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A review of strategic charging–discharging control of grid-connected electric vehicles

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ABSTRACT

Charging–discharging coordination between electric vehicles and the power grid is gaining interest as a decarbonization tool and provider of ancillary services. In electric vehicle applications, the aggregator acts as the intelligent mediator between the power grid and the vehicle. In recent years, researchers have introduced the concepts of aggregated energy management, centralized-decentralized planning, and ideal charging–discharging through improved technologies and integrated energy planning. These methods have the technical ability to adapt the distribution network according to load, aggregator-controlled optimal charging–discharging, demand management systems, strategic load assessments, and management. A comprehensive review suggests that large-scale electric vehicle charging technologies for controlled charging–discharging is becoming a pitfall within the grid and distribution network. This paper reviews several controlled charging–discharging issues with respect to system performance, such as overloading, deteriorating power quality, and power loss. Thus, it highlights a new approach in the form of multistage hierarchical controlled charging–discharging. The challenges and issues faced by electric vehicle applications are also discussed from the aggregator's point of view.

1. Introduction

Electric vehicles (EVs) are considered essential in reducing greenhouse gas emissions and in facilitating e-mobility through the high penetration of renewable energy sources. In the future, increasing demand for oil is expected to become a critical issue in terms of both cost and availability. This motivates researchers to use EVs to solve global environmental problems. Individually, EVs are less efficient in dealing with these challenges than traditional generators and other battery storage systems. However, with the rapid growth in EV infrastructure, EVs represent a promising option to provide stability to the power grid. Technological advances in EVs have led to the concept of an EV aggregator in the power grid, offering attractive, and competitive controlled charging–discharging strategies. The concept of this EV aggregator was first introduced by Kempton et al. in coordinating EVs and managing their charging and discharging processes bi-directionally. EVs can act as an energy storage system to shift load from peak to off-peak hours, and hence help in reducing electricity bills [1–3]. Vehicle to Grid (V2G) enabling technologies, such as batteries, act as storage devices that supply power during peak demand in the grid. The V2G technique is suited for large-capacity requirements in the distribution grid, facilitates a smart grid approach during fluctuating electric loads, and supplies ancillary services to the grid [2]. V2G also has faster response times than traditional power plants. These factors combine to make V2G attractive for voltage and frequency control. Furthermore, batteries are also more efficient than most other energy storage technologies. In the V2G system, the main objective is to realize charging–discharging coordination, and maintain a charging equilibrium plan to eliminate the problems of stress on the power grid, charging urgency, power balance, stability, and unstructured energy deviations in V2G applications [4,5].

Proper EV coordination for charging and discharging becomes possible through collective decision-making. Central coordination of V2G technology is considered practical because of its effectiveness. For example, it avoids pulling demand and excessive charging, which has an effect on battery life. Presently, V2G coordination is more effective than Grid-to-Vehicle (G2V), but significant challenges remain. For example, in large power systems, the existing V2G infrastructure cannot

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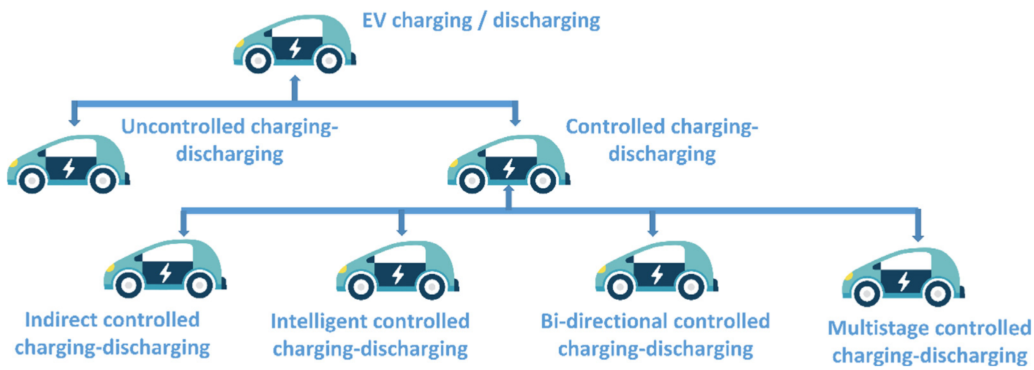

Fig. 1. Different EV charging–discharging methods.

rapidly and repeatedly receive bulk power injections without considering factors such as the energy market, power system operation control, and demand response management of EVs. In addition, EV owners are not willing to inject power into the grid; this can cause voltage deviations and reductions in voltage stability and grid reliability, leading to issues with battery efficiency [6–8]. To achieve superior power demand management, an interdisciplinary computational model is needed to ensure EV aggregator coordination [8,9]. Recent research has focused on the commercial gain of the aggregator, ancillary services, and the optimization of various problems in V2G to obtain solutions for specific problems. At present, some researchers are using a multi-aggregator coordinated method and implementing different cases in which inter-aggregator coordination satisfies an overall optimization problem. The above concept makes the strategically-controlled coordination of charging–discharging demand in V2G systems attractive to the research community.

This paper describes and explains both present and future coordinated charging–discharging strategies for EV aggregators by comparing various charging–discharging optimization techniques and hierarchical multi-agent solutions. V2G topology particularly focuses on the use of existing infrastructure to reduce the burden on the power grid, which reduces the negative impacts on power quality, efficiency, and electricity cost. This smart decision-based hierarchical multilevel V2G approach is entirely different from other techniques in several ways. This paper also highlights methods of adopting the V2G framework according to the charging–discharging capacity of the infrastructure in addressing significant problems. The systematic review of existing infrastructure in this paper provides detailed knowledge that can be used to establish distributed networks for low, medium, and high-range EV fleets in the power grid, thus reducing grid load. Furthermore, the exchange of power demand from peak to off-peak hours to maintain grid stability is also discussed in this paper as a means of reducing the complexity of power injection.

The remainder of this paper is organized as follows: Section 2 focuses on techniques for charging and discharging management and constraints. A strategic aggregator-controlled charging–discharging optimization strategy with existing infrastructure is proposed in Section 3. Section 4 discusses future directions. Section 5 presents the conclusion.

2. Literature review of charging–discharging techniques for aggregators

This section presents a detailed literature review of EV charging–-discharging methods and grid-based energy management studies. The concept of V2G was first developed by Amory Lovins and William Kempton, who attempted to put a positive spin on the assumption that EVs would be common in society and that a significant amount of electricity capacity would be available to provide valuable storage facilities for the electricity grid [10–12]. The basic idea of V2G is that when demand increases, parked EV batteries inject power into the grid; the batteries of EVs then charge during times of low demand [13]. In this way, V2G systems provide backup to the distribution grid, and the potential impact of EVs on electrical utility could be significant as they penetrate the distribution system. The effect is small in terms of the generation and transmission side; however, it is not possible to ignore the impact on the distribution system [14]. The impact analysis demonstrates that the charging of EVs influences the present distribution network through its generation capacity, transformer aging due to overloading, battery aging, and power quality problems in the distribution system. Several schemes for reducing these impacts are also presented, including multilevel hierarchical charging–discharging, clustering of energy management, and direct control using smart charging algorithms.

At present, EVs are a fast-growing segment of the market, although the infrastructure is inadequate for existing EV demand. Several challenges have been evaluated over recent years, such as the impacts on the utility grid and distribution network, power quality, and voltage regulation [15–17]. Technically, the charging–discharging method is dependent on the location of the majority of parked EVs, and the load demand. Fig. 1 illustrates a general EV charging–discharging scheme with both controlled and uncontrolled charging. Controlled charging is further classified into four sub-groups: indirect controlled, bi-directional controlled, intelligent controlled, and multistage controlled.

2.1. Uncontrolled charge–discharge method

In uncontrolled charging–discharging, no attempt is made to schedule the requested EVs. In uncontrolled charging, EVs start to receive charge immediately when connected to the power grid during off-peak and peak hours. The uncontrolled charging–discharging method is very simple and directly exposes the grid. In this method, the grid operator does not receive any user information about the system, which may result in problems with grid stability, power quality, operational efficiency, and battery state-of-charge (SOC). In reality, large-scale EV charging, and discharging has a vital influence on the grid, and the electrical storage components of EVs offer new possibilities for the reliable operation of renewable energy power systems. Load modeling of EV charging is required to study the impact on electric power systems and to sign the EVs' charge–discharge control [6,7].

