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Chapter 7

Control Strategies for Smart Charging and Discharging of Plug-In Electric Vehicles

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Abstract

This chapter aims to provide an overview of the plug-in electric vehicle (PEV) charging and discharging strategies in the electric power system and the smart cities, as well as an application benefiting both consumers and power utility. The electric vehicle technology will be introduced. Then, the main impacts, benefits and challenges related to this technology will be discussed. Following, the role of the vehicles in smart cities will be presented. Next, the major methods and strategies for charging and discharging of plug-in electric vehicles available in the literature will be described. Finally, a new strategy for the intelligent charging and discharging of electric vehicles will be presented, which aims to benefit the consumer and the power utility.

Keywords: plug-in electric vehicles, smart charging and discharging, control strategies, smart grid, vehicle-to-grid

1. Introduction

The automotive industry is growing rapidly, and the vehicles powered by fossil fuels make up the largest share of this sector. However, environment concerns have also increased considerably, raising questions about the harmful effects of pollutants emitted by these vehicles.

The plug-in electric vehicles (PEVs) represent an alternative to reduce the emission of pollutants from vehicles powered by fossil fuels. These vehicles are propelled by electric motors powered by the energy stored in their batteries. Thus, to charge the battery, it is necessary to connect it to an electrical outlet.

Despite the charging need, a PEV can also be used to provide ancillary services to the power system, aiming the grid benefit. Such vehicles are abbreviated as V2G, from vehicle-to-grid, and, as major examples, are able to provide regulation, renewable sources support and distribution losses minimization.

Putting a car to charge its battery will cause it to act as a load to the power grid. Then, if a significant amount of electric vehicles starts to request charging at the same time, the system may suffer certain complications. Given so, it is important to make a coordinated charging control of the electric vehicles.

With the previous approaches that are further discussed, the PEV plays an important role in smart cities. In this sense, this chapter presents an overview of the PEV charging and discharging strategies in the electric power system and the smart cities. An application that benefits both consumer and power utility is presented as well. In addition, the main impacts and benefits brought up from the PEV charging and discharging are discussed. The challenges associated to this technology are showed.

First, the electric vehicle technology is presented, and distinction and comparison between major types are made. In the following section, the main impacts, benefits and challenges related to this technology are presented. Furthermore, the role of plug-in electric vehicles in smart cities is exposed. Then, the major methods and strategies for the PEVs charging and discharging are presented. Finally, a new strategy for smart PEV charging is presented, which aims to benefit both the consumer and the power utility.

2. Electric vehicle technology

The EVs are vehicles propelled by electric motors, the latter being powered by electrical energy stored in energy storage devices, such as batteries and supercapacitors. Generally, they are classified into three distinct groups: battery electric vehicle (BEV), hybrid electric vehicle (HEV) and plug-in hybrid electric vehicle (PHEV). A broader classification, called plug-in electric vehicles (PEVs), is commonly used to comprise the BEVs and PHEVs, because both types need to connect to the power grid to charge their batteries.

Battery electric vehicles, also known as purely electric, are powered by electric motors that receive electricity stored in a battery. The battery is charged through a power grid connection or through replacing it for another one already charged. The HEVs combine the previous vehicles with conventional ones powered by internal combustion engines (ICEs), with the first allowing higher efficiency and fuel economy, and the latter providing greater driving autonomy. The batteries of these vehicles are charged by regenerative brake and by the combustion engine. Finally, the plug-in hybrid electric vehicle has the same electric and combustion motors

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combination of the HEV, but the battery can be charged by connecting the PHEV in the power grid in addition to regenerative braking and combustion engine [1].

In terms of energy consumption [2], it was proved that BEVs and HEVs provide higher fuel economy when compared to internal combustion vehicles, including the case when the electricity is generated from petroleum-derived resources. Besides that, the use of HEVs and BEVs can lead to greenhouse gas emission reduction. Despite the fuel economy increase, the global reliability of HEVs and PHEVs is lower when compared to combustion engine vehicles, as the architecture of the first two is more complex than the latter, given that numerous subsystems are involved [3]. **Table 1** shows some comparisons between BEV, HEV and PHEV, including: the propulsion engine type that they have, the kind of energy storage system and from where it comes, and the major aspects that differentiate them and the main problems faced.

