and decision-makers.

***Keywords: Electric vehicles, smart charging Electric vehicles aggregator, Vehicle-to-grid Charging infrastructure Smart charging challenges*.**

1.Introduction

Nearly 25% of worldwide CO_2 emissions and 55% of the world's oil consumption are attributed to the conventional transportation sector [1] and [2]. Electric vehicle (EV) development is now happening as a crucial step for the direct reduction of CO_2 emissions. The energy problem [3] and environmental concerns [4], such as global warming and local air pollution, especially in cities [5], are the key forces behind the development of EVs. One of the decarbonization strategies is the use of EVs to electrify active buildings, according to the research [6]. By taking part in demand-side response initiatives, EVs can function as market participants in the electric grid [7]. Economic, environmental, and technological effects are all consequences of EVs [8]. The power exchange between EVs and the electrical grid via vehicle-to-grid has an impact on the economy[12]. Payment from EV owners, the V2G reduces the proportion of expensive generators, such as gas turbines in the power system, benefiting EV owners [9]. Emissions over an EVs lifetime or the total of electricity produced to power EVs and direct tailpipe emissions are related to environmental effect. This means that charging an EV from a coal-fired power grid results in more overall emissions for EVs than charging an EV from another energy source, such gas or natural gas [8]. The implementation of green energy for charging EVs is progressing in order to address this issue [10]. Additionally, due to the variance in the temporal and spatial patterns of EV charging, the technical factors are connected to EVs positive and negative influences on the power system [11]. Since everyday vehicle travel considerably reduces the charging time, the battery charging of EVs is primarily done at night. Early night charging of cars has a detrimental impact on power grid characteristics including overloading and quick ramping of power generators as a result of the development of such vehicles. Additionally, due to the synchrony of EV charging with the peak load, the greater penetration of EVs may worsen grid features, such as feeder congestion, unfavourable peak demand, higher power loss and reduced negative consequences [13]. Smart charging for electric vehicles (EVSC) [14] is the answer to the problems listed above. To address the technological limitations of the network, EVSC can efficiently manage the charging of EVs, especially at night. According to studies, cars travel just 4–5% of the time on average each day, with the rest of the time being spent parked in driveways or parking lots [15]. These vehicles combined batteries can be thought of as large-scale, distributed energy storage devices [16] that are useful for enhancing network characteristics through EVSC. The pleasure of EV owners and consideration of grid features for choosing the quantity of EVs and corresponding charging/discharging locations in each time period are both facilitated by the coordinated charging of EVs under an EVSC mechanism [17]. The EVSC approach should take into account the maximum use of renewable energy generation in renewable-based power networks in addition to taking into account EV owners and technical power network constraints [5]. From the standpoint of the power grid, EV charging via EVSC may contribute to maintaining or improving the power grids operational condition while offering operators extra services like frequency regulation [18]. Fig.1 displays the EVSC schematic diagram. In centralised or decentralised regimes, EVSC can recharge EVs. Decentralized charging is the process of batch charging EVs at a parking lot , whereas centralised charging is the process of connecting EVs to smart houses. The energy cost for charging EVs can be reduced by up to 60% with the help of EVSC, in addition to timely charging and auxiliary services [19]. As previously indicated, EVSC uses auxiliary services to enhance the features of the power grid in addition to reducing the negative effects of evening charging [20]. The EVSC may offer a variety of ancillary services, including those related to power quality, grid loss reduction, voltage support, frequency response services, constraint management etc. [21]. Both vehicle-to-grid (V2G) and grid-to-vehicle (G2V) techniques are required to enable bidirectional power exchanges in order for EVs to demonstrate auxiliary services [22]. In the G2V mode, EVs are charged to satisfy the energy requirements of the batteries, but in the V2G mode, EVs are charged to improve the grid characteristics during peak load hours [23]. By charging parked EVs during times of low demand and implementing load valley filling operations, EVSC can manage peak load while also increasing load factor [24]. Other techno-economic goals, such as lowering charging prices, enhancing voltage profile, reducing peak load and cutting power losses can also be achieved by the EVSC [25]. The limitations imposed by EVs and the power grid must be taken into consideration for the EVSC strategy [26]. In order to coordinate EVs for smart charging, the EVSC method is carried out under the control of an EV aggregator, either as an individual or an organisation [27]. The EVSC can get around the challenges with EV charging brought on by variations in travel patterns, state-of-charge (SoC) levels, energy requirements and the propensity of EV owners to charge their vehicles every night at times of peak load. Considering the time, it takes for the batteries to store the energy required for the next day's travel, the EV aggregators shift the charging time of EVs to the low-demand hours of the night as far as possible. Battery swapping/switching stations, public parking, houses, buildings, charging stations (normal AC charging stations or DC fast-charging stations) and even energy exchange with other EVs are all ways that EVs can recharge. The charging stations can be powered by local energy systems that accept a variety of energy sources or by a utility grid. The several types of systems that can be used to charge EVs include distribution networks, microgrids, energy hubs, virtual power plants (VPPs) etc. For instance, to charge the batteries of EVs, wind and solar power plants can be connected to the national grid or directly to a regional grid like a microgrid. EVs can be charged by stationary energy storage systems, which can help lessen the intermittent nature of renewable energy sources. The EVSC implementation faces a variety of difficulties. Providing and managing the energy needed for EV charging is the key difficulty in this regard. Another issue that requires focus is the use of information and communication technology (ICT) in EVSC systems for effective operation management and coordination, as well as the quick and dependable communication infrastructures required to connect the charging systems and the EVs. For EVSC, predicting the load of the EVs is also essential to maintaining their best performance while fulfilling the needs of the grid. Although it is impossible to anticipate the load of each individual EV because to the variations in EV travel patterns, the overall load of EV fleets can be predicted using current techniques like machine learning, support vector machines and time-series models. Another factor that needs to be taken into account for EVSC is the competitive nature of the power market. Due to the competition among market participants, prices are unclear and EVSC is complicated. Another obstacle to the adoption of EVSC is the technical requirements for the SoC level of the EVs for the following day when maintaining the grid characteristics. The expanding penetration of EVs in the system should also be covered by an EVSC procedure in addition to the responsibilities listed above, as the load from EVs will soon make up a sizeable portion of the utility load. As a result, this article fills in this gap by thoroughly addressing a variety of EVSC-related topics, including smart charging techniques, technologies and problems for EVs. In this context, the EV aggregator's function and prospective EVSC goals are discussed. The infrastructure for the relevant enabling technologies, such as the charger (wired and wireless charges), is also examined. Additionally, a thorough review of the obstacles to implementing EVSC is provided, including grid-related issues, the cost of electricity for EV charging, security issues, etc. This article will also cover "green charging," a sustainable method of meeting the energy needs of electric vehicles. Fig. 1. Shows the schematic diagram for electric vehicles smart charging in power systems.