In uncontrolled charging, EVs are charged rapidly upon plug-in or after a user-specified delay. The delay is entered to give the vehicle owners the possibility of charging their vehicles using off-peak rates. Once charging has started, it usually continues until the battery is fully charged or the vehicle is used, whichever occurs first. Research on uncontrolled charging has concentrated on scrutinizing and investigating the impact of EV interconnection on the electrical grid [8–17].

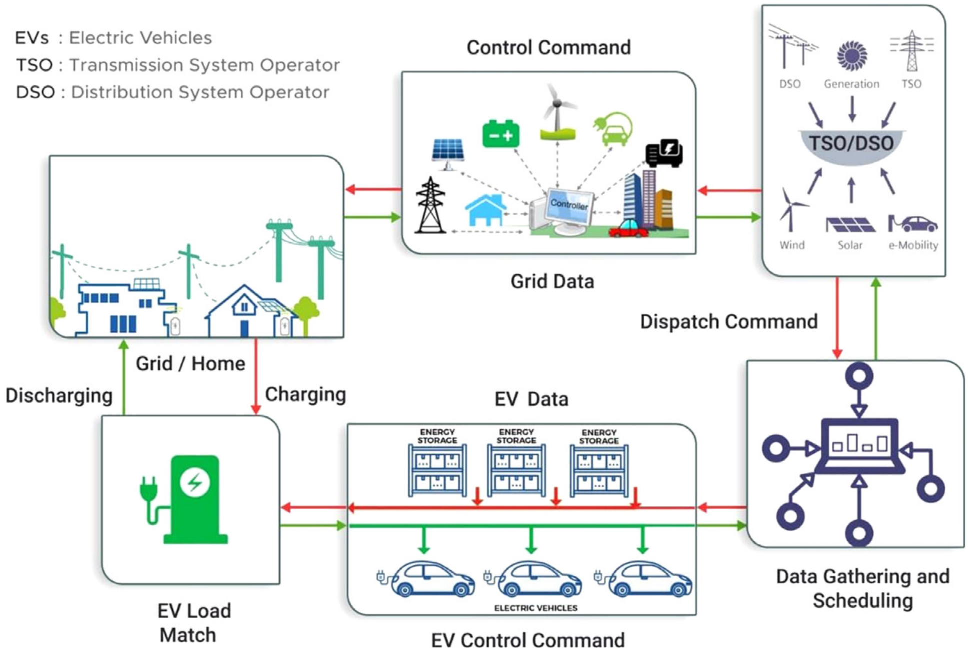

Fig. 2. Regulated EV charging–discharging method utilizing a control center.

2.2. Controlled charge–discharge method

The controlled method of EV charging–discharging has enjoyed increasing interest in recent years. This coordinated method can be quickly adopted and monitored by the operator, who prepares the charging–discharging schedule to avoid issues with power quality and disruptive destabilization while meeting the driver's charging requirements and satisfying financial or operational review objectives. The operator's performance objective is related to infrastructure and upgrading of the existing system. Depending on the types of control parameters, established charging–discharging can be incorporated into indirect controlled, intelligent controlled, and bi-directional controlled. In indirect controlled approach, the design does not constrain the charging parameters such as the charger's control, loading time, and charging extent. Preferably, these systems should control any out-of-system parameters that influence the charging method. A system may control energy cost, which defines the charging judgment of individual drivers in the course of preventing grid overload. Fig. 2 illustrates the controlled charge–discharge model, with centrally controlled and coordinated charge–discharge control performed by a schematic algorithm [18–20].

2.2.1. Indirect controlled charge–discharge method

The indirect control method considers consumers' behavior and decisions. In recent years, indirect charge-discharge is increasing in popularity because of the electricity market time framework with adjustable price incentives. Increasing energy prices are expected to push some charging loads to off-peak hours when spare grid capacity is available, thereby preventing grid overloading [15]. There is a distinct type of indirect control known as spatial load shifting. In other words, the shifting of spatial loads can be coordinated by the criterion of self-determination of EV users. Fig. 3 illustrates a controlled charging interface that is indirectly controlled and works in between EVs and different smart grids.

This method can be implemented in two different ways: the first is based on charging cost, the second involves providing ancillary services to EVs to ensure optimized grid operation. A real-time EV charging method has been proposed that considers the time-of-use and real-time pricing, helping to regulate demand [21]. In the time-of-use scheme, three study parameters were considered [22,23]. First, energy and charging cost in the distribution network were considered. Second, hierarchical EV management was highlighted, in which the upper layer of the controller directly controls the lower-level controller, resulting in market-based cost control and EV management. The third parameter was the holistic design method followed by a cost control model using spatial load shifting [22,23]. In the time-of-use scenario, [24] EVs were studied at different penetration levels without upgrading the infrastructure. Network parameters such as transformer burden, battery SOC, voltage, load profile of the distribution network, and status of plug-in EVs were assessed at penetration levels of 20%, 30%, and 50%.

2.2.2. Intelligent charging–discharging method

Intelligent charging-discharging methods can only be implemented in real-time when the control mechanism requires a long-term solution at higher levels and also in ancillary services. Intelligent charging–-discharging refers to a system whereby a data connection is shared between an EV and a charging station, and the charging station is connected to a transmission/distribution system operator. Intelligent charging allows the operator of the charging station to track, control, and limit the remote use of their devices to optimize energy demand. Intelligent charging–discharging methods are often developed through the constrained formulation of optimization problems that can be solved by suitable optimization techniques or intelligent controllers [25]. Optimization techniques usually aim to keep power quality and stability within marginal levels to avoid disruptive grid instability and to satisfy all charging criteria. Certain optimization variables, such as charging power, forecasting of price, charging–discharging status, and power balance control the behavior in these formulations [26–31].

Fig. 4 illustrates the existing intelligent charging–discharging model. Overall, the operation of EVs should take into account, but not be limited to, a limit on charging and/or discharging power, initial SOC, customer travel practices, initial demand for energy, and battery capacity. In addition, the operation of a power system is restricted by the limitations of generation units, network structure, efficiency of transformers, voltage, and frequency requirements. All these problems suggest that it is important to have a standard algorithm to meet the current demand for EV charging and to support future bi-directional charging.

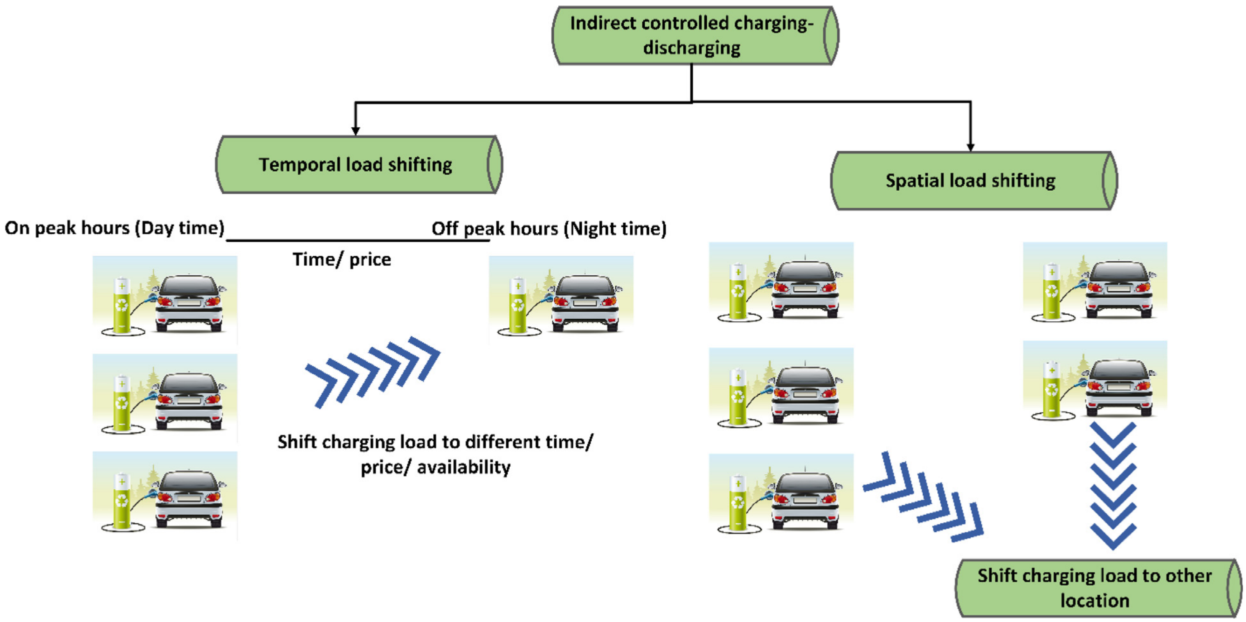

Fig. 3. Indirect charging-discharging model.