Characteristics	BEV	HEV and PHEV
Propulsion	• Electric motor	• Electric motor • Internal combustion engine (ICE)
Energy storage subsystem	• Battery • Supercapacitor	• Battery • Supercapacitor • Fossil or alternative fuels
Energy source and infrastructure	• Power grid charging facilities	• Gas station • Power grid charging facilities (for PHEV)
Main observations	• Zero local emissions • High energy efficiency • Fossil fuel independent • Short driving range • High initial price	• Zero local emissions • High fuel economy • Fossil fuel dependent • Long driving range • Higher cost than ICE vehicles
Main issues	• Battery storage capacity • Charging stations • Cost • Battery lifetime	• Battery storage • Control, optimization and management of different energy sources

Adapted with permission from Chan et al. [4].

Table 1. Major comparisons between BEV, HEV and PHEV.

By not emitting locally harmful gases, the purely electric vehicles appear as an ideal solution for dealing with the energy crisis and global warming. However, due to the high initial investment, low driving range and long charging time, the BEVs still show themselves limited for large commercial incorporation. The HEVs are presented as a viable option to overcome the previous limitations, having expressive autonomy, but excessively emitting pollutants. Thus, seeking to maximize the driving autonomy of the vehicle along with minimizing pollutant emissions, PHEVs appear as the best alternative, overlapping the HEVs.

Combining the benefits and prospects mentioned above, the PEVs are presented as a new highly promising technology with great anticipation to play a major role in the power and automotive industries in the forthcoming decades. However, attention should be paid to the fact that the PEV can act both as a load and power source to the power grid. The first case occurs when the PEV is charging its batteries, that is, consuming power from the grid. The second case can happen with the vehicle communicating with the grid to act on its benefits, either providing active energy or controlling its charging rate. This type of concept is called vehicle-to-grid or V2G.

3. The PEV role in smart cities

The urban energy systems modernization, combined with the current requirements to meet the demand growth, contributes to the creation of a new approach for managing the electric power system, called smart grids. The smart grids seek to address modern energetic challenges in a city, using information technology (IT), automation and communication. In this way, the optimization of the power grid operation is aimed, allowing integration of equipments to the grid and including alternative sources of electric power generation, in addition to online data gathering of energy demand and supply to manage peak loads.

The integration of PEVs in the electricity distribution network is one of the major technological developments brought by smart grids, as it provides the application of charging and discharging control strategies in the vehicles to achieve a given goal.

Among the main benefits of the charging and discharging of PEVs, the following are highlighted:

- Greater integration of the PEVs in the power grid
- Reduction of pollutants in cities
- Cost reduction
- Smart charging according to consumer's need
- Power losses minimization
- Peak load reduction
- Profit maximization
- Energy demand management
- Energy resources management

- Greater integration of renewable energy sources
- Higher reliability and efficiency of the power system
- Power system operation optimization
- Among others

4. Impacts and benefits of PEV charging and discharging and challenges that prevent this technology diffusion

This section presents the key impacts, benefits and challenges that prevent the diffusion of the plug-in electric vehicle technology. In the first section, the impacts that the PEV charging without coordination can cause to the power grid are presented. Following, the main benefits originated from the vehicles, in environmental terms, ancillary services that can be provided to the grid and other benefits are exposed. Finally, the third section presents the key challenges linked to the low implementation of the vehicles under study.

4.1. PEV charging impacts

The plug-in electric vehicle charging is cyclical, variable and somewhat unpredictable, as it acts as a load to the power grid. If a significant amount of PEVs requests energy at the same time and if a proper coordination is not used, the charging process may randomly occur both in time and in space. This may bring certain complications to the electrical grid, particularly at peak periods. This is a very likely assumption, since the PEV owners could arrive at home after work and begin to charge the vehicles during a period of high demand.

