A Review on Charging Control and Discharging Control of Plug-in Electric Vehicles in the Distribution Grid

Mekapati Suresh Reddy[1](✉), Nalin Behari Dev Choudhury[1],
Idamakanti Kasireddy[2], and Satyaki Biswas[1]

[1] National Institute of Technology Silchar, Assam, India
mekapatireddy@gmail.com, nalin@ee.nits.ac.in, biswassatyaki9@gmail.com
[2] Vishnu Institute of Technology, Bhimavaram, India
kasireddy.nit@gmail.com

Abstract. The potential of electric automobiles to discharge their batteries to the power grid (namely V2G technology) is discussed in this article as a way to lessen pollution and provide extra services, including income generation and grid reliance. The widespread use of electric cars might provide difficulties for the electrical infrastructure, such as power outages, overloading of transformers, and variations in bus voltage. The electrical grid and electric cars are connected through a middleman called an aggregator. This article investigates novel technologies and coordination mechanisms to control the discharging and charging of electric cars. In addition to that, Various optimization techniques are reviewed and also try to explain about challenges and future advances in the EV charging process and discharging process.

Keywords: EV Technology · Aggregator · V2G technology

1 Introduction

The use of electric vehicles (EVs) is crucial for reducing pollution and advancing the use of renewable energy sources. EVs may be a solution to environmental issues as the globe may experience oil scarcity in the future. The distribution grid can be stabilized with their assistance when used in conjunction with additional infrastructure, despite the fact that they might not be as successful when used alone as other technologies. With increasing numbers of electric vehicles (EVs) on the road, the distribution grid has to pay closer attention to how these vehicles are being charged and discharged. A component of the energy system, the distribution grid transports power from the transmission grid to users, including homes, businesses, and EV charging stations.

In order to coordinate EVs and manage their bi-directional charging process and discharging process processes, [1] proposed the idea of this EV aggregator. Electric vehicles (EVs) can assist in shifting energy use to periods when it is more affordable and less demanding by acting as an energy storage system using

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V2G technology. This can reduce power costs and benefit the grid. EVs will boost the grid and lower demand on the electricity grid by moving the load from peak hours to off-peak hours to take part in demand size management [2].

V2G is also one other option for faster and more efficient than other storage options, making it a good choice for managing the power grid. The objective of V2G systems is to coordinate the charging process and discharging process and to achieve a reduction in dependency on the grid and acts as another source rather than generating power at remote locations and power balance to avoid problems with the grid [3–5].

For the charging process, efficient EV coordination is essential. Potential problems may be reduced by implementing group decision-making and centralised coordination within the scope of Vehicle to Grid (V2G) technology. It can be challenging to establish V2G coordination in big power systems, though. The present infrastructure, which was created only for loads without EV integration in the grid, could have problems, and EV owners might not want to immediately give electricity to the grid. This may result in issues with grid dependability and battery efficiency. Research is required to develop transdisciplinary computational models that may address these problems. Recent research focuses on improving the functionality of V2G systems as well as strategies to use V2G for commercial advantage and the provision of additional services. Some researchers are working together to find answers. This makes studying how to control the charging process and discharging process of V2G systems an exciting area of study [6–10].

This study attempts to illustrate how EV charging process and discharging process operations may be managed by associations of EV owners (aggregators). It compares different methods for making decisions about charging process and discharging process and looks at ways to reduce the pressure on the grid.

The use of technology namely (V2G) Vehicle-to-Grid, is the main emphasis since it may help to increase power quality and efficiency while lowering the cost of energy (CoE). It talks about ways to implement this approach, taking into account the capacity of the existing infrastructure. The paper provides a lot of information about how to set up networks for different sizes of EV fleets to help to reduce the load on the electrical grid.

2 Exploring the Literature on Charging-Discharging Techniques for Electric Vehicle Aggregators

The charging process and discharging process techniques of EVs are classified into two types controlled and uncontrolled, respectively. The uncontrolled method described does not involve the transmission of any details about the system from the user to the grid operator, which can potentially lead to issues such as instability of the grid, poor power quality, operational inefficiencies, and uncertainties regarding the battery's state of charge. To analyze the effect on electric power systems and establish control over the charging process and discharging process of EVs, it is necessary to conduct load modeling of EV charging [7,8].

