Hierarchical electric vehicles management in parking lots.

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***Abstract*— Since the beginning of the XXI century, it has been a significant increase in electric vehicles (EV) due to increased environmental concerns. Thus, the automotive industry faced a considerable challenge to develop efforts to adapt to the new reality, changing its production of vehicles from combustion engines to electric-powered vehicles. This paradigm shift brings numerous fundamental obstacles to today's society. The infrastructures that currently support electric car charging are not prepared to keep up with the expected increase in the demand for electricity consumption. It is known that electric vehicles spend most of their time parked, and this is the best opportunity to charge them. Thus, there is a real need to optimize the use of energy in parking lots. The following study aims to develop a system to manage the use of energy in car parks to solve the lack of capacity of the network itself to support the power demanded with the increased use of electric vehicles. Therefore, the system assumes that the vehicles remain parked and can be charged at any time, charging them in an intelligent and coordinated way. This system consists of a hierarchical management system with two optimization levels responsible for managing the charging of the vehicles and the parking of the same. The first level operates in a future timeline, and the second level operates in real-time.**

Keywords*— *Electric vehicles, Parking lots, Hierarchical systems, vehicle-to-grid

I. INTRODUCTION

Currently, fossil fuels (oil, gas, and coal) are the primary energy sources in the final consumption of the most diverse sectors worldwide. Consequently, the high dependence on fossil fuels has led to an increased of carbon dioxide (CO2) emissions, causing structural changes in the planet's climate. One of the goals defined by governments is the decarbonization of the transport sector[1]. This sector is essential for developing economies and increasing the population´s life quality as it enables the transportation of people and the distribution of goods and raw materials [2]. However, it is primarily responsible for the enormous dependence on fossil fuels, representing 30% of the final consumption of this non-renewable natural resource.

Electric vehicles thus emerge as the main alternative to vehicles with a combustion engine and have been affirmed as one of the most effective solutions [3]. In recent years, there has been a significant increase in their production and commercialization, as well as the development and implementation of structures to create conditions for their charging.

A crucial point in addressing this problem is that most of a car's lifetime is parked, which is the best opportunity to charge the vehicles. Today, most users of electric vehicles can charge them at their homes. However, when these become dominant in the car market, it will be necessary to create a network of chargers with easy access for all since 70% of the population does not have access to a private garage. Thus, parking lots assume a fundamental and essential role [4]. To this end, it is necessary to implement charging stations in parks on commercial surfaces, schools, business buildings, and residential areas to have easy access to a charging station.

Due to the infrastructures that support the parking lots not being prepared, the grid is not prepared to support the power associated with each charger. So, renewing the circuits and increasing the capacity of the parking lots is not a viable solution by itself, but it must be combined with other tools [5]. One possibility to mitigate this problem is the adoption of mechanisms that control the charging time, and the power supplied to each vehicle, allowing to control the peaks of energy demand, meet the needs of each user and minimize economic costs.

This master's thesis contributes to the literature by proposing the integration of the logistics management of parking lots with the management of charging for vehicles parked in them. In this way, the study presents a hierarchical management system composed of two optimization levels. Thus, this master's thesis contributes.

- A mathematical formulation of a methodology for the "Day-ahead" optimization of electric vehicle charging and parking of the same, knowing the duration of the parking and the users' energy needs for the next trip. The objective of this controller is to satisfy the owners of electric vehicles.
- Implemented a dynamic method of optimizing the charging for electric vehicles during the period they are parked, choose the place where the electric vehicle should park. The aim of this method called "Length of Stay" is to meet the needs of users.
- Present a method for real-time optimization of energy use in each CS installed in the parking lot.
- Implemented a tool for creating vehicle park users' profiles, defining standard behavior depending on the location of parking lots to test the different methodologies in realistic scenarios.

All the scientific contributions mentioned above and the final proposed system were designed in collaboration with the company *Électricité de France* (EDF).