A typical PEV under charging more than doubles the average load of a household, drastically changing the consumer's load curve. In addition, the PEV charge without coordination can increase the load at peak times and cause local problems in distribution networks, as well as increase energy losses and voltage deviations, compromising the power quality [5–9]. Another aspect is that they can also lead to conductor and distribution transformer overload and reduce the grid reliability and stability.

In the financial context, an increase in consumers' electricity bill is pointed out, due to the demand growth caused by the vehicle charging process, as well as capital expenditures, resulted from the need to reinforce the grid and also from the energy loss costs [10, 11].

The plug-in electric vehicle also affects the electrical power system reliability and efficiency. For instance, when requesting charging during peak hours, some fast response power plants with relatively low efficiency can be activated to meet the growing demand [12]. Therefore, the generation system global efficiency decreases. In addition, the reliability of these power plants is also low, reducing the overall system reliability.

Briefly, PEV charging without proper coordination can increase the consumers' average load, causing undesirable consumption peaks. Furthermore, it can overload transformers and violate transmission lines thermal limits. In addition, it can cause the dispatch of expensive and highly polluting power plants to meet the growing demand. Voltage deviations and reduction in reliability and efficiency may also arise. Finally, the electricity bill may increase and the system stability may be committed.

However, despite the aforementioned impacts, PEVs can also aid the electric power system through the implementation of effective measures to manage the loading. The following section presents these benefits from an environmental point of view and the possible advantages for the power grid.

4.2. PEV benefits

Plug-in electric vehicles can also create opportunities to the electricity sector if a planned and coordinated control strategy is applied. The benefits can be in environmental terms, through ancillary services provision and other benefits not included in the foregoing. The following three subsections feature, respectively, these benefits according to the literature.

4.2.1. Environmental benefits

CO_2 emissions can drop dramatically if the PEVs replace the conventional internal combustion vehicles. In addition, the use of PEVs can directly reduce the emission of greenhouse gases. The analysis made by Ramteen and Denholm [13] shows that the PHEV can lower pollutant emissions associated with the automotive industry and, adopting the V2G concept, these reductions can be much more significant. Much of this decrease is dictated by the conditions in which the vehicle will be charged, since emissions can be significantly reduced if pollutant sources are used in power generation.

In scenarios with low, medium and high penetration of PEVs, a significant reduction in greenhouse gases can be achieved, lowering the automotive industry reliance on fossil fuels. The work by Samaras and Meisterling [14] obtained a 32% greenhouse gas reduction with the inclusion of PHEVs, compared to conventional ones. However, if the electric power generation is not derived from a source with low pollution rate, this reduction becomes short.

It is evident that the plug-in electric vehicle adoption will significantly reduce the pollutant emission into the atmosphere when compared to traditional vehicles powered by fossil fuels. However, one should be careful when comparing the global emissions reduction that includes pollution generated from power plants used to meet the demand. In this case, the reduction may not be as significant, and even worse in some scenarios. Allied to these reductions, PEVs can also benefit the electric system through the provision of ancillary services, as will be seen in the next subsection.

4.2.2. Ancillary services

In electric power systems, ancillary services are the services necessary to maintain the system reliability and the balance between supply and demand and also aid the operation. Among

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these services, the frequency control, voltage control, spinning reserve, peak load leveling, assistance in starting emergency generators (black start), support for reactive power and active loss compensation are highlighted.

The plug-in electric vehicle combined in the V2G concept can work for the grid benefit by providing various ancillary services. However, a single electric vehicle unit has limited capacity to represent a significant benefit to the grid. Thus, the PEVs are usually grouped in fleets or, as [15] defines and explains, in aggregators.

