Charging Management Controller Concept for Electric Vehicles in Parking Lots

Pedro António Palhavã Marques da Silva

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Department of Electrical and Computer Engineering, Instituto Superior Técnico

Abstract: The growing penetration of EVs (electric vehicles) in the automotive market, triggered by environmental concerns, has boosted the integration of chargers in the electric power system. Also, electric vehicles, like any other car, spends 90% of their time parked. Thus, parking lots are ideal places for installing multiple chargers. This installation will require complex energy management of the systems to be installed in the parking lot. This thesis proposes a deterministic methodology for the management and control of the charge stations for electric vehicles in parking lots. The proposed model takes into account several aspects related to the chargers' operation and the design of the parking lot. The proposed methodology is tested and validated in three case studies. The first case compares the performance of the model in the management of individual chargers versus central chargers while the second case evaluates the option of premium users. The third case study puts into practice the conclusions drawn in the previous case studies through the simulation of possible charging architectures for the wide adoption of electric vehicles. The results show that the proposed method overcomes the economic and technical barriers associated with parking lots and guarantees a good EV charging.

Key Words: Electric Vehicles, Parking Lots, Energy Management, Optimization Problem.

1. Introduction

The uninterrupted use of fossil fuels in the transport sector is directly associated with increased concentration of carbon dioxide (CO_2) in the atmosphere. In 2017, road transport represented 72% of all emissions related to the transport sector. Of these emissions, 44% come from passenger vehicles, 9% from light commercial vehicles and 19% from heavy vehicles [1]. The development and implementation of EVs is seen as one of the solutions to adopt in order to mitigate the negative effects of greenhouse gases emissions. Nevertheless, there are many barriers to EVs' expansion such as the autonomy when compared to the internal combustion engine vehicles (ICE) and the charging time. Regarding the charging of EVs several aspects that complicate its commercial success such as the necessity to create and install a public and accessible network of chargers. As an answer to this difficulty, European governments have created incentives and have been the main drivers in installing charging infrastructures [2]. Additionally, electric vehicles spend most of their time parked which makes parking lots ideal for the installation of multiple chargers.

The large-scale adoption of EVs has a series of challenges for the electric grid perspective like the significant increase of load in the distribution grid which can lead to an overload of network assets [3]. However, in the future, a huge number of EVs will raise the energy demand forcing the power systems to its limits. In [4], the uncontrolled integration of EVs in the grid could lead to increase of peak demand and the creation of new peaks in off-peak periods thus putting at risk the stability of the power grid.

In this paper, a model of optimization and control of the charging system for electric vehicles in a parking lot is proposed. This model aims to understand the influential factors for EVs charging. The proposed method is capable of distributing the power associated with the car parks and charge stations.

The rest of the paper is organized as follows: Methodology, Case Studies and Conclusion.

2. Methodology

This thesis proposes a controller for the charging system of EVs in parking lots that optimizes the distribution of energy to each EV. The optimization of the model is mixed integer programming problem. The deterministic technique reaches a solution through the minimization of one linear objective function while being subject to different restrictions, including integer variables. The models were implemented using the following tools: Microsoft Excel, MATLAB and GAMS. The complexity of the problem is due to the challenges associated with the large-scale integration of EVs. The description of the objective function and constraints of the proposed methodology is made in this section.

2.1. Objective Function

The objective function intends to minimize the penalties associated with the parking rules, thus ensuring that the distribution of the energy is optimal. Moreover, vehicles with lower SOC levels will be prioritized. The proposed objective function covers only technical goals whereby it will be made an additional analysis for financial ones.

The F_{OBJ} that should be minimized is given as:

$$F_{OBJ} = \left(\sum_{CS=1}^{N_{CS}}\left(P_{CS(CS)} * \eta_{CS}\right) + \sum_{EV=1}^{N_{EV}}\left(PF_{MCP(EV,t)} * P_{minMCP(EV,t)}\right) + \sum_{EV=1}^{N_{EV}}\left(PF_{SocL1(EV,t)} * P_{SocL1(EV,t)}\right) + \sum_{EV=1}^{N_{EV}}\left(PF_{SocL2(EV,t)} * P_{SocL2(EV,t)}\right) + \sum_{EV=1}^{N_{EV}}\left(PF_{SocL3(EV,t)} * P_{SocL3(EV,t)}\right) + \sum_{EV=1}^{N_{EV}}\left(PF_{VarP(EV,t)} * \Delta P_{ch(EV,t)}\right) + PF_{minSOC(t)} * minSOC_{(t)}\right) \quad (1)$$

where, for each period, t, the controller will optimize the EVs' charging according to each vehicle's penalization. The term η_{CS} represents the charging efficiency of each charger which was assumed as 95%. The first term of the equation is associated with the charging efficiency. The second and the sixth terms are associated with the minimum power delivered and the maximum variation of power delivered to each EV in each period, respectively. Additionally, the penalizations of the battery levels are present while the EV with the lowest level of SOC has an additional penalty represented in the last term of the equation.