II. STATE OF ART

Studies in the literature show that integrating electric vehicles will increase the energy demand in parking lots, reinforcing the need to create strategies to increase energy efficiency in these places [6]. Thus, there have been studies from several points of view to develop parking lot management from logistical and energy perspectives. The following concepts are being implemented: controllers of the power and duration of vehicle charging, integration of renewable resources, and vehicle-to-grid technology.

A. Control algorithms for electric vehicle charging

In the paradigm of electric vehicle adoption at a large scale, it is known that a non-controllable charging system will cause several problems in the grid, such as grid congestion at peak power demand [7]. A non-controllable system means that the vehicle starts charging as soon as it is plugged in. Its charging process is finished when it reaches the battery's maximum capacity or is disconnected from the grid. These systems require a higher energy capacity than systems with intelligent control.

Several studies point out that the solutions passed through a system that controls the charging process (time and power) of each EV. Several proposed methodologies are used in the literature: fuzzy controller, centralized controller, and decentralized controller:

- Fuzzy controller: the author [8] propose a fuzzy control model to adjust the charging and discharging of vehicles to satisfy the user. The authors tested this algorithm for different cases. A decrease in grid overload and an increase in the number of successfully charged vehicles were found compared to a non-controllable system. The limitation of this study is that the algorithm does not consider users' energy needs for the next trip.
- Centralized controller: finds the globally optimal solution [9]. However, as the number of EVs increases, the dimension of the optimization problem also increases, causing this type of control to have a high computational cost. So, one of the solutions is to resort to hierarchy control, where the central controller allocates the energy to a group and, in turn, has another controller that manages the distributed power.
- Decentralized controller: is a system consisting of more than one agent, acting in different groups of the overall design[10]. The reliability of this type of control decreases as the complexity of the optimization problem increases

Another point charging algorithms diverge is in the implementation of the objective function. Each control may have one or more objectives depending on the point of view for which they were designed: EV user, aggregator, or grid. Thus, the objectives could be to maximize the satisfaction of the vehicle owner[8], maximize the number of charged vehicles [11], maximize the car park sales [11], minimize the peak electricity demand on the grid.

The algorithms studied also differ by the timeline used for decision-making. Some approaches make decisions for real time [12], others for the following day [13]. Some methods use a hybrid model, in which they execute the scheduling for the next day and make corrections in real-time [11].

Finally, some methodologies foresee the integration of renewable energy sources or even energy storage systems. As the author Yao L. demonstrates, this kind of system maximizes the EV owners' satisfaction. It minimizes the operational cost by prioritizing energy from renewable sources or battery storage systems [12].

B. *Integration of renewable resources*

The use of renewable energies is one of the solutions to mitigate the increase in energy demand expected with the integration of vehicles in parking lots. The renewable sources with the most significant expression in electricity production in Portugal, hydro and wind[14], are mostly high-power installations (MW) and require conditions for their building (e.g., windy areas). In this way, photovoltaic panels present an alternative since their installation can occur locally in parking lots.

Depending on the parking lot profile, this solution could be determinant since vehicles spend most of the day parked (e.g., company parking lot), during the day period with higher solar incidence and lower energy demand from other sectors [12].

C. *Vehicle-to-grid technology*

The vehicle-to-grid technology allows the energy stored in vehicle batteries to supply power to the grid. In this case, the connection between the vehicle and the grid is bidirectional. In this way, in periods of higher demand, the energy stored in a vehicle can be used so as not to overload the grid. Later, with fewer restrictions in the operation of the grid, this energy is charged again in the batteries. In these cases, the discharged EV user will also be financially rewarded since he provided a service to the car park during his parking.

III. Case Studies

A. *Contructions of Parking Lots Scenários*

In this study, it was implemented a tool to create scenarios of realistic parking lot users. First, it is necessary to define the parking lot location and then define the probabilities of the EVs' models in the zone/country of its location and the users' profiles according to the type of the parking lot. Three parking lots have been identified: commuter (one-way flow park), business (near offices), and residential (close to residential areas).