2.2.3. Bi-directional charge–discharge method

Bi-directional charging is different from intelligent charging–-discharging in that it strongly reinforces the V2G concept, which authorizes EVs to inject energy into the grid. Supplying the electrical grid with energy from EVs is convenient since the vehicles are usually parked for 90–95% of their total lifetime. Furthermore, less availability or the EV owner's willingness do not allow maximum EVs to inject power into the grid during peak hours [26–28]. The V2G system reduces negative impacts on the grid of the charging–discharging mode of operation. Various smart bi-directional charging functions can be used to extend the long-term benefits of V2G, such as connect/disconnect, soft start/stop, auto charging–discharging, and ramp rate functions. These functions provide EV owners with reduced charging costs, smoother EV voltage output, and voltage stabilization [29]. Additionally, EVs can collectively serve as a reservoir in bi-directional V2G, thus filling the gap between unpredictable supply and random demand. By ensuring a closer match between supply and load, bi-directional V2G supports both higher EV penetration and greater integration of renewable energy into smart grids. EV can provide such ancillary services in both forms. Then, when necessary, charging power can be throttled down. Furthermore, using bi-directional charging solutions allows electricity to be restored to the electrical grid [30].

Three matrix AC-AC and wireless power transfer DC-DC bi-directional have been used to increase power transmission efficiency, frequency stabilization, and effective constant current–voltage during V2G and G2V. To improve the power factor, phase difference between the voltage, and current is controlled from the grid side, with space vector control pulse width modulation using bi-directional charging employed to handle AC voltage, and current switching frequency [30–33]. In general, bi-directional and intelligent charging methods are comparable in terms of their review objectives and control mechanisms, with bi-directional charging offering additional control over the direction of the energy flow. In most cases, the review goals are to decrease the expenses or maximize the advantages of the operator, aggregator, and EV

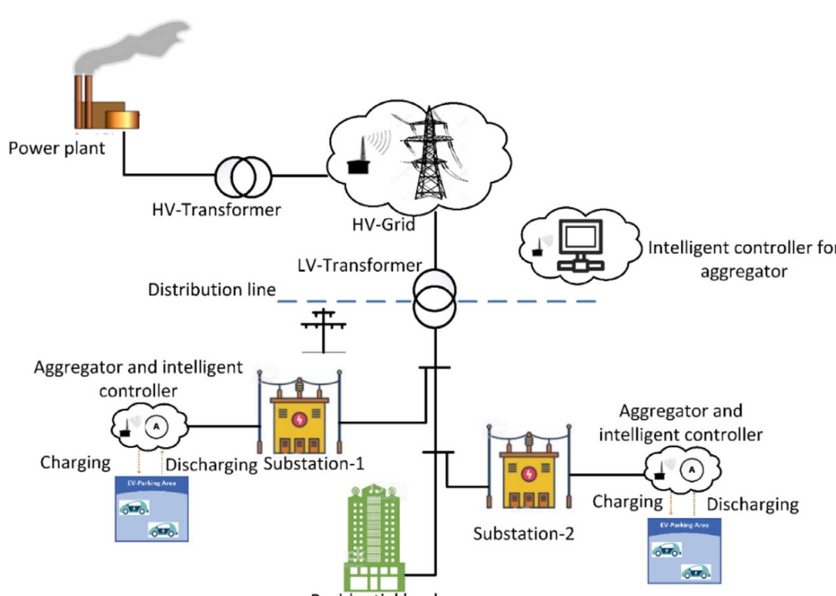

Fig. 4. Illustration of the intelligent V2G charging–discharging model.

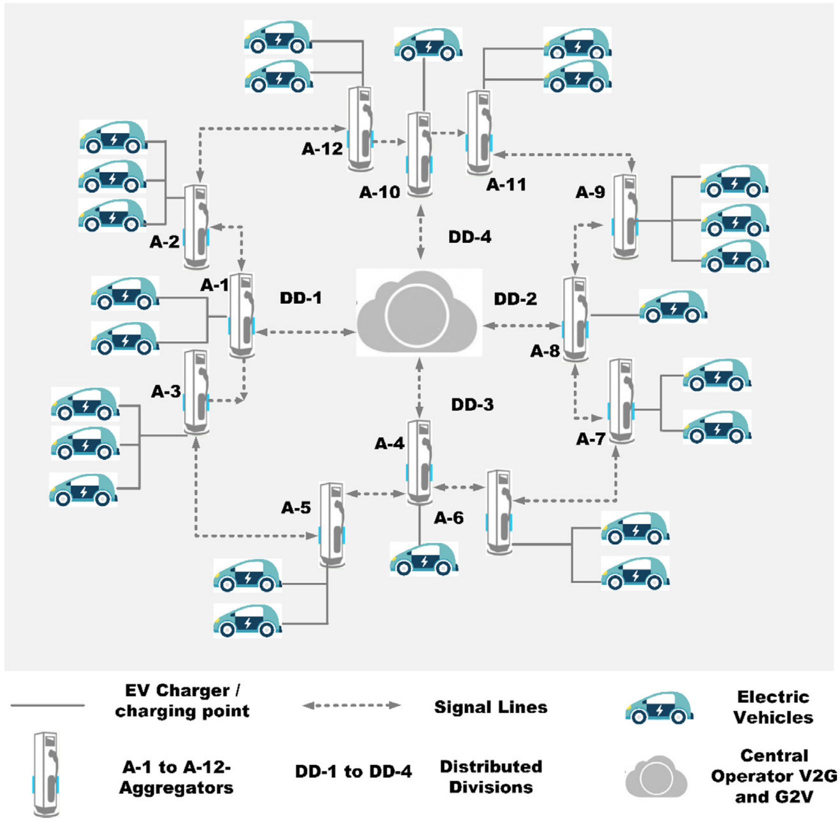

Fig. 5. Schematic view of the multistage hierarchical charge–discharge control method.

by controlling charging and discharging profiles of the EV [34–36].

2.2.4. Multistage hierarchical controlled charge–discharge method

The multistage hierarchical controlled charge–discharge method is very different from the three control techniques described above. This method consists of a multilevel decision-making tool that operates on a priority basis. Using the existing infrastructure control technique, multistage hierarchical charging–discharging provides a unique solution using decision-based control through a genetic algorithm (GA) with fuzzy- or artificial intelligence-based control tools. This simple technique of controlled charging–discharging is illustrated in Fig. 5. The working mechanism of the hierarchy is maintained by organizing four distinct distribution divisions according to the load capacity of the current infrastructure, priorities such as battery SOC, charging cost, and time-of-use. During peak times, these distribution divisions are connected to the grid while recognizing supply and demand rates according to the highest number of connected EVs parked in the area. When there is a mismatch between demand and supply rates, all aggregators start communicating to determine the maximum number of EVs that can inject power into the grid. These distributed divisions for large- (above 50 kWh), medium- (25 to 50 kWh), and low-capacity (5 to 20 kWh) EV injections are created according to the range of the EVs to ensure a suitable demand and supply configuration. This control mechanism also helps with frequency regulation, voltage fluctuations, and power quality, and improves other critical optimal solutions. At present, this method is purely hypothetical and review-based, but could be quickly implemented. Other advantages of this technique are that it reduces electricity costs and provides more benefits to commercial users [44–48].