2.2. Parking Lot Rules and Restrictions

The minimization of the objective function is subjected to many constraints associated with the charging service and the design of the parking lot. First, if an EV is parked, it is expected that the EV is being charged with at least the minimal power, $P_{minMCP(EV,t)}$, in each period. This is a subjective value to the management of the parking lot that has been defined as 2kW. This variable only takes values below 2kW in the case when the charging need is lower that this value. $P_{ch(EV,t)}$ represents the power injected on each EV in period *t*.

$$P_{minMCP(EV,t)} - PF_{MCP(EV,t)} \leq P_{ch(EV,t)} \quad (2)$$

$$P_{minMCP(EV,t)} = \min\left(2kW; \left(1 - SOC_{(EV,t)}\right) * \frac{E_{maxEV(EV,t)}}{t_{period}}\right) \quad (3)$$

Additionally, the penalizations in (4) have as objective to give more importance to the EVs with lower SOC. Three levels are considered, the first is the critical level and has an upper limit between 40 to 60% of SOC. The third level is the less priority level and has a lower limit inside the interval of 80 to 90%. Usually, the EVs with the SOC higher than level 3 have enough driving range for normal use. The power need to each EV in each level, are computed previously to the optimization and can be seen in (5).

$$\begin{gathered} P_{SocL1(EV,t)} - \left(PF_{SocL1(EV,t)}\right) \leq P_{ch(EV,t)} \\ P_{SocL2(EV,t)} - \left(PF_{SocL2(EV,t)}\right) \leq P_{ch(EV,t)} \\ P_{SocL3(EV,t)} - \left(PF_{SocL3(EV,t)}\right) \leq P_{ch(EV,t)} \\ P_{SocL1(EV,t)} - PF_{SocL1(EV,t)} + P_{SocL2(EV,t)} - PF_{SocL2(EV,t)} + P_{SocL3(EV,t)} - PF_{SocL3(EV,t)} \leq P_{ch(EV,t)} \end{gathered} \quad (4)$$

$$\begin{aligned} P_{SocL1(EV,t)} &= \max\left(0\,;\ \left(0.4 - SOC_{(EV,t)}\right).\frac{E_{maxEV(EV,t)}}{t_{period}}\right) \\ P_{SocL2(EV,t)} &= \max\left(0\,;\ \left(0.85 - SOC_{(EV,t)}\right).\frac{E_{maxEV(EV,t)}}{t_{period}}\right) \\ P_{SocL3(EV,t)} &= \max\left(0\,;\ \left(1 - SOC_{(EV,t)}\right).\frac{E_{maxEV(EV,t)}}{t_{period}}\right) \end{aligned} \quad (5)$$

To promote the continuity of charging, it is proposed a penalization to limit the variation in the power charge in consecutive periods. However, the limitation is only imposed in the charging power decrease. $\Delta P_{ch(EV,t)}$ represents the variation of power charge.

$$P_{Ch(EV,t-1)} - P_{Ch(EV,t)} + PF_{VarP(EV,t)} \leq \Delta P_{ch(EV,t)} \qquad (6)$$

The next constraint aims to give priority to the EV with lower SOC penalizing the minimum SOC of all EVs in the parking. This penalty factor is different from the others since it is expressed in percentage.

$$PF_{minSOC(t)} \leq SOC_{(EV,t)} \qquad (7)$$

The previous constraints are related to the management of the charging of vehicles while the next constraints are associated with the dimensioning of the parking lot. First of all, the maximum power should be lower than the maximum capacity of the parking lot, $P_{maxPark(t)}$, which can be imposed by technical or a contractual requirements. This limit can be different for each period and the power limit is not applied to the EVs but to charging stations (CS).

$$\sum_{CS=1}^{N_{CS}} P_{maxCSt(CS,t)} \leq P_{maxPark(t)} \qquad (8)$$

The power supplied by the charging station CS should be lower than its' maximum capacity, $P_{maxCS(CS)}$, and also lower than the maximum defined in the parking management system. The variable X_{ev} contains the information if the EV is connected to the charging station Cs during the instant *t*.