In commuter parks, the flow direction is unidirectional. Al the vehicles arrive simultaneously and leave simultaneously. Table I describes the user's profiles and each probability for the business and residential parks.

TABLE I. Users Profiles

Parking Lot Type	***Description***		
Business Park	Worker 1	Arrives at work around 9h and leaves between 17h and 18h in the afternoon.	40%
	Worker 2	Same behavior as worker 1; however, this user uses the EV to commute during lunchtime, leaving between 13 and 14h.	40%
	Visitor	Is not a member of the company staff and stay in the park will be between 1h30 to 2h30.	15%
	Company Car	this vehicle is used to transport company employees during the day, leaving the park at 9h and arriving only at around 18h.	5%
Residential Parks	Resident 1	Leaves home between 8h and 9h, and is expected to return between 18h and 22h	45%
	Resident 2	It differs from resident 1 by the fact that he goes home at lunchtime.	30%
	Weekend Car	Vehicle which spends much of its time parked at its owner's home and used only at weekends.	10%
	Guest	Visit to one of the building's residents during 1h30 and to 2h30.	15%

Then, using a random normal distribution and already with the number of vehicles in the problem defined, the profiles of each user are obtained. Before the scenario is created, it is still necessary to determine the entry and exit periods of the vehicles based on their profiles and the duration time of each simulation period.

B. Case Studies Description

To facilitate the reading, Table I presents the different case studies identified, considering the methodology applied, the type of parking lot, and the analysis's objectives.

TABLE II. RESUME OF THE CASE STUDIES

Methodology	*CE*	*Parking Lot Type*	*Objective*
Day-ahead	CE 1.2	Business	Evaluate user satisfaction.
Length of Stay	CE 2.1	Business	Evaluate User Satisfaction.
			Demonstrate the readjustment of the charging profile whenever a vehicle enters.
			Impact of vehicle-to-grid technology.
	CE 2.2	Residential	Evaluate the advantage of parking the vehicles in the optimization.
Hierarchical System	CE 3.1	Business	Evaluate the performance of the final system.
			Analyze communication between the first and second levels.

C. CE 1.1 - Business

This scenario aims to verify whether the proposed methodology can satisfy users with different energy requirements and parking durations.

It is considered that the parking lot can park 10 EVs simultaneously and is equipped with 2 CS with a maximum active power of 22 kW. The car park also has an active power limit of 40 kW.

The parking occupancy over time, using the toll explained at IV-A, for car parks in business zones, in this way:

- EVs 1 and 8 are vehicles whose parking is of a long duration (> 12 hours).
- EVs 2, 9 and 10 are vehicles whose parking is of medium duration (> 6 hours).
- EVs 4, 6 and 7 enter and leave the park twice.
- EVs 3 and 5 are short-term parkers (< 2 hours).

The values in Table II are obtained by applying the "Day-ahead" methodology for this scenario. The first and second columns discriminate the levels of energy that the EV enters the park and that the users require, respectively. In the third column is the value of the energy stored in each EV battery. $SOC_{(Ev,t_{final(Ev)})}$.

TABLE III. VEHICLE BATTERY STATUS- CE 1.1

ID	$SOC_{i(Ev)}$ ***kWh***	$SOC_{req(Ev)}$ ***kWh***	$SOC_{(Ev,t_{final(EV)})}$	
			Day-Heady	***Baseline***
1	72	90	90	90
2	24	40	40	40
3	18	72	51	18
4	4,18	6,84	6,84	7,6
	5,55	7,6	7,6	7,6
5	44,1	67,5	67,5	60
	27	54	54	40,75
6	50,25	72,75	72,25	75
	60	75	75	75
7	46,5	69	69	75
	61,5	75	75	75
8	5,32	6,84	6,84	7,6
9	56,25	75	75	75
10	16	39,2	39,3	40

The EV 3(enters the park at 8h and leaves at 9h15) is the only one that presents a difference between the required energy and the final energy. However, as shown in Fig. 2, this vehicle will be charged practically with the maximum active power of the CS during the parking period.