In summary, studies of the literature indicate the practicality of grid-connected V2G aggregators in various contexts. For aggregator interaction in the V2G, major research opportunities include the impact, and assessment of charging–discharging. The consensus is that V2G technology with aggregators is beneficial from a commercial point of view under appropriate charging–discharging. Generally, V2G cannot achieve charging equilibrium during spatial load shifting. This may result in reduced charging–discharging costs.

The multistage decision approach to charging–discharging may be feasible for future V2G integration, helping to avoid excessive charging costs, improve power quality, and enhance the power factor (see Table 1). Table 2 summarizes comparative studies of controlled and uncontrolled charging–discharging methods.

Table 1
Comparison of charging–discharging methods [19–28, 36–48].

No.	Charging–discharging control method	Limitations	Response	Positive impact
1	Indirect controlled charging–discharging [19–24]	No direct action during peak demand	Slow	• Power quality is maintained
2	Intelligent charging–discharging [25]	Long loading and unloading time	Generally fast	• Good power quality • Good grid stability
3	Bi-directional charging–discharging [26–28,36]	Load capacity cannot be changed	Slow	• Voltage fluctuations are avoided
4	Multistage hierarchical charging–discharging [37–48]	Multistage decision	Fast	• Improved power quality • Good power factor is maintained • Voltage fluctuations are avoided • Frequency regulation is achieved

Table 2
Comparison of controlled and uncontrolled charging–discharging methods [26–43].

Charging type	Benefits	Disadvantages	Effect on grid	Point of view
• Controlled charge–discharge (smart charging) [26–31]	• Peak power is reduced • Demand profile is smoothened • Better ancillary services are provided • Effective distribution network • Low maintenance cost	• Complex distribution network design • Battery SOC is reduced fast • More losses in grid • Customers' readiness is required • Different controlled techniques are required in different critical situations	• Peak load is managed easily • Easy coordination between grid and load • Increased reliability and stability in power grid • Reduced electricity cost • Reduced burden on grid elements	• Real-time optimal algorithms have been designed • Demand-side management • Linear, dynamic optimal problem has been solved • Valley filling using optimal computation of algorithms
• Uncontrolled charge–discharge [32–43]	• Easy to use • Instant system adoption during peak time	• Large voltage fluctuations • Grid overloading increases and bad impacts found on grid elements • High electricity cost • Poor power factor	• Power quality degradation • Overloading of grid elements • High power losses • High electricity cost • Increase in uncertainties	• Charging begins irrespective of cost and demand

3. Strategic EV optimization control of charging–discharging methods

This study presents a survey of EV charge–discharge optimization techniques for various aggregator methods. In this context, it is important to review the optimization of the energy management system (EMS) for EVs. Previous studies of EMS optimization for EVs will be described and discussed in this section. EV charging has negative effects on the power grid, including system failures, voltage drops, phase asymmetries, stability problems, reduced power factors, and the additional burden on the grid when existing infrastructure is used [49-51]. The major optimization objectives for charging–discharging control are illustrated in Fig. 6.

3.1. Two-stage charging strategy for EVs using fuzzy logic control

This method is an extension of a previous approach [52] in which an optimization method based on Pontryagin's Minimum Principle (PMP) is applied for EV charging and discharging in the network. This PMP-based method uses a dynamic optimization structure aggregator, wherein each optimization step smooths the load profile by using a fuzzy controller, and considering the priorities of the charging–-discharging EVs. This method has been employed to smooth charging–discharging load profiles through independent decision-making optimization [52]. Initially, load profiles of 24 apartments were examined under the bi-directional approach in terms of primary SOC (before run-time battery discharge rate), plug-in, and unplug-in times for the ith EV ON/OFF, and real-time SOC (run-time battery discharge rate) of the EVs [46]. In the first step, time-of-use and optimal charging power were determined using a bee colony algorithm, and aggregator power distribution was then obtained using a fuzzy controller. This algorithm smoothed the peak load and reduced transformer burden. Nevertheless, this system was not especially effective when uncoordinated scheduling occurred. Therefore, appropriate controls were placed on the battery and transformer. The nonlinear dynamic distributed controller may affect the transformer and cause hot spots in the windings. Fig. 7 illustrates different fuzzy optimization models that have been applied [54,55].

3.2. Real-time charging strategy using model predictive control

The model predictive control (MPC) approach can be used to optimize standard output according to past and current values. In MPC, automatic generation scheduling controls the charging–discharging of fleet EVs in a bi-directional manner [56]. In general, a two-way design is used to assess real-time controllers with different complexities and features. MPC has been used to extend benchmark values in real-time range scenarios for regulation and efficiency of batteries [57]. To ensure a suitable power factor and reliability, energy management for EV optimization can use MPC with particle swarm optimization (PSO) to regulate power demand [58]. Additionally, myopic MPC-based trajectory optimization for minimum power usage can be employed to forecast the accuracy of automated generation scheduling and update the SOC constraints [59]. Fluctuating electrical prices cause uncertainties in charging–discharging. To avoid this two-stage optimization, some analysis of charging–discharging power can be undertaken [60,61]. Although use of predictive models for energy management reduces the burden on the grid under day-ahead predictive control, strategic scheduling of V2G is unsatisfactory for large grids. To avoid uncertainties, multi-stacking of a predictive model with operational capacity, battery SOC, and frequency regulation can be employed. Thus, another way to diminish demand for grid support and active power is to use a stochastic distributed predictive model that minimizes reactive power impact [62]. Fig. 8 illustrates the flow of various predictive models investigated in this paper. The most suitable hypothetical approach to MPC stacking coordination is to use decentralization, which helps

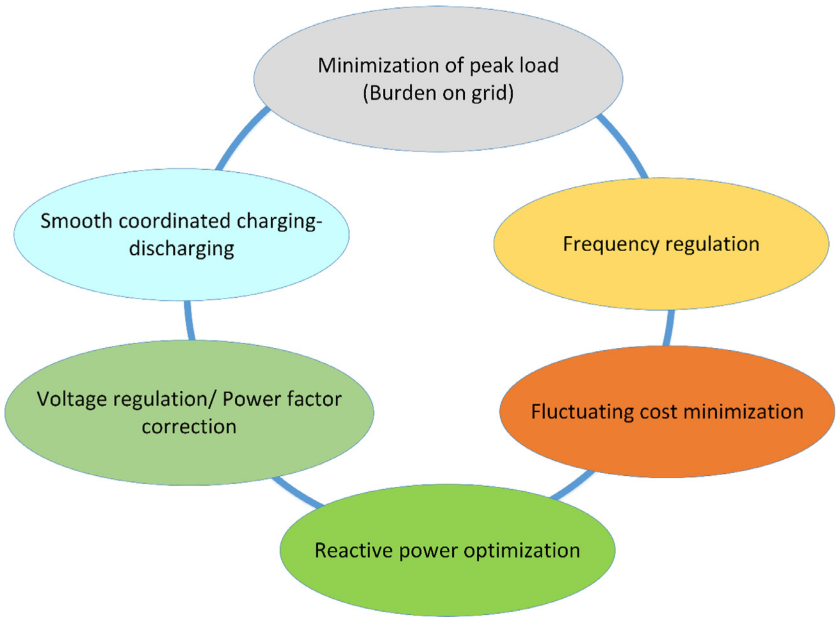

Fig. 6. Main objectives considered in EV charge–discharge control methods.

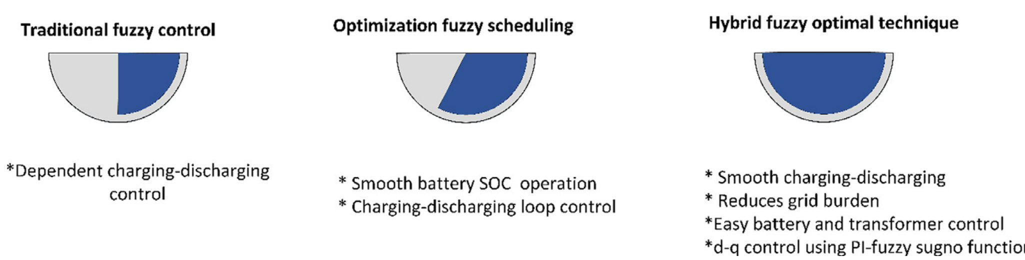

Fig. 7. Fuzzy-based optimization methods.

minimize charging times, while segregated objective functions can be considered for real-time implementation.