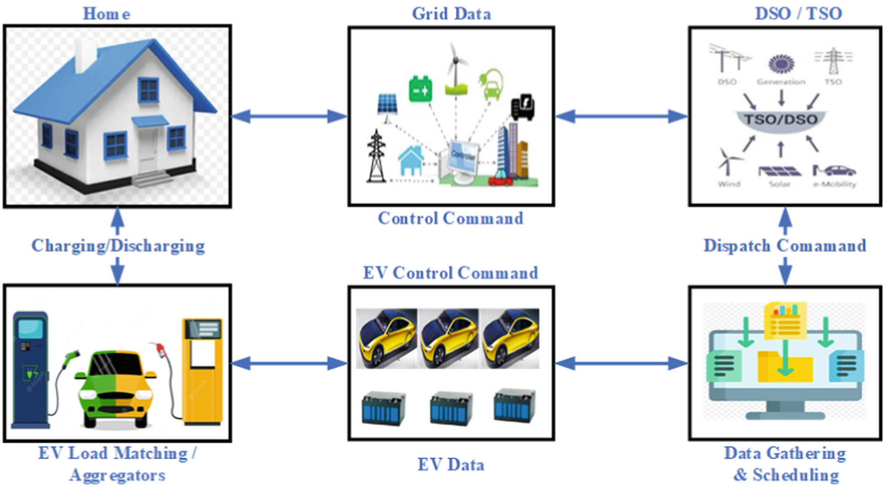

Fig. 1. EV Charge - Discharge using Control Center

The technique of controlled EV charging-discharging, also referred to as coordinated charging-discharging, has received significant attention in recent years. The coordinated and centrally regulated charge-discharge model is shown in Fig. 1, and it is carried out using a schematic algorithm. This method makes it easy for the person in charge to track and control how electric vehicles are charged and used. They can plan the schedule to avoid problems with electricity and make sure it works well for both the drivers and the company. The person in charge's goals includes making sure the system is working well and making improvements. Depending on how the system is controlled, there are different ways of charging process and discharging process using electric vehicles such as indirect control, intelligent control, bidirectional control, and multi-stage hierarchical control method and it has been referred to in Table 1.

Table 1. Control methods of charging process and discharging process

Method	Control	Suitable
Indirect control [11–15]	Energy cost, and Preventing grid overload	Small Scale EV
Intelligent control [17–27]	Reducing grid overload, Electricity costs and balancing the power grid	Large-scale EV
Bidirectional control [28–32]	EV as Energy storage to reduce peak load	Big-scale EV
Multi-stage hierarchical control [33–38]	EV owners, local aggregators, and a central coordinator	Large-scale EV

The Indirect Controlled Approach is a way of managing how electric vehicles are charged and used where there are no rules on how the charging should happen, such as how the charger is controlled, how long the charging takes, and how much the vehicle is charged.The emphasis is instead placed on minimizing grid overload and regulating extraneous variables like energy costs. EV owners make the charging schedule based on their own needs, while the operator's role is limited to providing information and incentives to influence their decisions. This approach is more straightforward and flexible but less effective in balancing the power grid. It may be used as a starting point for constructing more sophisticated techniques and is appropriate for small-scale EV charging stations [11–16].

The intelligent managed method is a technique for managing the charging process and discharging process of electric cars. In order to optimize the charging-discharging schedule, the operator actively manages the charging-discharging process. This approach is considered more complex than the Indirect Controlled Approach. Still, it can provide more accurate and efficient results, such as reducing grid overload, balancing the power grid, and reducing electricity costs. The operator uses techniques like real-time pricing, game theory, and optimization to determine the best charging-discharging schedule. This process is suitable for large-scale EVs charging systems and can significantly benefit the grid and EV owners. Based on the waiting times of EVs and their battery capacity, an individual EV-charging plan with a clever coordinating technique reduces overall charging costs. Based on the network's maximum daily power usage, the maximum number of electric cars that may be connected to the distribution grid at once is determined [17–27].