$$\sum_{EV=1}^{N_{EV}} P_{ch(EV,t)} . X_{Place(EV,CS,t)} \leq P_{maxCSt(CS,t)} \qquad (9)$$

$$\sum_{EV=1}^{N_{EV}} P_{ch(EV,t)} . X_{Place(EV,CS,t)} \leq P_{maxCS(CS)} \qquad (10)$$

From the EVs' perspective, the power charge should be lower than the maximum power accepted by the EVs, $P_{maxCh(EV,t)}$. It can also be considered that the EVs do not allow power charge below a limit, different for each EV and can also depend on the state of charge of the battery.

$$\begin{aligned} &P_{ch(EV,t)} \leq P_{maxCh(EV,t)} . X_{Ch(EV,t)} \\ &P_{ch(EV,t)} \geq P_{minCh(EV,t)} . X_{Ch(EV,t)} \qquad (11) \\ &P_{ch(EV,t)} \leq \left(1 - SOC_{(EV,t)}\right) . \frac{E_{maxEV(EV,t)}}{t_{period}} \end{aligned}$$

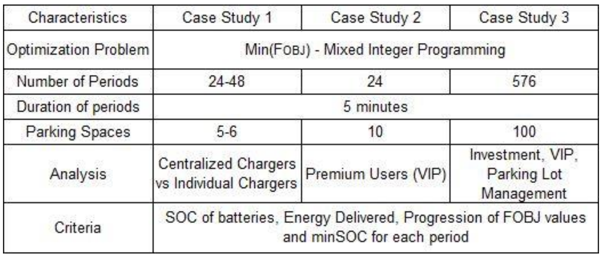
The last restriction is associated with the transfer of energy. For each EV, the energy available at the end of the period, $E_{f(EV,t)}$, must be equal to the sum of the energy available at the beginning of the period with the energy delivered by the charger to the EV during that period. Additionally, it is necessary to verify that the final energy of each EV is equal to or less than the battery capacity of that specific EV during the entire simulation.

$$\begin{aligned} &E_{f(EV,t)} = E_{i(EV,t)} + P_{ch(EV,t)} \qquad (12) \\ &E_{f(EV,t)} \leq E_{maxEV(EV)} \end{aligned}$$

3. Case Studies

Three case studies were developed to test and validate the proposed method. For all the case studies the method will minimize the objective function and will take into account the following criteria: SOC of batteries, Energy Delivered, Progression of F_{OBJ} values and *minSOC* for each period. The subject of each case study will be different. The object of study of the first case study is to compare the performance of the proposed method while controlling centralized chargers versus individual chargers. The case study 2 analyzes the possibility of creating *premium* users that pay more to assure a better service. The last case study implements possible architectures of charging stations and analyses the performance of the controller for each one.

Table 1 - Description of each Case Study



Characteristics	Case Study 1	Case Study 2	Case Study 3
Optimization Problem	Min(FOBJ) - Mixed Integer Programming		
Number of Periods	24-48	24	576
Duration of periods	5 minutes		
Parking Spaces	5-6	10	100
Analysis	Centralized Chargers vs Individual Chargers	Premium Users (VIP)	Investment, VIP, Parking Lot Management
Criteria	SOC of batteries, Energy Delivered, Progression of FOBJ values and minSOC for each period		

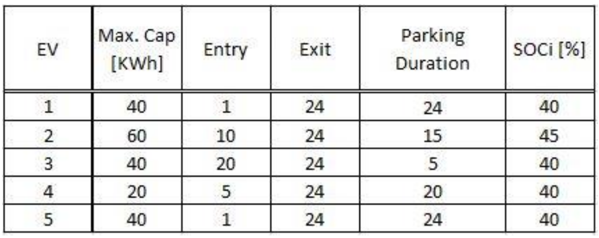
3.1. Case Study 1

As it is described in Table 1, this case study compares the performance of centralized chargers versus individual chargers. To understand the differences between these two types of chargers, three scenarios were developed:

1) Simulation with 5 parking spots and duration of 24 periods;
2) Simulation with 6 parking spots and duration of 24 periods;
3) Simulation with 6 parking spots and duration of 48 periods.

For each scenario, several hypotheses were posed each considering distinct sets of chargers. For the simulation with five parking spots: the first hypothesis has 1 centralized charger of 22kW; the second hypothesis has one 8,8kW charger (responsible for 2 parking spots) and one 13,2kW charger (responsible for 3 parking spots); the hypothesis 3 has three chargers, two of 8,8kW (each responsible for 2 parking spots) while the remaining parking spot is charged by a 4,4kW charger; the last hypothesis has a 4,4kW individual charger for each parking spot. Table 2 describes the EVs used in the first scenario.