3.3. Metaheuristic charge–discharge control optimization

Meta-heuristic approaches are used for large-scale solutions to optimization problems in the case of inadequate information such as charging rate, charging status, pricing, and load curve. Such methods are also appropriate for finding optimal solutions under appropriate assumptions. PSO has been used for frequency regulation and to stabilize frequency in power distribution systems. Determining parameters are the mobility pattern, charge–discharge method, and energy pattern. The stochastic PSO method is judged against other swarms for specific problems [63,64].

Structured optimization of energy management is performed in two steps using a multi-objective approach, which uses predictive model control in the second step for EV charging [64]. In multi-objective optimization, the aim is to maximize revenues of the EV stations, alleviate battery management problems, and reduce power fluctuations imposed by the grid at the point of common coupling [65]. A new bi-

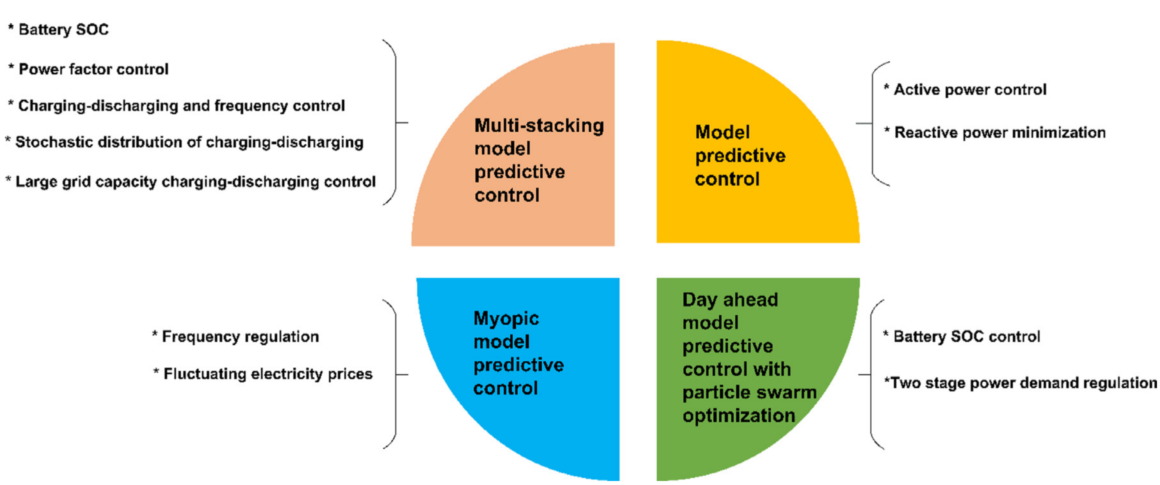

Fig. 8. Model predictive control techniques and proposed method.

Table 3
Optimization objectives and optimized charge–discharge methods [51–82].

Optimization Objectives	Optimization Methods	Charging Methods	Restrictions	Benefits	Drawbacks
Minimize peak load [51–55]	Fuzzy logic control	Intelligent and centralized	Charging availability	• Easy load calculation for grid • Reduced burden on grid	• Limited operating range in state feedback • Lack of real time response
Regulate frequency/ minimize cost [56–62]	MPC	Intelligent and centralized/ decentralized	Applicable for least power resources and more power losses	• Price uncertainty is minimized • Smoothed load spatial operation	• Different scaling based on conditions • Costly computation
Reactive power management [59–65]	MPC	Decentralized	Low-capacity grid control	• Smooth charging	• Poor scaling
Peak load smoothing coordination [66,67]	Meta-heuristic approach	Centralized and decentralized	Driving pattern affects the performance High cost	• Predictive results obtained from case to case in real-time	• Long computational time • Not suitable for theoretical analysis
Smart smoothing of charging–discharging schedule [68]	Heuristic optimization	Centralized and decentralized	Parking availability Uncertain behavior	• Voltage deviation is reduced • Peak shaving • Load fluctuation is avoided	• Unable to deliver optimal solution for planning and scheduling
Minimization of fluctuating cost of EV charging [51–71]	Heuristic optimization with PSO	Centralized only	Complex and firm solution is not obtained	• Cost minimization • Frequency is controlled • Burden is reduced on grid • Peak load variation is minimized	• Local optimal solution is obtained (not global optimal solution)
Regulate frequency [72,73]	Integrated fuzzy-pi and MHSA	Centralized and decentralized	Large complex solution is not obtained Used for linearization process only	• Frequency is controlled • Light burden on grid during islanding condition	• Needs high accuracy measurement
Manage peak load, voltage deviation, and line loading [73–80]	Quantum binary evaluation algorithm distribution network	Decentralized	Guaranteed violation of results if limit is exceeded	• Multi-objective functions are solved within limit only	• Needs complex mathematical calculations
Minimize the energy cost using intelligent scheduling [77]	Multi-modal approximate dynamic programming (MM-ADP)	Decentralized	Global optimal output is not guaranteed	• Cost minimization • Smooth price scheduling	• Continuous feedback is required in each iteration
Charging cost reduction with hourly peak/ base load contract [81]	V2G-optimal logical control algorithm (V2G-OLC)	Decentralized	Not suitable during massive EV penetration Unable to maintain buying/ selling unitary ratio	• Helps to maintain constant daily load profile	• Large complex algorithm calculations
Improved service and reliability of routing [82]	Quality of service scheduling optimization (QoS)	Centralized	Slower response obtained during night time	• Average waiting time • Smooth coordinated scheduling and charging	• Unable to quantify the mathematical tightness of expressions

level optimization technique has been developed for hierarchical zonal architectures. This serves two purposes: first, it achieves optimal charging–discharging using minimum peak load, thus optimizing the dispatching scheme and allowing fast decision-making by the aggregator; second, it obtains coordinated goals by using day-ahead scheduling with adaptive control, thus making a typical residential distribution grid more flexible for more economical dispatching [66,67]. A charging control model for multi-agent scenarios was developed by forecasting response and economic factors in maximizing performance using responsive and unresponsive signals [68].

The vehicular node group, called a "cluster," was the focus of a meta-heuristic PSO for the social behavior of smooth and robust communication between nodes, thus smoothing load operation of the grid [64]. Charging–discharging behavior for day-ahead scheduling is effective for real-time spatial data management, such as for optimal load shuffling, demand power management, and price control from a commercial point of view [69]. Aggregated energy management-based optimization is used to provide a balance among the power system, peak load shaving, frequency regulation, voltage control, and valley filling [70]. Table3 compares optimization methods applied for various objectives. Table4 presents the charging-discharging equations for control purposes.

3.4. Heuristic control optimization in charge–discharge method

Heuristic optimization can be applied to achieve some critical resolutions to a specific optimization problem. The heuristic optimization solution to any specified problem may not be the same for different practical implementation cases [47]. A lightweight EV forecasting method based on electrical rates and the number of EVs has been developed to avoid price fluctuations [71]. This heuristic method cuts down the vastly complicated optimization problem using iteratively equivalent time slots. Real-life demand pattern results have shown that revenue is generated in a simplified way. The strategic multi-dimensionality of the objective function allows EVs, under V2G operation, to reduce overall system operation costs, decrease network complexity, and remove a degree of nonlinearity. Furthermore, PSO with a heuristic approach can reduce EV charging costs. A forward-and-back sweep algorithm-based load flow solution helps to manage incidences of peak load shaving [72]. Scheduling policy for V2G and G2V in workplace parking lots can be analyzed through a GA with a heuristic approach to EV connection in technical and business scenarios. This can help to minimize daily costs, peak load, frequency regulation, and grid overloading [73]. V2G control can be applied to compensate for short load frequency deviations during grid islanding.