A method for managing the charging process and discharging process of EVs is named a bi-directional controlled approach (V2G). With this strategy, the EV is able to serve as energy storage at the dispersed end, enhancing the electric grid's capabilities and lowering peak demand. The grid and EV owners may benefit from additional benefits even though this strategy is thought to be more difficult than the indirect and intelligent controlled approaches. The V2G technology is appropriate for the large energy demands in the power distribution system, aids in managing the flow of power during variations in demand, and offers additional services to the power grid. This approach is appropriate for large-scale EV systems and advantageous to both the grid and EV owners [28–32].

An approach for organising the charging and usage of electric cars is the multistage hierarchical controlled technique.It incorporates a multi-level hierarchy of organisations (such as EV owners, local aggregators, and a central coordinator) making choices regarding charging process and discharging process, with each level of the hierarchy being in charge of various parts of coordination. The process is referred to as "multistage" because it entails a number of levels or phases of decision-making. For instance, at the beginning, EV owners will choose when to charge and discharge their cars. In the second step, local aggregators may plan the charging process and discharging processes of several EVs in a certain region. To guarantee the best possible functioning of the power grid as a whole, a central coordinator in the third stage coordinates the charging process and discharging process of EVs across several geographical locations. The approach is known as “hierarchical” because it uses a hierarchy of decision-making levels, with each level in charge of a distinct component of coordination. It is now feasible for EV collaboration to be more effective and efficient due to the increased alignment of the interests of numerous parties. The multistage hierarchical controlled charge-discharge approach may be applied in a variety of contexts. According to the demand and how the other groups of electric cars are being utilized, the power network may be adjusted using this technique [33–38].

3 Strategic Electric Vehicle Charging Management

The goal of this study is to compare various charging and operating techniques in order to determine the most effective strategy. It aims to improve the performance of electric cars by managing the way they use and store energy. This includes techniques like predicting the vehicle’s future energy needs and correctly managing power usage or finding ways to optimize the charging process and discharging process of the battery. The ultimate goal of our study is to increase the performance and range of EVs so that they are more extensively used. The study will review earlier research on EMS optimization for EVs and discuss the various methods and ideas proposed. The authors of the study stress that adding EVs to the electrical grid may have negative consequences. Effective optimisation methods for EV charging process and discharging process are provided in Table 2, which can be used to reduce these problems. This essay aims to provide a detailed analysis of various approaches and the effects they have on the grid.

Fuzzy logic-based two-stage charging is a technique for managing the charging of electric vehicles (EVs) in a way that balances the needs of EV owners and the power utility grid. The initial step of decision-making in this strategy is concerned with the EV’s urgent charging needs. This method uses fuzzy logic control to choose the appropriate charging rate while considering the driver’s preferences, the battery’s current state of charge, and factors like remaining driving distance into account. The second stage accounts for the grid’s and the EV’s long-term charging requirements, adjusting the charging schedule in accordance with the grid’s overall load, the time of day, the availability of renewable sources, and other elements. This approach is considered to be more advanced than others since it allows for a flexible and responsive charging procedure while taking into consideration the needs of both EV owners and the power grid. While the second stage enables real-time modifications to the charging schedule to match the changing demands of the power grid, the first stage uses fuzzy logic control to produce a more effective and precise charging process. This approach is appropriate for large-scale EV charging stations because it has several advantages, including cutting electricity prices, balancing the power grid, minimising grid overload, and increasing grid reliability [24,39–43].