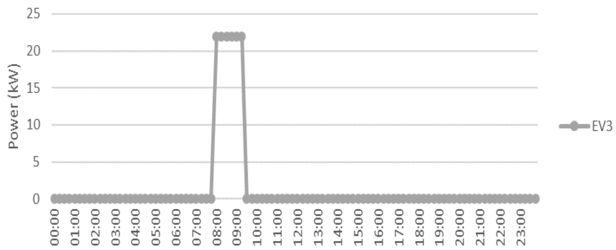


Fig. 1- Active Charging Power EV 3 – CE 1.1

In the following figure is the evolution of the SOC of each EV:

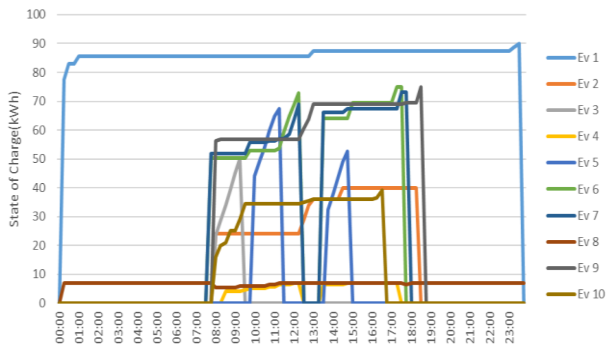


Fig. 2 - Evolution of the State of Charge of each EV

The results obtained by the proposed methodology are compared with a non-controllable system, where the latter neither has access to the users' needs nor is responsible for parking the vehicles. In a non-controllable system, whenever a vehicle is connected to the grid, this one supplies it with the available power, respecting the power threshold of the CS. This system only interrupts the charging of the vehicles when they reach the maximum capacity of the batteries or when they are disconnected from the network.

Considering the results obtained and by analyzing the last column of Table II, EVs 3 and 5 were left with energy levels well below those required. While vehicles such as EV 7 were charged above the requirements. Thus, it becomes noticeable that an uncontrollable system does not have an intelligent and coordinated use of available power. This case study demonstrates the importance of power control and charging times.

D. CE 2.1 – Business

By applying the "Length of Stay" method to the same scenario described in IV-C, the following diagram is obtained for the temporal evolution of the state of charge of each EV. It is shown that all the EVs achieve the required energy, except the EV3, for the same reasons as in CE 1.1.

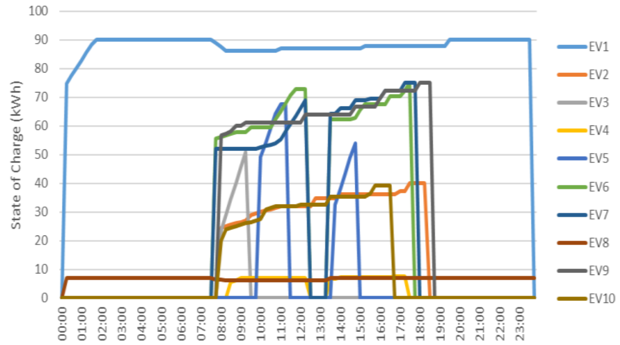


Fig. 3- State of Charge Time Evolution – CE 2.1

It is interesting to analyze in the graph of Fig.5 the differences between the scheduling done at 7h45 when EVs 6 and 7 enter (EV 3 is not yet in the park) and the scheduling is done at 8h00 when EV 3 enters the parking lot:

- 7h45: EV 6 and 7 are parked and need to be charged. The vehicles are scheduled for charging concerning the two existing charging levels (orange and solid blue lines). These vehicles will remain parked until 12:15.
- 8:00 am: EV 3, a vehicle with a short parking time, enters the car park. The algorithm adjusts the load profile of EV 6 and EV 7 (orange and blue dashed lines) to supply maximum power to EV 3 (green dashed line) during its whole parking period. According to this scheduling, EVs 6 and 7 resumed charging when EV 3 left the park.