Many other uncertainties can be handled by General Type-2 Fuzzy Logic System (GT2FLS) and Modified Harmony Search Algorithm (MHSA) techniques, with integrated fuzzy and heuristic algorithms offering distributed load control and frequency deviation [74]. Economic benefits to the distribution network, reduced cost of charge--discharge control, and improved efficiency can be achieved through evolutionary algorithms such as GA, PSO, and ant colony optimization. Differential charging coordination requires GA optimization, along with peak load shaving and reductions in large-scale complex power system uncertainties for the selected number of EVs [75]. Considerable attention is focused on appropriate V2G technologies that minimize line loading, voltage deviation, and circuit power loss. This technique has become an important mechanism in implementing backup power sources for distribution networks. EVs require charging service stations (CSS) to receive power from the grid. Thus, in a distribution network, the performance of V2G technology must be considered alongside the peak time demand control before the deployment of optimal CSS [76–80].

Table 3 compares the various optimization objectives and charging–discharging optimization methods for EVs. Benefits and restrictions of the optimization methods, such as price uncertainty minimization, smooth spatial load shifting, frequency regulation, peak load shaving, and the burden on grid elements, are summarized in detail

4. Future prospects and limitations of EV charging–discharging methods

On the basis of the survey presented above, this section presents several promising directions for future research. These can be categorized into two main groups, the first consisting of future prospects identified in the literature (wireless charging EVs, block-chain-based peer-to-peer tools to enable V2G with clean energy, V2G/G2V security and privacy, and smart charging method optimization) and the second concentrating on various limitations (e.g., performance and efficiency improvement with existing infrastructure, optimization techniques, cost-effectiveness, and time saving).

4.1. Future prospects

There are strong points for future development, such as wireless charging, block-chain management in V2G, privacy and security, and smart charging optimization. To date, the electrification of large EVs has been limited; this is linked to factors described forthwith, and, simultaneously, creates major challenges in EVs deployment. Planning as far ahead as possible is important.

4.1.1. Wireless charging EVs

Various papers have examined the effect of EVs on the power grid [100]. Most of these studies were performed for traditional EVs with traditional driving patterns, and charging was mostly done at home or at public charging stations [96]. However, this assumption is not applicable when wireless charging is used. Consequently, careful studies are needed to determine the effects of wireless charging EVs on the power grid in terms of demand response, wireless charging infrastructure, and the burden on grid elements. Another interesting area is V2G wireless integration with renewable sources such as solar and wind power. In the future, separate testing modules will be needed to investigate the performance of V2G wireless infrastructure.

4.1.2. Block-chain-based peer-to-peer tools to enable V2G with clean energy

Use of block-chain techniques in V2G is still in its early stages, but is progressing at a fast pace. Moreover, block-chain-based peer-to-peer tools have been used in distributed-network smart contracting with the aim of connecting EV drivers. Such tools should also provide fully optimized solutions to avoid load fluctuations, facilitate energy management, and ensure smart smoothing of charging–discharging schedules [97–99]. In the context of a block-chain-based tool, charging and discharging are two faces of the same coin, between which the tool maintains a balance. It is to be hoped that more people will eventually be convinced to charge their vehicles using clean energy. Benefits of e-mobility provided by EVs will offer both individuals and commercial enterprises with incentives to do this. In the future, prepaid wallets for EV taxis will be used to offer discounts and money-back policies, and e-mobility trading will become easy. Thus, an advanced platform for the implementation of V2G is important from both commercial and economic perspectives. Fig. 9 illustrates the conceptual idea of a smart block-chain-based peer-to-peer tool to enable V2G.

4.1.3. V2G/G2V security and privacy

Security and privacy are both important aspects of the use of block-chain V2G for managing and monitoring power usage in smart grids. A typical V2G network includes four main entities: EVs, a smart grid, an aggregator, and a control center. To set up power exchange in a V2G network, a bi-directional wired or wireless communication protocol is used. Such V2G technique can be considered as part of a future "Internet of Energy (IE)." Using an IE network architecture, EVs can

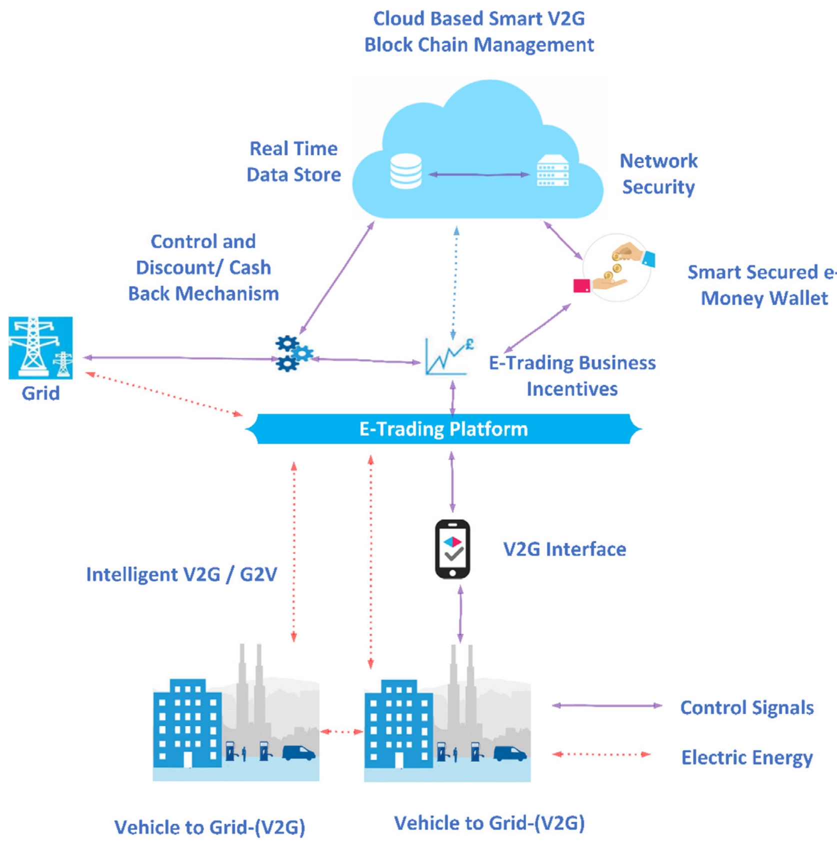

Fig. 9. Smart block-chain-based V2G.

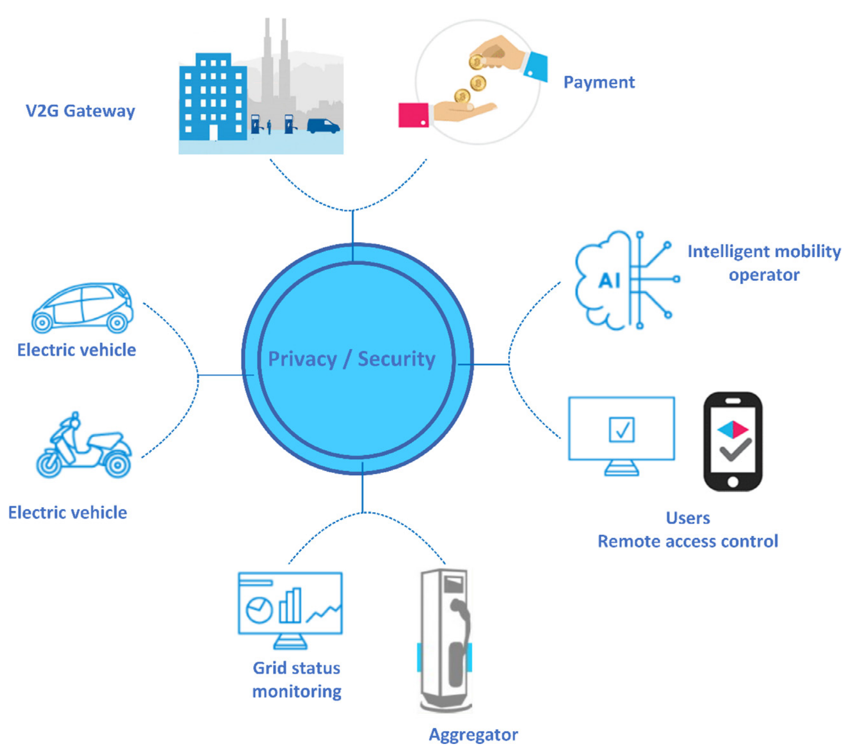

Fig. 10. Future "Internet of Energy (IE)" technique for V2G security/ privacy.

exchange energy with the help of aggregators. A future IE technique for V2G/G2V security/ privacy is shown in Fig. 10.