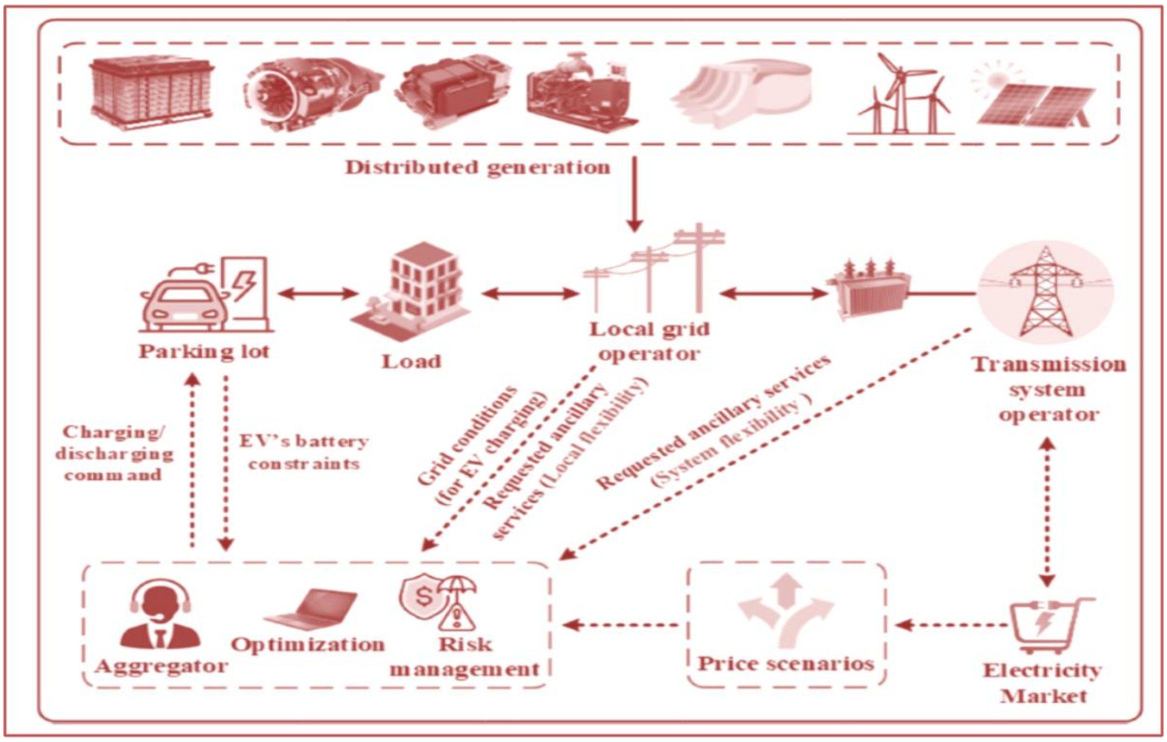

Fig. 1. Schematic diagram for electric vehicles smart charging in power systems.

2.Role of electric vehicle aggregator in smart charging

Between the power system and the end customers, aggregators serve as intermediary for profit organisations, so that distributed generation and responsive loads can deliver energy services effectively, increasing the flexibility of the power grid. One of the aggregators responsibilities, for instance, is to directly regulate end-user appliances like air conditioning systems in emergency situations with high demand. In addition to earning money through energy aggregation, aggregators can benefit the electricity system and end customers. Aggregators are also in charge of installing necessary technologies including communication systems and measurement and control equipment. In order to provide ancillary services for the power network, the aggregator manages various distributed generation resources or various flexible load types by taking part in day-ahead and intraday electricity markets under relevant energy bids. Different forms of aggregators, including retail aggregators, demand response aggregators, generating aggregators and EV aggregators, have been described in the literature on power systems. This study concentrates on EV aggregators. As a dispersed energy resource that aggregates EVs to enable the V2G mechanism, the EV aggregator is referred to as an interface entity. According to another definition, the EV aggregator is in charge of delivering power and managing the charge and discharge of EVs within its contracted territory. The EV aggregator has been described as a central coordinator who oversees the battery SoC level of geographically dispersed EVs in another study. To suit the mobility needs of EV users and provide energy and grid regulation services, EVs created a virtual storage capacity. A specific number of EVs are managed by each aggregator, which is viewed as flexible power demand or an energy storage unit. According to a different source, EV aggregators strive to maximise their profits by charging EVs during periods of low demand and participating in the markets for auxiliary services during periods of high demand. The EV aggregator typically helps the electricity network, the EV owners, and itself. An EV aggregator must overcome a number of obstacles, such as the minimum SoC standard for EVs, the dependability of the power supply, the unpredictability of electricity market prices, the provision of reserve and regulation power for EVs etc., all while maintaining the level of satisfaction of EV owners. An EV aggregator has two distinct goals in the client-side retail sector and the wholesale-side market. In the wholesale market, EV aggregators compete with other demand-side market participants to make the best electricity purchases and secure ancillary services. In the client-side retail sector, aggregators help end users compete with other agents who offer comparable goods and services. Fig 2 shows a schematic diagram illustrating the function of aggregators in EVSC.