The aggregator is an entity that herds several PEVs to generate a significant, beneficial and effective impact in the power grid, acting as an interface between the system operator, usually the distribution management system (DMS), and the fleet connected. Therefore, it enables the vehicle participation in the electricity market. It behaves as a decision-maker, having an optimized strategy to effectively act as generation/storage, being capable to provide ancillary services to the grid or to operate as a controllable load to be charged in the most beneficial manner for the system.

The basic scheme of communication between the aggregator and the electric power system is illustrated in **Figure 1**, where the electricity flows in a single direction from generating plants to consumers. Between the PEVs and the aggregator, the energy flow is bidirectional, the latter having control over the charging or discharging of the first. The ancillary services necessary for the grid and that can be performed by the PEV fleet are remotely requested by the system operator, characterizing the energy and communication flows in both directions.

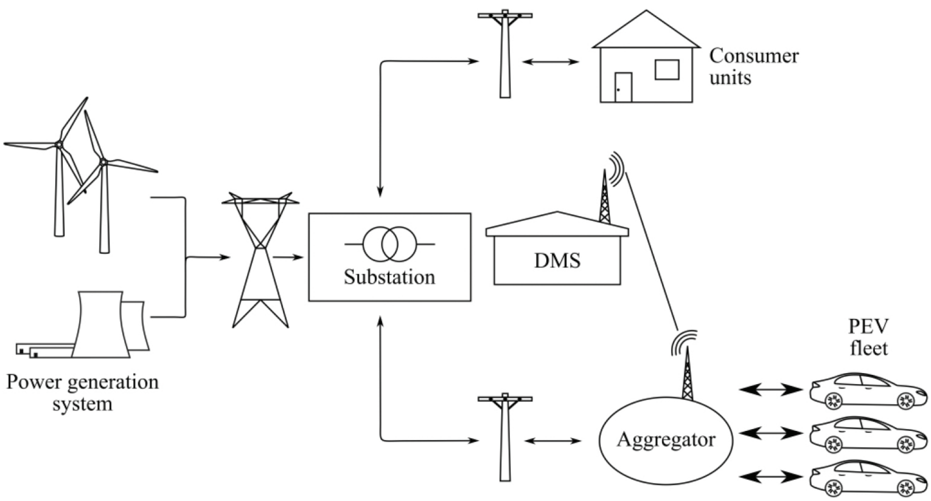

Figure 1. Illustrative scheme of the communication between the aggregator and the electrical power system [16].

By the V2G concept, the PEVs can be used to provide the following ancillary services for the electric power system:

- Frequency and voltage regulation [16, 17]
- Transient stability improvement [18]
- Peak shaving [19, 20]
- Valley filling [19]
- Spinning reserve [20, 21]
- Power flow optimization [20]
- Power quality improvement [20]

Briefly, plug-in electric vehicles can provide ancillary services of frequency and voltage regulation through V2G concept, and they have been proved to be economically feasible. Furthermore, they can also be used to improve transient stability, manage peak load, fill the consumption load valleys, serve as spinning reserves, optimally manage the power flow and improve the power quality. However, in order to have a share in the market and provide significant services, vehicles are usually concentrated in aggregators, which act as an interface between the fleet and the system operator.

In addition to the already mentioned benefits, the next subsection introduces a modern and undergoing study topic about the use of electric vehicles to support the renewable energy entry and other benefits that are not considered as ancillary services.

4.2.3. Further benefits

The use of EV fleet may considerably increase the demand forecast accuracy. To do so, the vehicle fleet acts as a variable power storage system, absorbing prediction errors and, consequently, reducing the cost to be paid for them. This type of benefit is only achieved from a certain EV penetration level [22].

By combining the photovoltaic solar energy generation with the PEV charging, it is possible to maximize the benefits and minimize the costs, through high penetrations of the two technologies in the electricity sector, what reduces emissions from the EV charging at peak times. The first provides power during peak midday in summer, reducing the need for additional generation capacity. The second absorbs energy from photovoltaic plants that would be wasted due to low demand in the spring [23, 24].

The V2G concept increases the flexibility of the grid to a better use of intermittent renewable energy resources, acting in a way to increase the demand forecast accuracy as a variable source of storage.