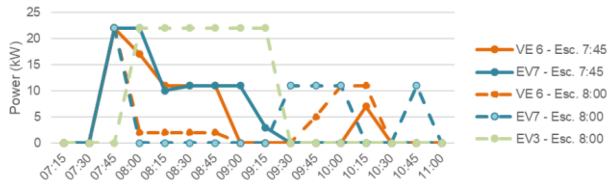


Fig. 4 - Readjustments on the scheduling of the charging power when EV 3 enters the parking lot

Another essential aspect of studying is the impact of vehicle-to-grid technology. As the parking lot has only 40 kW of power installed, the two CSs cannot operate at the maximum limit simultaneously, only using the parking lot power. For that to happen, the system must request the energy stored in the batteries in the vehicles. That only occurs in cases where the grid is congested. In fig.4 it is noticeable that when several vehicles enter at 8 am, EV 1 is discharged.

This technology makes it possible to reduce the power installed in the park and still satisfy users. The same scenario was tested for a park with 25 kW installed power. In table III the results are presented and compared with the results of the 40 kW installed power.

TABLE IV. VEHICLE BATTERY STATUS- CE 1.1

ID	$SOC_{i(Ev)}$ kWh	$SOC_{req(Ev)}$ kWh	$SOC_{(Ev,t_{final(EV)})}$ kWh	
			$P_{MaxPark} =$ 40 kW	$P_{MaxPark} =$ 25 kW
1	72	90	90	90
2	24	40	40	40
3	18	72	51	49
4	4,18	6,84	7,6	7,6
	5,55	7,6	7,6	7,6
5	44,1	67,5	67,5	67,5
	27	54	54	54
6	50,25	72,75	72,75	72,75
	60	75	75	75
7	46,5	69	69	69
	61,5	75	75	75
8	5,32	6,84	6,84	6,84
9	56,25	75	75	75
10	16	39,2	39,2	39,2

All vehicles leave the park at the same level except EV 3. However, the difference is only 2 kWh which is not significant. This is possible because the management system uses more energy from EV 1 and EV 8. These vehicles are parked for more extended periods, and the energy provided to the grid can be restored later (Fig.6).

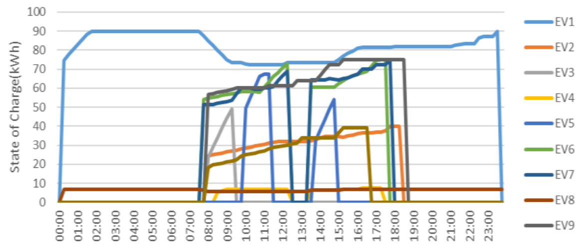


Fig. 5- State of Charge Time Evolution – CE 2.1

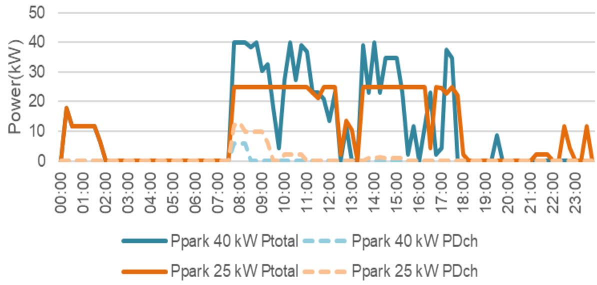


Fig. 6- Power of the park and discharge power for the 40 kW scenario and for the 25 kW scenario

The analysis of this study method demonstrated how effectively the system updates the vehicle charging profile with the input of vehicles with different energy needs. Furthermore, the importance of the vehicle-to-grid technology was shown to guarantee the charging of vehicles with short parking duration. This importance increases when the restrictions on the active power of the park are tighter.

E. CE 2.1 – Residencial – Parking the EVs

The EV 1 arrives at the park at 19h45 and indicates that it will leave at 21h. The car park is empty, and the algorithm indicates that the vehicle should connect to CS 1 and schedule the active power of the CS.