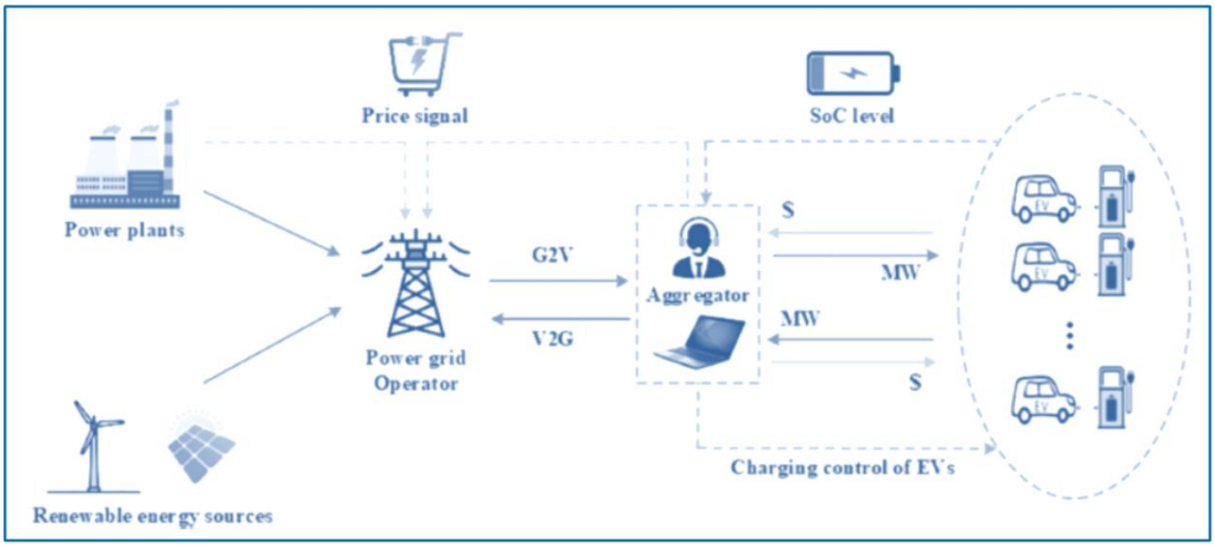

Fig. 2. Role of EV aggregator in electric vehicles smart charging.

3.Smart green charging

Researchers have become interested in "green charging," or charging EVs with renewable energy, as a result of environmental concerns and the need to close fossil fuel plants. Variable renewable energy sources have received increasing attention in this regard due to their higher production costs. The uncertainty in such energy sources specifically solar panels and wind turbines can be reduced by integrating EVs with variable renewable sources in addition to providing the load of EVs with clean energies, for example by absorbing the excess energy of variable sources, particularly during low-demand hours. This section discusses how to integrate EVSC with both non-variable and variable renewable energy sources. By combining a 20 kW charging station with biogas resources, green charging has been made possible in [86]. The suggested biogas-based charging station could reduce carbon emissions by 65.61% when compared to the grid-based station. The proposed topology has lifetime and payback periods of 10 and 5, respectively. According to the findings, the suggested solution has the potential to cut carbon emissions by 34.68% when compared to grid-based charging stations.

The ideal size and location of solar-powered charging stations in a city were examined. This reference took into account the solar panel production unpredictability, investment costs and energy consumption for electric vehicles. In this reference, the maximum station capacity and the shortest possible EV charging line wait times were taken into account. The charging time was decreased by 10% by implementing the suggested EVSC technique. Additionally, the integration of rooftop solar panels with EVs has received attention in an effort to increase the use of solar energy. In order to lower the cost of charging PHEVs, a system for gathering on-road solar energy for smart charging of solar PHEVs has also been studied. A wide range of potential locations for wind-assisted charging stations have been looked, taking into account the wind potential of the intended locations. The authors in have combined charging stations with wind turbines to disperse the demand for EV charging across the power network. The environment and financial elements of charging stations are improved further when solar photovoltaic panels and wind turbines are integrated with charging stations. In a standalone system, EVs have been combined with solar photovoltaic panels and wind turbines. The results demonstrated that the proposed topology for EVSC might reduce carbon emissions by 12,780 kg/day. Fig.3 shows the existing methods for electric vehicles smart charging.

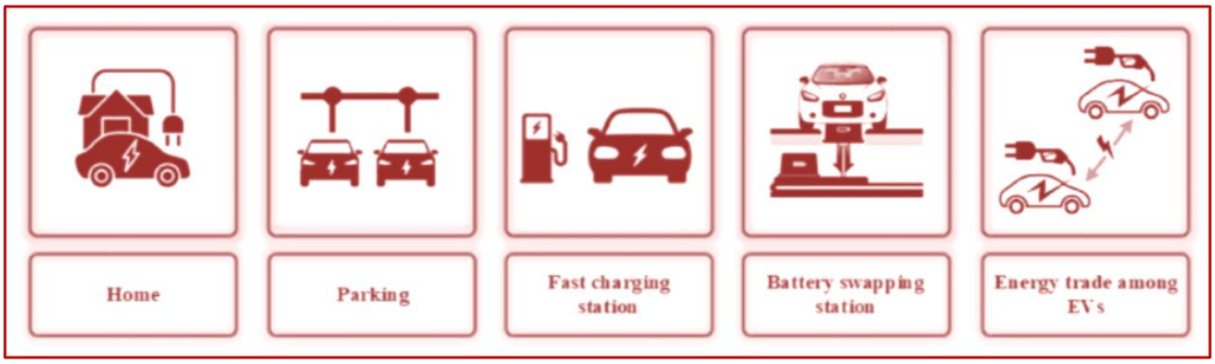

Fig.3. Existing methods for electric vehicles smart charging.