The PEV benefits to the electric power system have been proven by several studies. However, some challenges are still imposed to the full accomplishment of the benefits. Next, some of the challenges that prevent the PEVs and V2G concept diffusion are presented.

4.3. Challenges of the V2G concept

Despite the many benefits from the PEV application in the V2G concept, some impediments and barriers still hinder its implementation, as shown below.

In terms of the vehicle battery, its use to provide ancillary services will reduce its lifespan due to the extra charge and discharge cycles. To estimate a cost related to this degradation is an interesting feature to incorporate in the economic viability calculus, but this is a complex task, given that the technologies are still under development. Reference [15] states that through intelligent control, charging time and optimal energy flow it is possible to minimize the additional battery degradation rate because of ancillary services. Still, there is a major barrier to achieve this intelligent control.

A secure communication among the aggregator, a large number of PEVs and the system operator must be ensured, where a reliable bidirectional infrastructure must exist. In addition, sensors and smart metering should be installed. The charging energy growing demand may require, in some cases, expansion of the generation capacity, as mentioned previously, since the PEV charging process may cause considerable impact on distribution equipments, overloading them. All these points converge to the need for significant investments in the electrical power system to meet the changes.

Other commonly presented challenges that prevent the PEV diffusion are as follows: the high initial investment cost compared with conventional vehicles, their low autonomy, the resistance that the automotive and oil industries may offer, as well as consumer acceptance of this new technology.

5. Strategies and methods for PEV charging and discharging

The plug-in electric vehicle charging can be coordinated or uncoordinated. In uncoordinated charging, there is no control over the charge rate of the PEVs. They begin to charge immediately when plugged in or after a predetermined time and only cease charging when the battery is fully charged or the vehicle is disconnected from the grid. The coordinated charging applies a type of strategy that controls the PEV charging.

Coordinated charging control can only be done to limit or define the PEV charging rate or through active power injection. The first case is characterized by unidirectional power flow (from the grid to the vehicle), and the second case is characterized by bidirectional flow (from the network to the vehicle and vehicle to the network). It is through coordinated charging that the impacts and benefits of the previous section can be mitigated and availed.

The unidirectional power flow is only used to charge the PEV battery, having a low cost of implementation. In this regard, the battery presents no additional degradation, given that it does not discharge by supplying power to the grid. For this type of flow, only one electrical connection to the power grid is required. Among the main benefits, it includes the possibility of applying a simple control for coordination, which facilitates the mitigation of impacts on the network, achieved by limiting the charging rate.

The bidirectional power flow involves higher costs than the previous one, but can be used both for charging control and supplying energy to the grid when required. However, due to the discharge cycles, the battery undergoes additional degradation. For its implementation, it is necessary to have bidirectional communication and smart metering deployed. Thus, this type of power flow allows providing ancillary services to the grid and renewable energy sources entry support. **Table 2** lists some points of comparison between unidirectional and bidirectional power flow.

	Unidirectional power flow	Bidirectional power flow
Power flow	• Power flow in one direction • Only PEV charging	• Power flow in two directions • PEV charging and discharging
Cost	• Low	• High
Battery effect	• No extra degradation	• Extra degradation due to battery discharge
Electrical distribution system	• No need for investment and modernization	• Investment and modernization required
Requirements and challenges	• Power grid connection	• Bidirectional communication and power grid connection • Smart and suitable metering and sensors • Considerable information exchange • Extra cost and investments • Energy losses • Device stress
Benefits	• Simplify power grid connections • Simple control and management • Provide services based in the adjustmentof charging rates • Supplies or absorbs reactive energy without discharging the battery	• Ancillary services • Active power regulation and voltage and frequency stabilization • Spinning reserves • Reactive power support • Peak shaving • Valley filling • Energy balance • Harmonic filtering • Renewable sources entry support

Adapted with permission from Yilmaz and Krein [25].

Table 2. Comparisons between unidirectional and bidirectional power flow.