In a V2G network, it is necessary to transmit information securely between aggregators and drivers [98,99]. In addition, e-transactions/e-trading may be subject to a number of vulnerabilities that could be exploited by hostile agents. Therefore, it will be necessary for a future Internet of Things (IoT)–V2G network to incorporate a private centralized architecture. This will help to deal with issues such as security

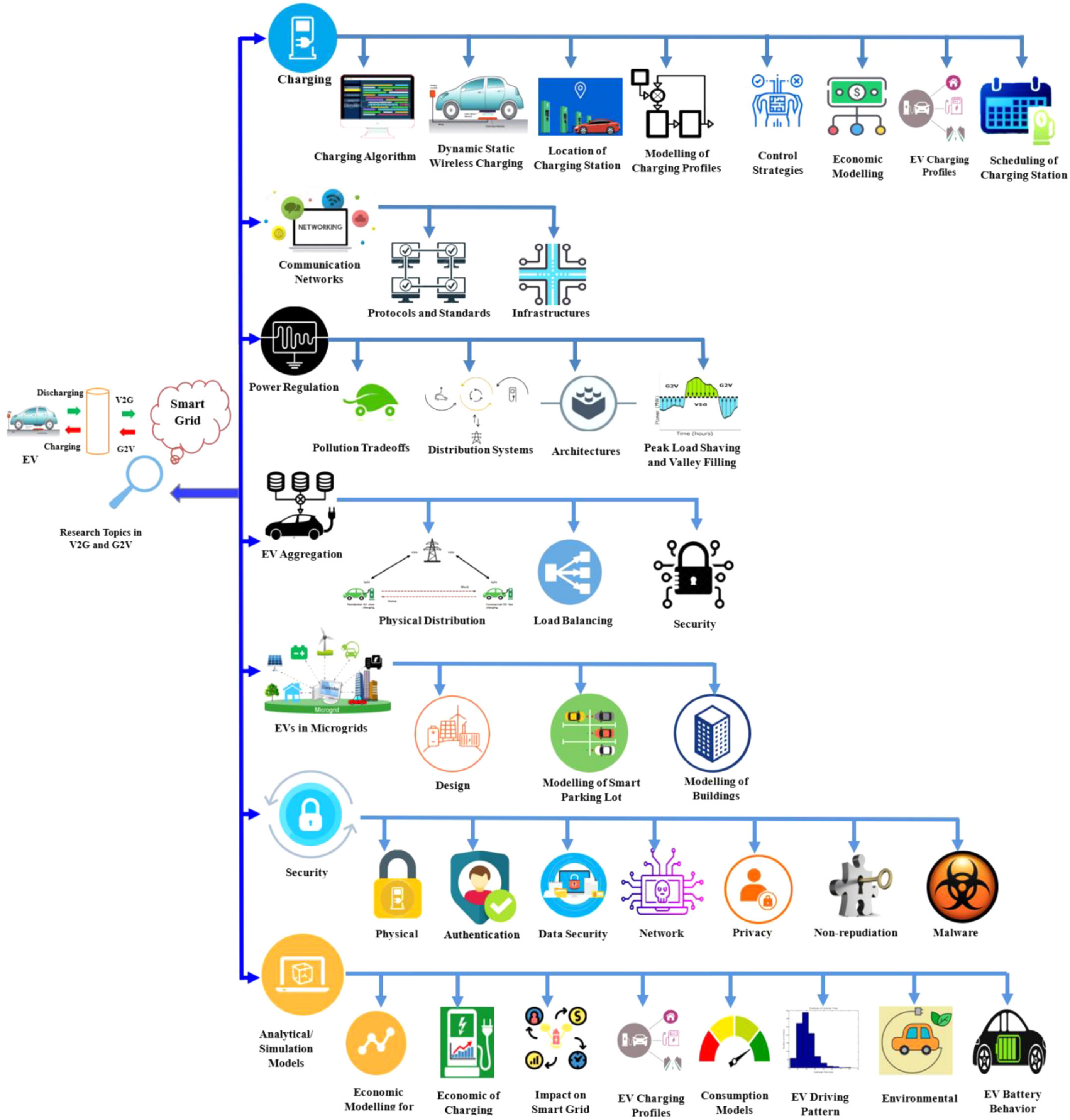

Fig. 11. Major challenges in V2G commercialization.

and privacy, mutual authentication, verification, and e-trading access authentication. In the IE technique, security, and privacy issues are important challenges faced by smart V2G/G2V. The following detailed, stepwise assumptions are adopted during implementation:

- Mutual authentications between EV and network entities include aggregator and V2G gateway.
- Individual remote access control and privacy includes payment and available for all unauthorized mobile EVs to reveal an EV's real identity.

4.1.4. Smart charging and optimization

Smart charging is a more practical scenario than V2G, although it is also very expensive due to the need for a suitable infrastructure to permit bi-directional flow to and from EVs. With smart charging, when levels of demand are low, EVs provide power to the grid, whereas during periods of high demand, the reverse occurs. Time and cost play vital roles in smart charging, and artificial-intelligence-based bi-directional DC-DC fast chargers with price and time limiters should become available in the future. It is desirable to initiate charging at times when electricity prices are low, or at least prevent charging when prices are very high. Instantaneous price limiter algorithms should be

Table 4
Charging–Discharging Problem Equations. [75, 81-97].