4.Smart charging objectives

In the literature, various objective functions for EVSC have been investigated. The indicated restrictions pertaining to EVs and the power grid must be taken into consideration for each desired function. The objectives are to minimise the lost load while taking into account projected load loss and expected energy supply indices. The profit maximisation of the EV aggregator was taken into account as the objective function of involvement in the flexible ramping product market. A smart parking lot that incorporates a wind turbine a combined heat and power unit and power and energy storage devices has also been studied for profit maximisation and reducing the overall operational costs of a microgrid that included an EV charging station, solar photovoltaic panels and battery storage systems. The operational costs in this study were related to the costs of bidirectional energy exchange (buying and selling), the wearing cost for charging/discharging storage systems and costs associated with EVs. On the other side, EV-related expenses included the price of charging an EV, the cost of draining an EV and the cost of replacing batteries during both charging and discharging and a strong model based on minimising operation and investment costs for parking lots, solar panels and wind turbines has been used to alleviate the voltage stability caused by the rising penetration of EVs in a renewable-integrated microgrid, by focussing on increasing the solar photovoltaic systems contribution with EVSC in a parking lot. It was determined that the objective function of EVSC was to minimise the voltage deviation from a nominal value while also reducing active and reactive power losses by optimising the voltage profile in comparison to the base case (i.e., the absence of EVs). Numerous other academics have looked into the emission reduction of microgrids using EVs combined with demand response programmes. The authors have concentrated on a multi-objective approach based on minimal cost and emission for smart charging of EVs in renewable energy-integrated microgrids. Numerous advantages for EVSC have been mentioned in the literature. In addition, this source indicated how EVSC might cut power grid operating expenses by 10% and renewable curtailment by 40% by 2025.

5. Electric vehicle-penetrated energy systems

Since EVs operate as both energy consumers and producers, they play a crucial part in the development of future power networks. EVs can be thought of as mobile energy storage resources because of their use of power electronics devices, sophisticated grid connections and interactive charger control. EVs can also be incorporated into energy systems that support applications that are both grid-connected and stand-alone. Connecting local networks to the main grid demonstrates their capacity for energy exchange, which is crucial for enhancing the economic performance of such local networks through intelligent EV charging and discharging. Additionally crucial to renewable energy systems is the availability of EVs. In such systems, EVs can store excess energy from renewable energy sources and use it later for economical and environmentally friendly everyday commuting. The assessment of the understudy network from the perspective of energy sources for charging EVs is necessary for integrating EVs into an energy system. The main grid or distributed energy sources could provide the EVs electricity needs. EVSC is used in many energy systems for intelligent charging and discharging. Buildings are essential for V2G because most EVs are hosted at night (i.e., peak load time). EVs can also access distribution systems through public parking spaces or charging stations.

5.1. Home/Building

Many EVs will be connected to homes or other structures in the following years so they may be charged using the power grid or distributed generating systems. In order to save costs through the most effective energy management, EVs have been linked with a cluster of residences outfitted with a wind turbine, combined heat and power (CHP), boiler and electrical and thermal storage. The solar photovoltaics and PHEVs are integrated with buildings to offer greater operational flexibility and lower energy consumption costs. The combination of electric vehicles and solar photovoltaics has been considered as responsive building components to peak load mitigation and profit maximisation. For peak load reduction, a photovoltaic/battery system has been linked with vehicle-to-building. Additionally, integrates an office building with a hybrid photovoltaic/EVs/battery system taking into account the unpredictability of EV and PV generation driving patterns.

Furthermore, demand-side management of commercial buildings has been implemented with connected elements, such as EVs, HVAC (heating, ventilation, and air conditioning) systems and electric water heaters.

5.2. Distribution system

Distribution systems will house a large number of EVs in the future because of the rapidly expanding demand in green transportation. The distribution networks are connected with parking lots that have a high EV penetration rate. The direct participation of parking in the retail electricity market is handled by a load aggregator. EV parking lots gain from selective participation in both price-based and incentive-based demand-side response programmes in distribution systems. The effect of various parking lot participation rates in such demand-side response schemes on daily profit has been discussed in the same study. Additionally, EVs were combined with distributed generating units (DGUs)-integrated off-grid distribution systems for bidirectional smart charging with the goal of increasing reliability. The authors look into ways to reduce the harmonic distortion brought on by widespread EV penetration of the distribution system. Additionally, solar photovoltaic power with real-time reactive power optimization of the distribution system to enhance operational costs, power losses and voltage profile. Finally, the study has looked into the best location for fast charging stations inside the distribution system in order to reduce power losses and voltage deviation.

5.3. Microgrid

Electricity grids that are tailored for enough generation or that can interchange energy with larger grids are known as microgrids. When dependability and economics are taken into consideration, microgrids can enable EVs for smart charging. Incentives are given to EV owners in to take part in demand response initiatives of renewable-based microgrids. Day-ahead scheduling of microgrids has been investigated to cost reduction in which various EV charging/discharging patterns were taken into account. Microgrids include EVs, renewable energy sources, energy storage, fuel cells, microturbines and distributed generators. The generation scheduling and feeder reconfiguration of a microgrid, incorporating EVs and various distributed generation units have been studied. The integration of EVs with renewable-based microgrids in both stand-alone and grid-connected modes to reduce operational costs which contained the profit of EV owners. The combined heat, power and hydrogen microgrid was connected with an EV parking lot, hydrogen refuelling station, fuel cell, wind farm and solar photovoltaic plant to meet the energy and thermal loads. Additionally, to design a hybrid islanded system that includes an EV parking lot, battery storage and renewable energy sources while minimising construction and running costs and taking various uncertainties into account. The findings showed how the EV parking lot reduced the price of installing stationary battery storage devices.

5.4. Virtual power plant

With the ability to engage in the wholesale electricity market, VPP is a decentralised network that manages a broad and diverse range of distributed energy resources over a big geographic area. A group of EVs acting as a large-scale battery storage in a VPP can not only provide the energy required for everyday transportation but also enhance the viability of VPPs economically. The EVs are combined with VPPs, renewable energy sources and demand response programmes to reduce the systems overall operational costs while taking into account the scheduling phases inherent uncertainties. The emphasis was on employing EVs to enhance VPP's frequency responsiveness. EVs have helped to control the power reserve of VPPs at the cost and emission reduction of an EV that infiltrated a VPP from the perspective of consumers. Additionally, smart EV charging and discharging has been taken into account in to reduce VPP carbon emissions.