Model Predictive Control (MPC), a technology used to control EV charging in the Real-time Charging approach, aims to strike a balance between the

Table 2. Optimizatin Techniques for EV charging process and discharging process

Approach	Optimization	Impact
Two-stage [24,39–43]	Fuzzy logic control	Reducing grid overload, balancing the power grid, lowering electricity costs, and improving grid reliability
Real-time [44–47]	Model Predictive Control	
Metaheuristic Control [48–51]	Advanced than others and used for Solving complex, Non-linear optimization Problems	
Heuristic Control [52–56]	Greedy algorithm, Dynamic Programming, Tabu search, Scatter search	

needs of EV owners and the power grid. MPC is a very advanced control technique that uses a mathematical model of the system in issue to predict its future behavior. In the context of EV charging, this technique uses a model of the grid and the EV battery to predict their future states. Based on this prediction, the algorithm optimizes the charging schedule to fulfill both the demands of the EV owner and the power grid, making it a more advanced charging strategy than others. It is a resource-use approach that is effective and better able to manage dynamic and unpredictable systems because of its flexibility and reactivity to the changing needs of the power grid in real-time. Large-scale EV charging systems can benefit from MPC because it allows the charging schedule to be changed to accommodate the changing needs of the power grid, reducing grid overload, balancing the power grid, lowering electricity costs, improving power grid reliability, and providing supplemental services to the grid [44–47].

A technique for managing how electric vehicles (EVs) charge and discharge that makes use of sophisticated optimisation algorithms based on metaheuristics is called metaheuristic charge-discharge control optimisation. Metaheuristics are a subset of optimisation algorithms that draw their inspiration from events in nature, such as animal behaviour or species development. The complicated, nonlinear optimisation issues that arise during the charging process and discharging process of EVs are ideally suited for these algorithms' solution. In this method, various metaheuristics are used to find the best charging process and discharging process schedule. The algorithm considers factors like the current state of the EVs battery, the remaining driving distance, the current demand on the grid, and the availability of renewable energy sources.

In comparison to previous charging-discharging techniques, the Metaheuristic Charge-Discharge Control Optimisation approach is seen to be more advanced since it enables a more adaptable and responsive charging-discharging process while taking the changing demands of the power grid and the EV owner into account. With the help of metaheuristics, the charging-discharging schedule may be modified in real-time to take into account the fluctuating demands of the power grid and lessen the burden of the EV on it. Due to its many benefits, including its capacity to reduce grid overload, balance the power grid, lower energy prices, increase power grid dependability, and provide ancillary services to the grid, this approach may be appropriate for large-scale EV charging systems [48–51].

An strategy for controlling the charging process and discharging process processes of electric vehicles (EVs) that makes use of cutting-edge optimisation algorithms based on heuristics is called the Heuristic Control Optimisation based Charge and Discharge Method. In contrast to mathematical proofs or comprehensive system knowledge, heuristics are optimisation algorithms that depend on practical knowledge, rules of thumb, and basic mathematical models. This approach uses a variety of heuristics, such as the greedy algorithm, tabu search, dynamic programming, scatter search, etc., to determine the best charging process and discharging process schedule for the EV, taking into account elements like the battery's current condition, the amount of remaining driving time, the current demand on the power grid, and the availability of renewable energy sources. This approach is more sophisticated than previous charging process and discharging process techniques since it enables a more adaptable and quick procedure for charging process and discharging process while taking into consideration the altering requirements of both the power grid and the EV owner. This technique is appropriate for large-scale EV charging systems since the use of heuristics allows the charging process and discharging process schedule to be changed in real-time. This strategy also has a number of positive effects, including lowering electricity prices, balancing the power system, increasing grid resilience, and delivering useful services to the grid [52–56].

4 New Advances and Challenges in EV Charging Process and Discharging Process Techniques

4.1 New Advances

As the market for electric vehicles expands, a number of attractive future research areas might increase the contribution of EVs to the grid. In one of these regions, there is no need for physical connections because wireless charging is used. As a result, EV owners won't need to plug in their cars to charge, which makes the process quicker and more practical. Because wireless charging pads may be deployed in a variety of settings, including parking garages, public areas, and even on the street, this may further enhance the number of charging alternatives for EV drivers [57–63].

Due to its capacity to shorten charging times and ease EV drivers' range anxiety, rapid charging for electric cars (EVs) has become more popular. This is accomplished by using high power levels of 50 kW to 350 kW, which may charge EVs up to 80% in as short as 30 min [64–66].

Lightweight PV cells that are mounted to the steel of all vehicle body panels facing upward will be used to wirelessly charge EV batteries when the vehicle is in motion or while it is parked outside. The best wireless charging method for increasing the range of electric vehicles (EVs) uses free, environmentally friendly solar energy to charge the batteries [67–70].