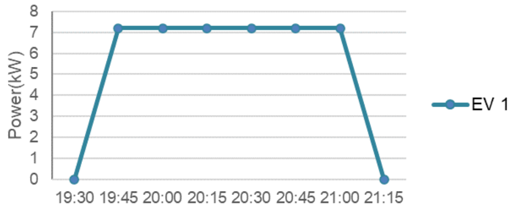


Fig. 7 - Active Charging Power scheduling at 19h45

EV 2 arrives at the park at 20h, indicating that it will leave the park at 8h the next day. This way, the algorithm assigns the CS 2 that is entirely free to vehicle 2, allowing the two now parked vehicles to be charged at the maximum active power of each CS. It is observed that both vehicles are scaled to charge at the active power of 7.2 kW.

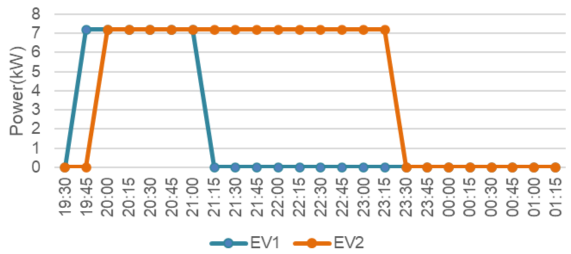


Fig. 8Active Charging Power scheduling at 20h

Vehicle 3 enters the park at 20h30, and both CS already have one vehicle connected. In this way, the system parks vehicle 3 in CS 2, loading the two vehicles with less parking time (1 and 3) in different CSs, scheduling vehicle 2 for later.

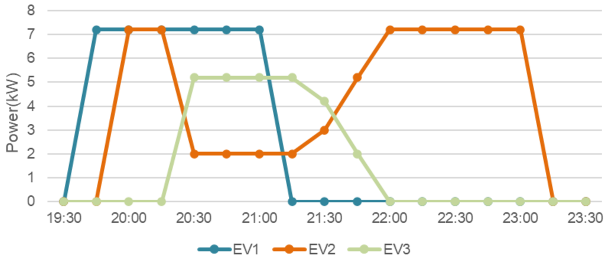


Fig. 9-Active Charging Power scheduling at 20h30

If the allocation of the vehicle to the CS was not optimized, the user of EV 3 could choose to park at CS 1, which would make it impossible to charge one of the vehicles fully. Therefore, vehicle 2, the least priority of the three vehicles, would have the highest active charging power since it would be the only car allocated to CS 2. Meanwhile, EVs 1 and 3 would have to distribute the active charging power of CS 1 between the two vehicles, ending up not satisfying both.

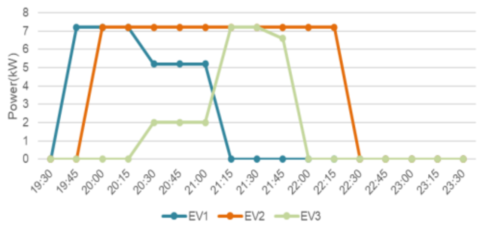


Fig. 10Active Charging Power scheduling at 20h30, without placement of the vehicles

The advantage of considering the vehicle's location in the park as the responsibility of the management system was demonstrated.

F. Day-ahead vs Length of Stay

The performance of the two proposed methodologies for the first level of optimization is analyzed. The differences between these two approaches reside in how they distribute the active charging power among the vehicles and the execution time for their optimization.

Regarding the scheduling of the charging power, the methodology "Day-ahead" does not have a mechanism to ensure a continuous charging process for each EV and simulate the two levels of charging rate power of the ion-lithium batteries.

Also, the "Length of Stay" methodology allocates each vehicle to a CS and only parks one vehicle at each optimization. On the other hand, the "Day-ahead" methodology allocates a vehicle to a place (this increases the size of the variables) and must park all the vehicles in an optimization. In Fig. 11, it is possible to compare the time execution difference depending on the number of EVs.