5.5. Energy hubs (multi-carrier energy systems)

Energy hubs also known as multi-carrier energy systems, have the ability to produce, transform and store energy. Since EV penetration may disturb the demand balance in such systems, appropriate energy management strategies are required, has researched the effect of EV uptake on energy hub energy management. The minimising of the purchase cost and emission tax cost of an energy hub integrated with EVs and energy storage has been studied .The energy management of a residential energy hub integrated with electric vehicles (EVs) and solar systems (solar photovoltaic and solar collector) was carried out with the goal of minimising operational costs, in which flexible power and thermal loads were taken into consideration. The sea water desalination machines were treated as flexible loads and EVs, fuel cells, hydrogen tanks and renewable energy sources were integrated with an energy hub connected to a smart commercial building. Additionally, electrical, thermal and cooling loads—including electric vehicles, combined heat and power systems, electrical, thermal and cooling storage—have been taken into account as load needs of an energy hub.

5.6. Integrated energy systems

Since variations in the electrical load affect how energy conversion systems such as CHP systems, gas-fired generators, boilers, etc., operate EV penetration is crucial in systems with all possible combinations of power, gas and heat networks. EVs can be useful in such systems for balancing supply and demand because they serve as energy storage devices and are non-coupling technologies. Combined power and gas networks have been integrated with EVs and renewable energy sources. The significance of EVs and gas-fired generators in boosting the interdependency between natural gas and electrical networks has been highlighted in the same work, as has the function of gas-fired generators in raising the share of renewable sources. An integrated power and gas network, comprising hydrogen storage, CHP, gas-fired units, non-gas-fired units and renewable sources has been combined with a domestic charging station, EVs in this context could only charge and not discharge. The EV charging in networks that include power distribution and mobility. The integration of EVs with a microgrid has been researched, which also includes numerous buildings with space heating, cooling and electrical loads.

6. Forecasting the electric vehicles charging load

For EVSC, which is in charge of optimising the quantity of EVs, charging/discharging rate and charging locations taking into account the grid characteristics, load forecasting of EVs is essential. Forecasting the load of EVs also aids in more economically allocating the available energy resources to meet the demand on the power grid. The load profile of EVs in a particular geographic area is influenced by factors like as daily driving patterns (driving distance and arrival/departure times), EV type, day of the week and season, the penetration rate of EVs, etc.

Table 1:Data source required for electric vehicles smart charging

Scheduling data	**Clustering data**	**Forecasting data**
Demand side	**Preprocess**	-survey -smart metering
-Distribution network transformers -transmission lines -Circuit breaker -Load demand profile -Large scale case studies such as city,state and the entire nation. -small-scale case studies such as university campuses, small cities, shopping mall	-Select -Merge -Clean -Formation	
Charging profile	-Data Mining -Clustering -Correction -Clean -Regression	
-Driving pattern - Driving behaviour -Type of vehicle -Battery size -State of Charge -State of Health -Connection time -Disconnect time -charging station ID -EV ID		

The techniques and data sources required for parameter forecasting in EVSC are shown in Table 1 . Clustering, forecasting, and scheduling are a few examples of data management mechanisms, as this table demonstrates. The load profile of EVs can be predicted using a variety of techniques. In a different study, the Monte Carlo simulation was used to predict the load of EVs by taking into account their types, charging modes, charging periods, daily mileage and charging power, while the Bass model was used to predict their number. First, the problem is divided into smaller ones at the lowest levels. These smaller ones are then solved using probabilistic models such quantile regression forests, gradient boosted regression trees and quantile regression neural networks. Then, to predict the total load of EVs for the high-level geographic area, an ensemble methodology based on a penalised linear quantile regression model is used. The collected findings demonstrated that distinct EV load forecast contributes to the enhanced EV load prediction as opposed to overall EV fleet projection. By using actual measured data, the studies have concentrated on the country, city and single charging station. The deep learning-based prediction method called the gated recurrent units technique has been used to overcome the uncertainty in EV charging load in reconfigurable microgrids caused by the charging strategy, numbers of under-charged EVs, charging length and charging start time. Additionally, uses an LSTM deep learning method to forecast the charging load to achieve non-intrusive extraction of EVs load. A generalised regression neural network-based model has been introduced as a machine learning technique to forecast EV travel patterns and arrival/departure times to create an EV load profile.The Q-learning strategy based on the recurrent neural network and ANN has been used in [171] as a reinforcement learning-based approach to forecast the load on the EVs. The outcomes demonstrated that compared to recurrent neural networks and ANNs, the Q-learning technique has a smaller forecast error. The load of EV charging stations has also been predicted using an ensemble learning-based prediction method .The long short-term memory (LSTM), recurrent neural network (RNN) and artificial neural network (ANN) techniques were integrated to create the proposed solution. Each base learners weighting was determined using a linear regression technique. Three neural network-based approaches to forecasting the load profile of the EVS have been compared ,the results showed that while the Radial Basis Function approach has a larger error and computational cost for EVs load prediction, the Multilayer Perceptron Training and Jordan Education methods produce good outcomes. Six distinct deep learning techniques have been compared in from the perspective of estimating EV load. ANN, RNN, canonical LSTM, gated recurrent units, stacked auto-encoders and bi-directional LSTM forecasting approaches were among the techniques used.Fig 4 shows the EV penetrated power networks from the viewpoint of grid connectivity and availability of renewable energy sources.

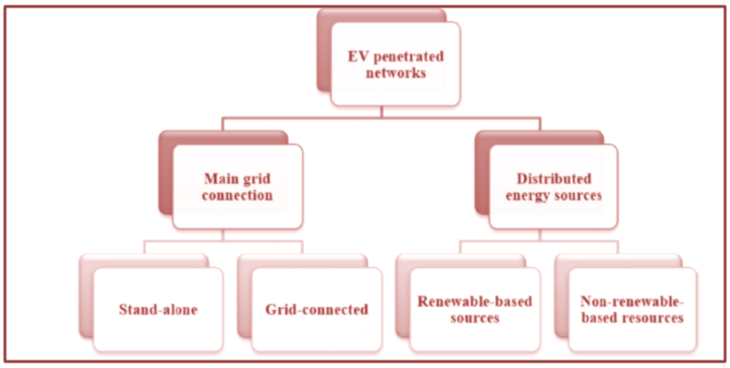

Fig.4. Categorization of EV penetrated power networks from the viewpoint of grid connectivity and availability of renewable energy sources.