The coordinated charging strategies can be decentralized or centralized. In the decentralized or distributed charging, the PEV owner decides when he will charge the battery. In the centralized, a central entity gathers information about the grid, load and generation, being able to decide and control the charging or discharging of a PEV fleet. **Figure 2** shows a flow chart with the strategies that descend from the PEV charging.

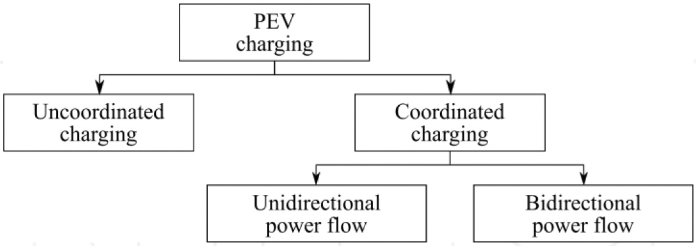

Figure 2. Different strategies arising from PEV charging and discharging.

The two following sections present some methods for uncoordinated and coordinated PEV charging. Each method is based on certain assumptions regarding the available infrastructure, charging rates and duration, status, size, technology and energy capacity of the battery, PEV type and mathematical approaches.

5.1. Uncoordinated charging

Strategies to uncoordinated charging are scarce, given the facts that do not result in significant benefits for the grid. They are directly dictated by the users, not being possible to carry out coordination and control to act in favor of the electric power system.

The first uncoordinated charging strategy happens when the PEVs start to charge immediately when connected or after a certain delay set by the owner. In the first case, the user has no incentive or information necessary to make a smart charging in favor of the power system. In the second case, he has information and the delay allows the charging to happen in periods outside the peak time. This strategy often happens because users come home after work and connect their vehicles to charge so the battery is fully charged the next day [26].

Even in an uncoordinated way, but with an incentive for the PEV owners to take action, it is common to use two electricity prices. A more expensive one is applied during peak periods and a cheaper off-peak. Thus, it is assumed that the users of the double tariff will charge the vehicles during low demand period where the value to be paid for the energy is lower.

It is noteworthy that with this type of charging strategy there is no control of the charging rate and much less of the energy flow from the vehicle to the grid. Impact minimization can be achieved by encouraging the PEVs to charge during off-peak periods through the use of differentiated tariffs. Coordinated charging is the solution to this problem, and the next section presents some of the major strategies, methods and approaches available in the literature.

5.2. Coordinated charging and discharging

The researches in methods and strategies of coordinated charging and discharging for the power grid benefit have grown significantly in recent years, each one considering different approaches with diversified assumptions. Some of the most relevant alternatives are presented below, separated into two subsections. At first, unidirectional power flow is considered and secondly, the two-way flow is taken into account.

5.2.1. Unidirectional power flow

Among the main objectives adopted for PEV coordinated charge with unidirectional power flow, the following are highlighted:

- Minimize energy losses [26–28]
- Frequency regulation [29]
- Maximize aggregator's profit [30, 31]
- Minimize charging cost [28, 32–35]
- Reduce voltage deviations [36]
- Reduce power grid overload [36]
- Minimize the deviation between energy bought in the market and energy consumed by the PEVs [37]
- Prevent the electricity distribution network congestion [38]
- Reduce peak load [31, 39]
- Maximize energy delivered to the PEVs [28]

The major techniques used to solve the coordinated charging problem with unidirectional power flow are as follows:

- Quadratic programming [26]
- Dynamic programming [26, 29, 40]
- Heuristic algorithm [30]
- Optimized selection [30]
- Linear programming [32, 38]
- Search techniques [33]
- Neural networks [33]
- Artificial immune systems (AISs) [36]
- Nonlinear programming [27]

- Evolutionary programming [34]
- Fuzzy linear programming [31]
- Fuzzy discrete particle swarm optimization [28]
- Fuzzy genetic algorithm [28]

5.2.2. Bidirectional power flow

The main objectives addressed by authors for the PEV charging and discharging considering the bidirectional power flow are as follows:

- Minimize energy costs [41–43]
- Power regulation [41]
- Improve the photovoltaic generation predictability [44]
- Maximize the satisfaction of vehicle owners [45]
- Minimize the electric power system operational cost [45, 46]
- Limit carbon emissions [46]
- Minimize power mismatch on the grid [47]
- Reduce peak demand [48]
- Increase the electrical system reliability [43]
- Frequency regulation [49]

Among the techniques used to solve the charging and discharging problem with bidirectional power flow, the following are listed:

- Sequential quadratic programming [41]
- Particle swarm optimization [44]
- Mixed-integer quadratic programming [42]
- Mixed-integer linear programming [46]
- Linear programming [47]
- Self-adaptive evolutionary algorithm based on symbiotic organism search [43]

In the simulations, the profiles and load characteristics due to PEV insertion were defined in various ways. Among them, it is highlighted the use of fuzzy expert system, deterministic programming, stochastic programming, mixed-integer quadratic programming, Monte Carlo simulation and fuzzy C-means clustering.

The analyzed methods approached both centralized and decentralized charge and discharge. Different interfaces were created to relate with the PEVs, such as the aggregator, the distribution system operator and each vehicle unit.

6. A new charging control strategy considering consumer's will

The PEV will only be used to assist the power grid if the consumer is willing to provide the automobile for this purpose. Therefore, besides taking into account the current condition of the power grid, one must consider the consumer's requirements to have the vehicle fully charged within the connection time.

Thus, it is defined that the vehicle owner must enter a priority in which he wants the battery to be fully filled within the connection time to charge. In this context, a low value indicates that he is willing to provide its PEV to the grid and the battery may not be fully charged after disconnection. A high priority ensures full charge, not providing the vehicle to benefit the power system. As this is information set by the consumer and it is uncertain to the system, the priority insertion is performed by applying a fuzzy logic-based system, given that it allows the incorporation of human knowledge in mathematical models.

This priority entered by the consumer is the major contribution of this strategy, as the studies available in the literature do not consider this type of information in the charging rate control.

Considering the two centralized and decentralized approaches of the coordinated charging as defined before, this study represents a combination of both. The centralized approach is considered because the aggregator gathers information about the grid, load and generation, and sends command to each PEV. The second approach is taken into account by the fact that it includes the will of the PEV owner to have a fully charged battery according to his need.

The unidirectional power flow was verified to be the most feasible when considering the battery degradation, so this type of flow is considered. In addition, the implementation of two-way power flow is further than the one-way, given the fact that the grid will have to be improved and the electricity market will have to undergo adjustments.

The optimization goal is to minimize the energy losses in the power grid. The applied optimization technique to solve this problem is the heuristic search for generating and testing or the exhaustive search.

The proposed system has two main interfaces: the distribution management system (DMS) and the aggregator. The aggregator is responsible for gathering PEVs and consumers' information, receiving a power value from the DMS to distribute between vehicles meeting the priorities. The DMS acts to meet the requirements of all aggregators under its command, determining a power value that optimizes the operation of the network.

The general understanding of the proposed charging control system for the benefit of the electric power system can be extracted from **Figure 3**, illustrating the exchange of information between the DMS and an aggregator.

Once connected to the network for charging, the PEV reports to the aggregator with the following data: (1) its initial charge (SOC_i), representing the charging state of the battery at the moment; (2) the connection starting time (t_i), indicating the time that it was connected to charge and (3) the battery capacity B_{cap}, that is the energy the battery can store.