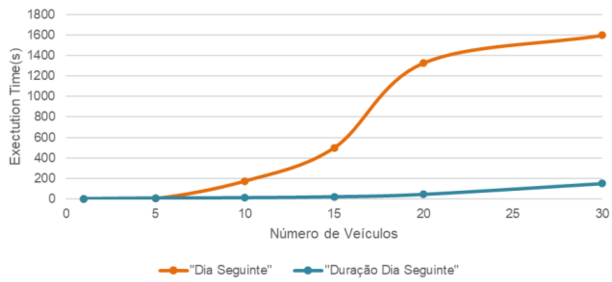


Fig. 11 - Time execution depended on the number of EVs

As a result of the analysis of the two methodologies, it concludes that they achieve the main objective with equal success: maximize user satisfaction and demonstrate clear improvements compared to a non-controllable charging system. However, it was possible to verify that the "Next Day" methodology becomes untenable for issues involving the number of vehicles exceeding 15. Because of this, it was decided not to use the "Day-ahead" methodology in the final system.

G. CE 3.1 – Business – Hierarchical System

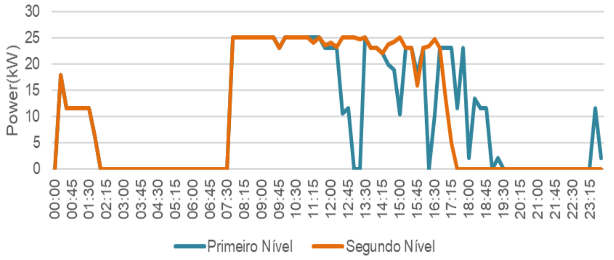
This case study aims to demonstrate the advantages of using the second optimization level. Also, to show the connectivity dynamics between the first optimization level and the second optimization level.

The same business park with 25 kW of installed power was tested for the hierarchical system. Table V compares the values of the final battery states and the time that the EV finish the charging, $T_{ChEnd(Ev)}$, for all vehicles of a system with only the first level implemented and the system with both levels implemented.

TABLE V. VEHICLE BATTERY STATUS AND HOUR OF THE LAST CHARGING- L.S(LENGTH OF STAY) AND H.S(HIERARCHICAL SYSTEM)

ID	$SOC_{i(Ev)}$ kWh	$SOC_{req(Ev)}$ kWh	$SOC_{(Ev,t_{final(EV)})}$ kWh		$T_{ChEnd(Ev)}$	
			L.S.	H.S.	L.S	H.S
1	72	90	90	90	23:45	16:48
2	24	40	40	40	18:15	15:53
3	18	72	49	51	9:15	9:15
4	4,18	6,84	7,6	7,6	12:15	12:15
	5,55	7,6	7,6	7,6	15:45	15:45
5	44,1	67,5	67,5	67,5	11:15	11:08
	27	54	54	54	15:00	15:00
6	50,25	72,75	72,75	72,75	12:15	12:15
	60	75	75	75	18:30	16:25
7	46,5	69	69	69	12:15	12:15
	61,5	75	75	75	17:45	17:07
8	5,32	6,84	6,84	6,84	00:00	16:02
9	56,25	75	75	75	18:30	15:38
10	16	39,2	39,2	39,2	16:15	16:01

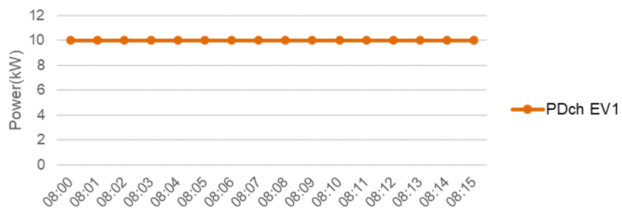
We also can analyse this difference in the charging time in the park power chart:



It becomes possible to conclude with the implementation of the second level, the active charging power of each CS in each minute is increased, thus decreasing the charging time of each vehicle. This time charging decrease allows the car park to increase the active power available to enable new vehicles to be charged.