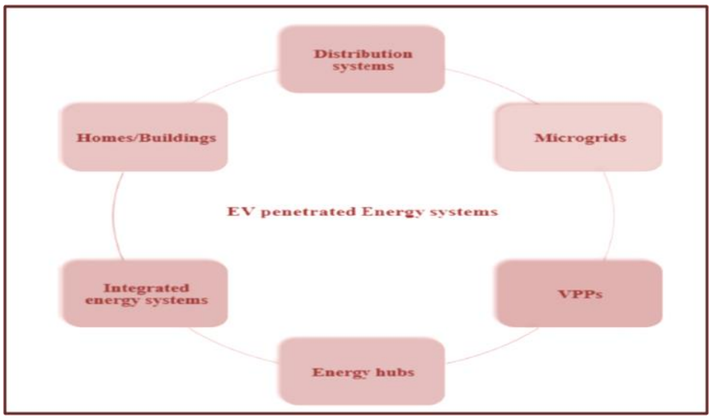

Fig. 5. Electric vehicle penetrated energy systems.

7. Required infrastructure for smart charging

Complementary technologies for the ICT and charging infrastructure are needed to achieve EVSC. These infrastructures must be installed by the EV aggregator. Currently, the policymaker’s involvement is vital in creating the necessary infrastructure for EVSC by giving the necessary subsidies to make it easier for people to acquire enabling technology.

7.1. Charger

Charging stations can be found within an electric vehicle (on-board charger) or outside (off-board charger). There are two unidirectional or bidirectional charger kinds from the perspective of charge direction. There are two different types of chargers from the perspective of the charging procedure: wired (conductive)and wireless (inductive/contactless) chargers. Direct current (DC) and alternating current (AC) charging modes are available for regular wired charging. There are two different kinds of AC chargers: AC fast chargers and AC slow chargers. While the second requires a three-phase supply, the first only needs a single phase. Despite the fact that AC power is the foundation of conventional power networks, research demonstrates that DC power significantly shortens the charging time and improves EV charging operations. The locations AC power can be converted on-site to DC power or charging power can come from standalone DC microgrids. As a result, the majority of the current charging stations are DC-based and run on a three-phase, four-wire system. However, as a slight drawback, compared to AC charging stations, DC fast-charging stations require a bigger charging cable size. Power electronic converters supply DC power for EV charging. DC charging stations consist of three main components: a charge controller, a tariff and control unit and an insulation detection module. Due to the shorter time needed to charge EVs in such stations, DC charging stations are more prevalent than AC ones at charging stations.

7.1.1. Wireless charger

Wireless V2G chargers are an alternative to wired chargers to eliminate the drawbacks of wired charging, even if commercially available EVs use the cable to establish the V2G system (i.e., wired charging). Due to open contacts and hanging charging wires in public places, there are related difficulties, such as vandalism and safety concerns. Wireless charging however, require safety precautions, just like cable charging. Static and dynamic charging techniques are two categories of wireless charging procedures, often known as contactless charging. While dynamic charging is connected to EV charging while EVs are moving, static wireless charging requires the EV owner to park the EV at a charger access point (and keep it there) for battery charging. Wireless charging that is "in-motion," "on-line," or "roadway powered" are other names for dynamic charging. The method of dynamic charging requires electricity of roads. Dynamic charging of EVs faces a number of technical and financial challenges, including the limited energy transfer distance, the power systems stability limit (particularly during peak load periods), the high investment cost of such infrastructure, as well as problems with efficiency, reliability and safety.

7.2. Information and communication technology

The other enabling technology for implementing EVSC is ICT, which allows for remote monitoring and control for battery charging, locating the closest charging station, determining charging rates at charging stations, taking into account grid characteristics in real-time. CT makes it possible for the EV aggregator to access, store, change and send data from one location to another more quickly, easily and conveniently by utilising associated technology like mobile phones, wireless networks and the internet. Software, hardware, services and communications are all part of the ICT tools. To effectively and consistently convey information, an EVSC communication system should be developed. The communication system of the EVSC infrastructure takes into account factors like the cost of electricity, the SoC level, driving habits, the closest charging station, etc. The Internet of Things, a novel ICT form that emerged in 2009, is an evolved version of wireless sensor networks and radio-frequency identification technology, both of which date back to the 1980s and 1990s, respectively .Radio Frequency Identification (RFID), Ultra High Frequency (UHF) and Wireless Sensor Network (WSN) are the most potential IoT-based enabling technologies for EVSC .A hybrid sensor network, smart gateway, cloud services and mobile applications are necessary for EVSC to employ ICT . To process the Big Data produced by the stakeholders, new and complex methods and technologies are also required. Vehicle-to-Infrastructure (V2I) connection is necessary for future connected vehicles in order to enable EVs to access the Internet via cutting-edge mobile communications networks like Bluetooth, WiFi, 4G, and even 5G networks. It is impossible to avoid data loss and communication system delays while employing ICT for the EVSC process. The systems performance can suffer from significant losses and delays. By locating the charging stations, the global positioning system (GPS) is also useful for boosting the charging opportunity during the day or at rest stops. Fiber-optics are useful for integrating the parking lot or charging station with the power network because of their dependability and speed. But for EVSC, wireless networks are more important. In this context, Vehicular Ad-Hoc Networking, or VANET, is useful for EVSC communications as a unique technology. Different factors need to be taken into account while implementing an EVSC system, including the information system, EVSC battery management system, sensors, physical system and EV owners. A communication interface, data storage, mobile application and control algorithm are all components of the information system. According to the studies, the development of EVSC involves four main parts: research and consulting, policy, the energy market and the market for charging infrastructure.