Another possible area for development is the application of blockchain technology in systems for voice-to-text communication. Due to its ability to provide secure, decentralised, and transparent transactions, blockchain technology is the greatest option for managing energy transfers between EVs and the grid. The efficiency and cost-effectiveness of energy trading between EV owners and energy providers may subsequently increase, and the security and transparency of energy exchange between EVs and the grid may be enhanced [71,72].

Concerns about privacy and security must be addressed as EVs become more integrated into the power system. With the rise of connected vehicles, there is a growing concern about the collection and sharing of personal data by EV manufacturers and energy providers. To handle these issues, clear rules and laws about how personal information is gathered, kept, and shared must be implemented [73–77].

Moreover, the optimization of smart charging is a crucial area that needs to be further developed to balance the energy demand of EVs owner and the distribution grid. Smart charging optimization involves managing the charging process and discharging process of EVs in a way that minimizes the impact on the power grid, reduces electricity costs, and improves the grid's reliability. This can be achieved through advanced control methods, optimization algorithms, and energy management systems [78–81].

Many electricity providers offer TOU rates, which provide lower rates during off-peak hours when electricity demand is lower. By charging their electric vehicle during off-peak hours, owners can take advantage of these lower rates and minimize their overall charging costs [82–86].

4.2 Challenges

The following are the challenges in EV charging process and discharging process Techniques [24,87–92].

- Availability and accessibility of charging infrastructure, particularly in remote areas or regions with limited resources. This can limit the use of electric vehicles for long-distance travel or in areas with insufficient charging options.
- When implementing EV charging-discharging methods, it is important to consider factors such as the ability to charge EVs, the expense of batteries and other parts, and the effect on the power grid are important factors to be considered. To ensure the safe and secure collection, storage, and exchange of personal data, privacy and security issues must also be taken into account.
- As EVs are driven on the road increases, there is a risk of grid frequency issues caused by the sudden injection of large amounts of power into the grid during periods of high charging demand. This can give quality issues such as flicker, distortion, and voltage sag, which can negatively impact the performance of other devices connected to the grid.
- Advanced methods for EV charging and discharge optimisation must be used in order to efficiently manage the EVs (electric vehicles) being integrated into the distribution grid. In order to lessen the load on the grid and increase

efficiency, this involves using control techniques, optimisation algorithms, and energy management systems.
- The need to commercialise V2G technology is growing as interest in the technology rises. designing a market for V2G energy and designing a business model that will enable energy companies to offer V2G services are two examples of what is involved.
- With the use of the advantage of government incentives, such as rebates and tax credits which can helps to reduce the upfront cost of purchasing an electric vehicle or installing a home charging station. These incentives can also help to offset the long-term cost of owning and operating an electric vehicle.
- Pricing thing also needs to think about dynamic pricing and cost minimization. One challenge is the structure of electricity rates. Some utility companies offer variable rates that fluctuate throughout the day, which can make it difficult for electric vehicle owners to predict the cost of charging their vehicles. In addition to that, some utilities charge higher rates during peak usage times, which can coincide with the times when electric vehicle owners need to charge their vehicles
- Adoption of V2G technology in military applications poses several challenges, such as the lack of standardization in the EVs charging process and discharging process technologies, the high cost of batteries and other EV components, and the lack of widespread EV charging infrastructure. Additionally, the military's unique requirements for mobility, reliability, and security present additional challenges for V2G adoption.

5 Conclusion

This article offers a thorough analysis of the latest charging process and discharging process techniques, optimization methodologies, and objectives for electric vehicles. It examines various approaches to charging process and discharging process electric vehicles in upcoming Vehicle-to-Grid systems, including optimization techniques in V2G control, maintaining power grid stability, and managing high energy demand. The paper focuses on the role of an aggregator in V2G integration, current research on hierarchical EV optimization methods, and emerging multi-objective techniques for multistage hierarchy in charging process and discharging process for commercial use now and in the future. The article also introduces the basic concepts of charging-discharging planning and operation and suggests new advances in the areas for future research.

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