It has already been shown that the second level makes it possible to increase the active charging power. Next, the behavior of the system is analyzed when it comes to unloading active powers.

The first optimization level schedules EV 1 to be discharged at an active discharge power of 10 kW in the period between 8:00 and 8:15. In this way, every minute of this time interval, the second optimization level will match this discharge value. The fig. represents the value of the active power discharge of EV 1 assigned by the second level for each minute:



To exemplify the communication mechanism between the two levels, let us take the example of two CSs. The main operator (first level) has allocated an active charging power of 22 kW for CS 1 and active charging power of 10kW for CS 2 between 9:00 and 9:15.

The local operators located at each CS maximize the charging power of their vehicles to reduce the difference between energy stored in minute t and the energy required. Taking this situation into account, we can consider two possible scenarios:

- If the park's installed power is higher than 44 kW, the main operator will authorize CS 2 to increase the active charging power for the vehicles allocated to it.
- If the installed power in the park is less than 44 kW, the two CS cannot operate at maximum charging power, the main operator will not allow CS 2 to charge the vehicles at a power of 22 kW. In this case, there are two hypotheses: if the installed power in the park is 32 kW, the main operator sends the local operators the values to be used, that is, 22 kW and 10 kW, respectively. For example, if the power is 38 kW, the main operator sends 22 kW to CS 1 and allocates 10 kW to CS 2 together with the remaining 4 kW available in the park.

IV. CONCLUSIONS AND FUTURE WORK

A. *Conclusions*

This dissertation contributes to state of the art by developing a methodology for controlling parking lot management through a hierarchical system that schedules the charging profile and manages the logistic management of the parking lots.

The "Day-ahead" methodology has been proven to maximise user satisfaction and compared with a non-controllable system, obtain better results, and use energy in a more coordinated way.

The "Length of Stay" methodology case studies demonstrated that it could satisfy clients similar to the " Day-ahead".

It also demonstrated the importance of using vehicle-to-grid technology for charging more vehicles in periods of more significant grid congestion. In addition, it was shown the advantage of considering the vehicle location in the optimisation problem.

Then, through the application of several case studies, it was shown that the integration of a second optimisation level allows decreasing the charging time of each vehicle, respecting the park's restrictions, without increasing the computational complexity of the problem. With the implementation of the second level, better use of the available power is guaranteed. It also allows corrections to be made to the first level scheduling if a vehicle leaves earlier than expected or arrives at the park with less power than initially predicted.

In conclusion, it was demonstrated that it is possible to guarantee that the user obtains the energy required during the stay in the parking lot in the hybrid system with two optimisation levels. In the case of CSs they operate at maximum power whenever possible.

B. Future Work

Despite the contributions that the present dissertation adds to the topic through the proposed methodologies, it is considered that there are still several opportunities for further research within the scope of this study.

It would be opportune to evaluate the optimisation of the system at the computational level to decrease the execution time of the optimisations and evaluate the use of other optimisation software.

Transversally, it would have an added value the deep study on the typology of conductors that can be installed in parking lots to dimension the electrical installation through the tool of "Circuits", As well as the evaluation of the necessary power to establish in the car park to satisfy its users.

It may be important to perform an economic study on the combination between the number of CSs, their maximum charging power, and the number of vehicles at the financial level. Additionally, an analysis of the tariff associated with the vehicle-to-grid technology can be performed, considering the electricity price and the degradation it may cause in the vehicle's battery.

Another aspect that may be relevant is to associate the park's power with a time-dependent curve. Most parking lots are conected to other infrastructures such as shopping centers, company offices, or residential buildings. It would be interesting to combine the charging of electric vehicles with the consumption of other appliances connected to the same infrastructure.

Keeping in mind the sustainability of the whole energy system, it is considered an exciting challenge to evaluate the possibility of using renewable sources to supply energy to the car park and its storage in batteries.

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