8. Challenges

Different obstacles must be overcome in order to adopt EVSC. The cost of battery depreciation, the requirement for intensive communication between EVs and the power network, infrastructure changes, the impact of charging on facilities used for power distribution networks, as well as security, social, political, cultural and technical barriers are all part of the general list of EVSC challenges. Generally speaking, EVSC should take economic, social and technological factors into account.

8.1. Grid-related challenges

The requirement for electric power to meet the energy demand of EVs with the growing number of EVs, especially during peak demand hours, is one of the major obstacles in this respect. The creation of this excess power could result in the repeated dispatch of expensive generators (such gas turbines), raising the operational expenses of the power network. Additionally, the EV charging process may cause problems for the current power network as an additional load, especially at lower voltage levels. Congestion of lines and transformers may be one result. Power losses , power quality problems , harmonic distortion , voltage drop and imbalance , peak load, poor load factor, thermal stress , frequency deviations , voltage instability , reliability degradation , decreased resiliency, etc. are some additional effects that could occur.Without taking into account factors like the energy market, power network operation control and demand-side response management, it is impossible for the V2G infrastructure in a bulk power network to receive large-scale electricity injections promptly and often . Despite being the only component that affects the power grid, charging and discharging power is indirectly impacted by the SoC level, which changes the networks characteristics. This graphic demonstrates how the SoC level affects network characteristics and should be taken into account, particularly for dynamic issues (of the power network) as opposed to static issues. Another grid-related issue that must be resolved in order to adopt V2G is the investment cost for the hardware and software infrastructure. The charge/discharge of a sizable fleet of EVs causes a significant energy loss in the power system, which is another issue in this regard because charge infrastructures are associated with energy conversion systems.

8.2. Bidirectional power flow challenge

Another obstacle is that the current distribution networks were not intended for the bidirectional flow of power, which places a cap on the EVSC mechanisms serviceability. Because reverse power is not a good fit for typical protective systems, they might not react to them. Power electronic converters are needed to control the bidirectional power flow as EVs become more prevalent. This problem can also be resolved by supplying nearby loads with the discharging power of nearby EVs.

8.3. Grid reinforcement challenge

New investments in overhead lines, underground cables and transformer capacity are required to handle the increased strain on the power network. The EVSC approach should, either directly or indirectly, address these issues. For instance, the power network congestion can be resolved by deploying distributed generators like renewable energy sources to power the charging stations. Reactive power compensation techniques can be used in another situation to address the voltage loss.

8.4. Pricing mechanism challenge

Electric vehicle (EV) use encourages market variety and opens up new business options. However, two obstacles prevent V2G from participating in electricity markets, just like other small-scale energy producers. When implementing V2G, these obstacles include the least allowable bid size, as well as the difficulty of managing many EVs in comparison to a sizable power provider. With the least amount of incentive offered to EV customers, efficient market mechanisms encourage EV participation. The type of energy market and associated market mechanisms for V2G have a significant impact on how economically efficient EVs are. However, the pricing mechanism is also impacted by the extent of EV penetration. An acceptable amount of willingness to participate is required for the load of EVs to shift as much as possible to low-demand hours. To encourage users to charge their EVs during these intervals rather than during peak hours, such price-based systems drastically lower the price of electricity during low-demand hours. As a result, another hurdle to EVSC integration with power markets is the price rules and processes of electricity. For EV charging, load-levelling, and frequency management in electricity markets, there are three alternative pricing methods: fixed tariff, dynamic tariff, and demand response tariff. The spot price of power serves as the foundation for dynamic rates for EV charging. For EV charging under fixed tariffs, the wholescale market determines a lower fixed price. Demand response tariffs give EV owners the chance to release their vehicles from payment in return for offering auxiliary services. The dynamic pricing of electricity is the most sophisticated price structure out of these three pricing algorithms. The total cost of charging is not determined in advance under this pricing structure since the charging price per unit of power varies over time and is not known before the charging procedure. By controlling how customers consume electricity, dynamic pricing schemes are used to increase users' flexibility. Another obstacle to deploying EVSC is estimating the cost of charging EVs for ancillary services under demand response tariffs. It's possible that EV owners won't be happy to add energy from their EVs to the grid. However, research has shown that by include EVs in ancillary services, EV owners can benefit significantly by providing some regulation services. EVs can engage in a variety of electrical markets, including the energy market, capacity market, and the market for ancillary services.

8.5. Battery degradation challenge

Another difficulty for EVSC is the battery degradation brought on by EV discharging and quick charging. Degradation causes the battery to exhibit increased resistance, which shortens the battery life. High SoC levels and low temperatures are two reasons that increase this resistance. Long-term battery degradation occurs when EVs are charged quickly. The battery switching station can be used as a solution, which is preferable for EV recharging. Two elements that could hasten battery deterioration and impair its condition are discharge depth and cycling frequency. The battery life is protected from early deterioration by maintaining the SoC level at a moderate level (about 50%). Since battery technology are continually evolving, it is challenging to estimate the cost of battery degradation when discharge. The most promising alternative for EVSC right now is Li-ion batteries, which have an investment cost of \$200–500 per kWh and offer high efficiency, high energy density, reasonable deep-cycling capability (2000–4000 deep cycles), and long life. A \$300/kWh initial battery cost with 3000 cycles and an 80% depth of discharge results in a \$130/MWh battery depreciation cost.

8.6. Optimal location of charging stations challenges

Creating a dependable and accessible charging infrastructure for EV owners is a difficulty in the development of EVSC. Optimizing the site for the charging stations construction is a difficulty in this regard. The site in question should be chosen to optimise the owner of the charging stations profit. Owners of charging stations can entice EV owners by increasing the stations charging speed. To increase the profitability of their charging stations, owners might also make the location appealing to EV drivers. Another difficulty that requires the station improvement to be linked to the load requirement of the station is avoiding on-site congestion to prevent long lines of EVs in the charging station.