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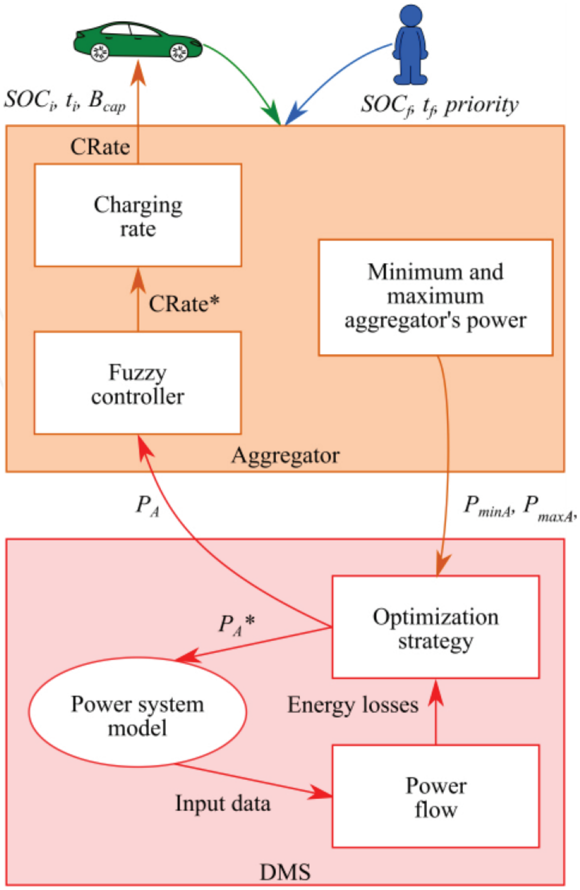

Figure 3. General architecture of the proposed charging control system considering the consumer's will. *CRate* – charging rate; SOC_i – initial state of charge; SOC_f – final state of charge; t_i – PEV connection time; t_f – PEV inserted disconnection time; B_{cap} – battery capacity; P_{minA} – minimum aggregator power; P_{maxA} – maximum aggregator power; P_A – available power to aggregator.

Still in the connection, the vehicle owner also informs three data to the aggregator: (1) the final state of charge (SOC_f) that he wants the battery to be charged; (2) the time he wants the battery to be charged (t_f) and (3) the *priority* in which he wants its battery to be fully charged to the final state of charge in the connection time to the grid.

Having received the six input variables from each vehicle in the fleet, the aggregator determines the minimum and maximum powers that should be received from the system to meet a minimum or total percentage of the vehicle charges in the stipulated time.

Each aggregator notifies the DMS with their minimum and maximum powers, respectively, P_{minA} and P_{maxA}. The DMS that has information about the electric power system, along with the aggregators' power, performs the energy distribution searching for an optimal way to minimize or maximize a certain goal.

The DMS returns the optimal power calculated to each aggregator within the range limited by the latter. The aggregator, based on a fuzzy controller acting on its interface, calculates each PEV charging rate, returning the value so that the vehicles can be charged.

The index * in the variables P_A and *CRate* indicates the initial and intermediate values for both the power available to the aggregator and charging rate. They are used in the proposed system but are not the final values to be returned. That is, P_A* and *CRate** are part of the calculation, but only P_A is passed on to the aggregator to be distributed among the PEVs and only *CRate* indicates with which rate each vehicle will charge.

7. Conclusions

This chapter presented the importance of plug-in electric vehicles for the electric power system and the smart cities. Faced with the characteristics presented, the main strategies and methods of PEV charging and discharging control available in the literature were showed.

Out of the different methods searched, it was verified that they are based on certain assumptions regarding the available infrastructure, PEV type, rates, charging duration, status, size, technology and energy capacity of the battery, as well as mathematical approaches. Among the methods, more attention is being given to the coordinated charging with unidirectional power flow, and the same is closer to be currently widely applied in smart grids and smart cities. This occurs given the fact that the method only controls PEV charging rate seeking benefits, such as reducing pollutants or cost. In addition, the current infrastructure does not need significant reinforcements.

Finally, a new strategy for PEV smart charging is presented, where the advantages of the application and its role in smart cities are presented. The proposed methodology aids aggregators to reduce the impact on the grid, since the charging is carried out in a planned and controlled way. Application of this methodology can also help evaluating how electric vehicles can contribute to ancillary services, and which of these services would be most appropriate for the participation of PEVs.

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