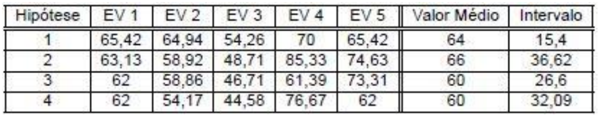
Table 2- EVs' Description – 5 Parking Spots



EV	Max. Cap [KWh]	Entry	Exit	Parking Duration	SOCi [%]
1	40	1	24	24	40
2	60	10	24	15	45
3	40	20	24	5	40
4	20	5	24	20	40
5	40	1	24	24	40

As seen in Table 2, the EVs have different parking duration and its' capacities can vary between 20 to 60kWh. Through the simulation of the method proposed for this parking lot and the four hypotheses, the progression of the objective function and the following values of SOC can be obtained (Table 3)

Table 3- Final SOC values – 5 Parking Spots



Hipótese	EV 1	EV 2	EV 3	EV 4	EV 5	Valor Médio	Intervalo
1	65,42	64,94	54,26	70	65,42	64	15,4
2	63,13	58,92	48,71	85,33	74,63	66	36,62
3	62	58,86	46,71	61,39	73,31	60	26,6
4	62	54,17	44,58	76,67	62	60	32,09

From the analysis of Table 3 it can be seen that the second hypothesis presents the best average value at the end of the simulation. Nevertheless, the first hypothesis shows that the last option presents a more balanced charging. The interval between the highest SOC value and the lowest SOC value of the second hypothesis is more than double of the interval value of the first hypothesis which supports the previous conclusion. Additionally, the third and fourth hypotheses present a weaker performance in relation to the first two hypotheses.

An evaluation of the energy delivered reveals that both the first and the second hypothesis use the total available power during the entire simulation.

The evolution of the objective function during the time shows that when a new EV arrives at the park, the value of the F_{OBJ} will always rise in function of the EV's SOC level. The performance of the model shows that the optimization is better if the hypotheses use centralized chargers.

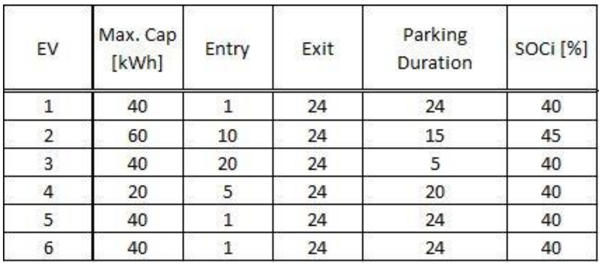
Figure 1 - Progression of Objective Function - 5 Parking Spots

Regarding the following scenarios, the method will control the charging for the next hypotheses:

1) Hypothesis 1 – 1 Charger – 22kW – responsible for 6 parking spots;
2) Hypothesis 2 – 2 Charger – 11kW – each charger responsible for 3 parking spots;
3) Hypothesis 3 – 3 Charger – 7,3kW – each charger responsible for 2 parking spots;
4) Hypothesis 4 – 6 Charger – 3,7kW – each charger responsible for 1 parking spot.

For the second scenario which has a duration of 24 periods, the description of the EVs is presented in the following table.

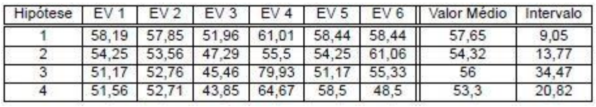
Table 4 - EVs' Description – 6 Parking Spots & 24 Periods



EV	Max. Cap [kWh]	Entry	Exit	Parking Duration	SOCi [%]
1	40	1	24	24	40
2	60	10	24	15	45
3	40	20	24	5	40
4	20	5	24	20	40
5	40	1	24	24	40
6	40	1	24	24	40

For this scenario, the objective is to reinforce the observations made in the previous case while increasing the degree of complexity. From the simulation of the four hypotheses, the following data is removed.

Table 5- Final SOC values - 6 Spots & 24 Periods



Hipótese	EV 1	EV 2	EV 3	EV 4	EV 5	EV 6	Valor Médio	Intervalo
1	58,19	57,85	51,96	61,01	58,44	58,44	57,65	9,05
2	54,25	53,56	47,29	55,5	54,25	61,06	54,32	13,77
3	51,17	52,76	45,46	79,93	51,17	55,33	56	34,47
4	51,56	52,71	43,85	64,67	58,5	48,5	53,3	20,82

In this case, Hypothesis 1 presents undoubtedly the best performance since the presence of only one charger allows a better distribution of the power employed. Additionally, the interval for this option is lower than 10% which reveals a balanced charging of the EVs.