8.7. Battery swapping challenges

The development of the battery swapping technique is hampered by a few factors. First and foremost, standardised batteries are necessary for the development of this technology. Additionally, compared to fast-charging stations, the initial capital cost for building battery swapping/switching stations is significantly greater. The development of battery switching stations is hampered by these two obstacles. The occurrence of different charging levels is another obstacle to the development of EVSC. The standardised methodology contributes to the acceptance of EVs and the rapid expansion of charging stations. Some factors in this regard, including communication, safety and the rated power of charging should be standardised. The greatest safety standards must be covered and the users' needs must be optimally satisfied by a standard charging technique. Compatibility, performance and safety are the three main pillars of standardisation in EVSC.

8.8. Needed space for installing charging equipment challenges

Another obstacle has to do with the fact that certain modern residences and buildings may not have a designated area for installing smart charging technology. The present homes and buildings must designate a dedicated space for the EV charging infrastructure, but future homes and buildings will adapt to this requirement.

8.9. Low capacity of batteries challenges

Other obstacles to the expansion of EVSC include the expensive cost of charging the EV battery, the lengthy charging process and the shorter range of EVs with a full battery compared to conventional vehicles. For EV users, especially when going on vacations and long distances, they could be quite important. The weight of EVs is, however, gradually declining, which has a positive impact on EV energy usage. EVs induction motors can be exchanged out for brushless DC motors or even switching reluctance motors to save energy consumption. However, the power network faces a significant problem due to the need for quick charging stations. Energy exchange between EVs is a solution in the event that an emergency charge is required but there are no charging stations available. In the literature, wireless V2G recharging mode has been researched as a way to travel farther without stopping. However, due to the wider air gaps, contactless charging is less effective for moving vehicles than conventional wired charging.

8.10. Security challenge

Security and privacy concerns are taking centre stage in EVSC challenges. An attacker could obtain a variety of information through the communication process in EVSC. The data consists of billing information, tariff details, SoC level, etc. Cyberattacks on smart charging infrastructure are carried out with a variety of objectives, including falsifying or tampering with charging data to prevent billing loss, stopping the power supply to EVs and securing charging data to prevent disclosure of the charging account and its associated location [83]. As a result, hackers using cyber-physical systems can disrupt charging and endanger both charging stations and user privacy. Because there isn't a reliable charging infrastructure, people are easily misleading into thinking the SoC level is real. For instance, the attacker might send the charging station a stop message to display the SoC level as 100% even when the EV is not completely charged. Attackers are more likely to compromise the billing system due to the lack of authentication methods in subscriber identity module (SIM) cards while dialling into the access point name (APN). As an emerging technology, Blockchain is currently being tested by researchers to see if it can enable safe data exchange and communications in peer-to-peer EVSC against cyber and physical attacks. To defeat a cyber-attack, security measures like identify, protect, detect, respond and recover must be taken.

8.11. Uncertainties challenges

Another difficulty is controlling the EVSCs uncertainty. An EVSC strategy should be able to deal with a variety of unknowns, such as load, grid state, SoC level, energy price, distributed generator generation, etc. Based on information gap decision theory, conditional value-at-risk , downside risk constraint , robust optimization and other theories, risk management is an efficient way to deal with the uncertainties in EVSC. The availability of EVs and the level of EV users desire to engage in EVSC are two of the primary uncertainties linked to EVSC that are described below:

8.11.1. Uncertainty in the availability of electric vehicles

For EV aggregators, offering additional services is problematic due to the unpredictability of EV availability. The ability to bid for these services is directly correlated with EV accessibility. Weekday and plugin-time constraints are important variables in the level of EV availability. The efficiency of the V2G programme is hampered by the fact that EV owners may not always plug in their vehicles. In order for the potential of EVs to deliver power services to be competitive in the energy market, an EV aggregator takes into account the uncertainties surrounding EV availability to improve the contracted bidding. To address this issue, scholars have offered a number of probabilistic techniques. The Copula function was used to model how probabilistic variables are interdependent in a Gaussian mixture model based on daily travel data. The availability of EVs has been assessed using trip chains. According to the findings, compared to other parking lots, houses and offices have the highest level of EV availability.

8.11.2. Uncertainty in willingness-to-participate of electric vehicles

To increase EV users desire to engage in such initiatives, it is necessary for them to be aware of the V2G idea and related activities. Concerns (the hassle of EV owners participating in V2G) and incentives both affect the willingness-to-participate level of EVs (revenue from participation in V2G). As a result, improving the level of vehicle owners desire to participate depends on the technological and financial designs of the V2G idea. The users of electric vehicles are more willing to allow for flexibility in the power system than users of heat pumps. From the perspective of EV users, the factors that prevent participation in V2G are either permanent or transient. For instance, an extended time of high driving range temporarily reduces an associated EV users desire to take part in the V2G programme. Another illustration is the fact that an individual EV user's willingness to contribute is permanently constrained by their lack of need to profit. Profit from the V2G programme depends on the program's goals, which include raising the proportion of renewable energy sources used to power EV loads and lowering the price of electricity storage in EV batteries. Another aspect that influences EV owners inclination to participate in V2G is the battery's deterioration. In the V2G programme, EV owners might put up with higher degrees of discomfort in exchange for a bigger profit. Since three individual, technological and financial components are effective in the level of EVs willingness to engage, even though two technical and financial variables are effective in creating V2G mechanisms.

9. Discussion and conclusions

Researchers have recently placed a substantial emphasis on EVSC as a result of the growing adoption of EVs. Various EVSC-related topics were covered in this review study. The EV aggregator was first brought up as a means of enabling EV owners to participate in auxiliary services of the power network as well as timely charging. We looked at several EV charging techniques as well as currently used EV charging strategies. The goals of smart charging, load forecasting for EVs, and ancillary services were also described in this study. Additionally, it was explored how to coordinate the EVSC with various EV-penetrated energy systems, such as the distribution system, microgrid, VPP, energy hub and integrated energy systems. This review study also covered enabling technologies and smart green charging .

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