Charging problem equations	Solution methods	References
Average load of charging station $\sum_{i\in I} * \sum_{h\in H} * \sum_{t\in T} *(\frac{W^{\omega}_{iht}}{\sum_{i\in I} * Cii\ Ylit - W^{\omega}_{iht}})$where, W^{ω}_{iht} = **Charging station capacity; Cii = Charging station** $\sum_{i\in I} * \sum_{h\in H} * \sum_{t\in T} * X^{c}_{ht}(\frac{W^{\omega}_{iht}}{\sum_{i\in I} * Cii\ Ylit - W^{\omega}_{iht}})$where, (h, t) = ratio of EV charging particular hour; **Ylit = size, location, time for charging;** X^{C}_{ht} = Load congestion price charged by charging station; W^{ω}_{iht} = **Total amount of power used**	• Two-stage stochastic Mixed-Integer Nonlinear Programming model (MINLP) • Metaheuristic and heuristic control algorithms • Artificial neural network (ANN) • Lyapunov	[75, 81-85]
Charging demand and prolong battery life with charging limit $Soc^{i}_{EV,\ min} \le Soc^{i}_{EV,\ t} \le Soc^{i}_{EV,\ max} \le Soc^{i}_{EV}$ ∀ t€ST, ∀ i€SE $Soc^{i}_{EV,t} = \{Soc^{i}_{EV,t,start} + \frac{\eta^{i}_{c} P^{i}_{EV}}{C^{i}_{EV}} \sum_{t=tstart}^{t} S^{i,c}_{EV,t} - \frac{P^{i}_{EV}}{\eta^{i}_{d} C^{i}_{EV}} \sum_{t-tstart}^{t} (S^{i,dV2H}_{EV,t} + S^{i,dV2G}_{EV,t})\}$ *s. t. t,* $tstart€T^{i}_{EV}$ **where,** $Soc^{i}_{EV,\ min}$ and $Soc^{i}_{EV,max}$ **prolong battery life**	● Linear programming ● CPLEX – GAMS ● PSO ● Fuzzy rule ● Linear programming + convex relaxation ● Multi-objective	[86-91]
The grid power fluctuation is reduced $\sigma_1 = \min \sum_{t=0}^{T} (P_{c,t} * N_{c,t} + P_{Load,t} - P_{d,t} * N_{d,t} - \hat{P})^2$where $P_{c,t}$ and $P_{d,t}$ = **charging − discharging power of EV;** σ_1 = **power fluctuation**; t=time $N_{c,t}$ and $N_{d,t}$ = **number of EV connected;** $P_{Load,t}$ = **basic load;** $\hat{P}$ = **Avg. load connect** $\sigma_2 = \min \rho_{c,t} * N_{c,t} * \rho_{c,t} * \Delta t - \rho_{d,t} * N_{d,t} * P_{d,t} * \Delta t \rho_{c,t}$ **and** $\rho_{d,t}$ = **price at the instant** $\min f = \alpha_1 * \sigma_1 + \alpha_2 * \sigma_2$ **where,** α_1, α_2 = **is the weight;** σ_1 **and** σ_2 = **power grid benefit**	• GA • Multi-objective	[91-93]
Power balance during V2G $P^{a}_{i,j,t} = \sum_{\varnothing=a,b,c} (\lvert V^{a}_{i,t}\rvert\lvert Y^{a\varnothing-n}_{i,j}\rvert\lvert V^{\varnothing}_{i,t}\rvert \cos(\theta^{a\varnothing}_{i,j} + \delta^{\varnothing}_{i,j} - \delta^{a}_{i,j})(\lvert V^{a}_{i,t}\rvert\lvert Y^{a\varnothing-n}_{i,j}\rvert\lvert V^{\varnothing}_{i,t}\rvert \cos(\theta^{a\varnothing}_{i,j} + \delta^{\varnothing}_{i,j} - \delta^{a}_{i,j})$ $Q^{a}_{i,j,t} = \sum_{\varnothing=a,b,c} (\lvert V^{a}_{i,t}\rvert\lvert Y^{a\varnothing-n}_{i,j}\rvert\lvert V^{\varnothing}_{i,t}\rvert \sin(\theta^{a\varnothing}_{i,j} + \delta^{\varnothing}_{i,j} - \delta^{a}_{i,j})(\lvert V^{a}_{i,t}\rvert\lvert Y^{a\varnothing-n}_{i,j}\rvert\lvert V^{\varnothing}_{i,t}\rvert \sin(\theta^{a\varnothing}_{i,j} + \delta^{\varnothing}_{i,j} - \delta^{a}_{i,j})$ **where,** *a* **= active and reactive power calculated at each branch; i, j at time t in seconds** $P^{a}_{i,j,t}$ **and** $Q^{a}_{i,j,t}$ **= load nominal active and reactive power at each phase; ∅ = phase of line and δ = angle** $\Sigma P_i(k) \le P^*(k)$, **and** $Q(k) \le Q^*(k)$ Also, $S_i(k) = \sqrt{P_i^2(k) + Q_i^2(k)} \le S_i^*$ **where, P and Q active reactive power; ≤ =positive active and reactive power; ≥ =negative active and reactive power;** S_i^* **= total power; k = constant**	• Grey wolf optimization (GWO) • Technique of order of preferences by similarity of ideal solution (TOPSIS) • PSO • Ant colony optimization	[94-96]
EV Charging scheduling and charging- discharging cost minimization $Revenue_t = Revenue_{grid,t} - Revenue_{EVS,t}$ $Revenue_{grid,t} = p_{up,t} * P_{up,t} * \gamma t$ $Revenue_{EVS,t} = \gamma t * \sum_{i=1}^{t=Nt} M_{c,i} * W_{c,i} * P_{base} * P_{c,i,t}$ where, i-is index for EV;t-current time slot; $M_{c,\ i}$-price modifier charging EV $Revenue_{EV\ S,t}$**and**$Revenue_{grid,t}$ **− RevenuefromEVchargingandgridw. r. t(t);** $W_{c,i}$ **− Differentcharginglevelpriority** $P_{c,i,t}$ **− PowerusedtochargeEVs;** P_{base} **− BasepriceforEVchargingandpower;** γt **− Timeslot**	● PSO ● Fuzzy rule	[96-97]

incorporated into future IoT–IE platforms [99–102]. With the use of suitable optimization techniques, intelligent DC chargers can minimize power losses and grid load, and help with frequency regulation during peak hours, as well as automatic load management.

4.2. Limitations of charging–discharging methods

4.2.1. Necessary considerations for EV charging–discharging methods

Currently, the greatest barriers to the expansion of V2G are the low number of existing charging stations and a lack of enthusiasm by the energy market. With sufficient cooperative effort, energy suppliers, distribution system operators, and transmission system operators should be able to adapt and upgrade existing networks to expand the use of EVs. This is a challenging prospect, but with this challenge also comes opportunity. Charging and optimization techniques that will need to be developed will also help to reduce stress on the grid, improve frequency regulation, and reduce costs [103–105]. In terms of optimization techniques, the scenario of dispersed EVs together with centralized charging, leading to the existence of some sort of charging equilibrium, has yet to be discussed in the literature, but is a topic for more detailed study in the future.

4.2.2. Grid frequency issue due to EV charging

Control of frequency as the one of the most important index terms is a challenge to the modern power system. At present, these temporary disturbances can be controlled. However, in the future, increased use of EVs and renewable energy sources (wind and solar power) will lead to introduction of further periodic frequency disturbances, and if a means of dealing with these is not developed, the grid will be subject to the risk of power outages [104]. Therefore, large-scale penetration of EVs should be designed for use as a reservoir to fulfill the balance between electricity demand and supply. This is controlled by an electrical signal and also by grid frequency control mechanisms.

4.2.3. Optimization of EV charging–discharging control

As described in this paper, there are a number of optimal schemes with various optimization objectives. However, there is still a need for a complete multi-stacking optimization technique for EV charging. Application of such a technique should provide an optimal solution that maintains a charging–discharging equilibrium in a cost-effective and timely manner. It should be possible to optimize the control of EV charging using a combination of various optimization schemes with the traditional approach to optimization based on a meta-heuristic architecture.

4.2.4. V2G commercialization

Although the technology involved in the implementation of V2G is very costly and not particularly effective in generating revenue for EV owners, it will encourage new e-trading market trends and allow the incorporation of intermittent renewable energy sources such as wind and solar power, as well as accommodate unclear grid acceptance requirements. Fig. 11 illustrates future major challenges in V2G commercialization [106–108].

4.2.5. Challenges of adopting V2G in military applications

Military applications need an independent and efficient power supply. It must provide power for basic mission applications, as well as sufficient capacity to deal with emergencies. Troops would not want to find themselves suddenly under attack only to find that the batteries in their vehicles have been nearly depleted and too weak to supply power for cooking their lunch. In such a case where security of supply is much more critical than cost, a V2G framework may well be suitable [109].

In short, widespread research has been conducted into V2G integration. Realization of V2G technology requires the active involvement of EV owners with the existing infrastructure to reduce charging–discharging costs. Nevertheless, the inadequacy of the existing infrastructure, along with wider network privacy issues, imposes several limitations preventing the implementation of wireless battery V2G. Therefore, further information is required to develop new solutions, i.e., V2G priority-based optimization decisions should be introduced to maintain charging equilibrium (Table 4).

5. Conclusions

This paper has presented a comprehensive review of cutting-edge charging–discharging methods, optimization strategies, and optimization objectives. Additionally, various strategies for EV charging–-discharging modes in future V2G technologies have been described. Main concepts related to optimization approaches in V2G control, frequency control, and peak load management have been introduced, and performance of uncontrolled optimization has been discussed. In addition, an introduction to general charging–discharging planning, and operation concepts, as well as V2G integration of the aggregator within this framework, have been explored. Furthermore, the benefits and limitations of each method have been identified, and discussed. Finally, contemporary research issues related to hierarchical EV optimization strategies, multi-objective trends in multistage hierarchy techniques for present and future commercial scenarios in charging–discharging and potential directions for future research have been presented.

In the future, EVs can be interconnected to smart charging stations, which include smart DC-DC meters, smart charging equipment technology, vehicle-to-everything (V2X) communication, power conversion technology, and wireless DC-DC fast-charging infrastructure. Moreover, policy makers and government should look toward the particularly smart commercialization requirements of end users such as financing and local business models, commercial EV charging infrastructure, charge point infrastructure identification using Google maps, and strong government plans/policies. All of these will need deployment for commercial EV infrastructure. This contemporary work analyzed the features of V2G services, sorted out V2G services into different categories, summarized their respective characteristics, and then described a full scheme in view of the coexistent relationship between the grid and the growth of the EV, via a dynamic and evolving perspective.

A physical exchange shape and its corresponding administrative, multi-objective, multilevel hierarchy, and proper management measures were proposed. This paper also provides a new perspective on the inspection of V2G service, and formulates charging and discharging planning techniques, counting on energy trading services using e-trading platforms to serve end-user needs as a pivotal point for future research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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