Through the analysis of the distributed energy, we can withdraw that although the third hypothesis has a better average value than hypothesis 2, the option can't balance the charging due to the architecture of the chargers and parking lot.

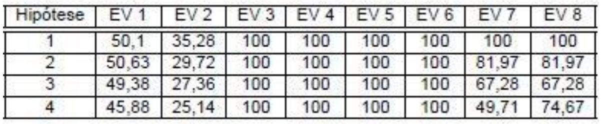
Figure 2 - Progression of Objective Function - 6 Spots & 24 Periods

It is possible to observe in Figure 2 that the first hypothesis stands out in terms of performance during most periods. The remaining hypotheses tend to have a similar performance.

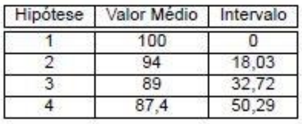
The last scenario of this case study take into account not only the entry of vehicles but also the exit of EVs from the parking lot. With this scenario, the goal is to understand the behaviour of the proposed model for longer simulations and movement of EVs. OnTable 6, it is possible to observe the results obtained during the simulation.

In this scenario, four of the eight EVs present a full battery at the end of simulation independently of the hypotheses. Thus, the performance is compared through the observation of the EVs 1, 2, 7 and 8. The differences between each hypothesis are relevant as the performance of the model follows the path of thought of the hypotheses. This means that the more centralized chargers, the better performance the model will have due to the ability to redistribute the power available each period.

Table 6 – Final SOC values – 6 Spots & 48 Periods



Hipótese	EV 1	EV 2	EV 3	EV 4	EV 5	EV 6	EV 7	EV 8
1	50,1	35,28	100	100	100	100	100	100
2	50,63	29,72	100	100	100	100	81,97	81,97
3	49,38	27,36	100	100	100	100	67,28	67,28
4	45,88	25,14	100	100	100	100	49,71	74,67



Hipótese	Valor Médio	Intervalo
1	100	0
2	94	18,03
3	89	32,72
4	87,4	50,29

The values of the objective function show that the entries of new EVs tend to approximate the different hypotheses while the exits create a gap between them.

Figure 3 - Progression of Objective Function - 6 Spots & 48 Periods

This Case Study shows that centralized charging architectures present better performance due to the bigger liberty degree of redistributing the power available each period. Regarding the proposed methodology, it is possible to observe that it will seek to maximize the delivery of power whenever it is possible and that is capable of distributing the energy across the EVs to provide a quality charging service.

3.2. Case Study 2

The second Case Study intends to analyse the possibility of existing premium users (or VIP) on the parking lot and understand its impact on the overall performance of the park. The VIP will be applied through an extra penalization which will give the respective EV a greater priority for charging.

In this case, it will be studied a parking lot with 10 parking spots and 10EVs. In a similar way of the previous case study, four hypotheses of charging architecture were studied:

1) Hypothesis 1 – 1 Charger – 44kW – responsible for 10 parking spots;
2) Hypothesis 2 – 2 Charger – 22kW – each charger responsible for 5 parking spots;
3) Hypothesis 3 – 4 Charger – 13,2kW and 8,8kW – each 13,2kW charger responsible for 3 parking spots while each 8,8kW charger is responsible for 2 spots;
4) Hypothesis 4 – 5 Charger – 8,8kW – each charger responsible for 2 parking spot.

The previous hypotheses will be simulated for parking lots with VIPs and without VIPs in allowing an evaluation of the impact of this type of contracts. The description of this case study is presented in Table 7.

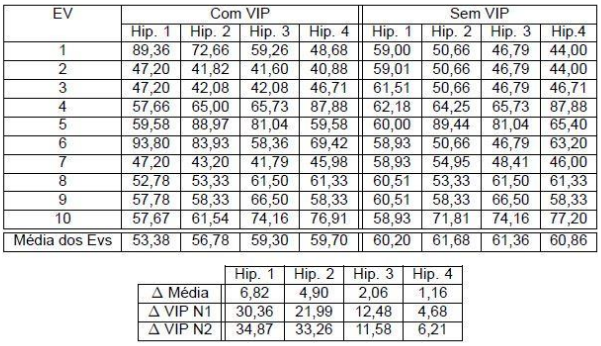
Table 7 - EVs description - 10 Spots

EV	Max. Cap [KWh]	Entrada	Saída	Duração do Estacionamento	SOCi [%]
EV 1 / VIP 1	40	10	24	15	30
2	60	10	24	15	35
3	40	20	24	5	40
4	45	5	24	20	45
5	50	1	24	24	50
EV 2 / VIP 2	35	1	24	24	35
7	30	1	24	24	30
8	40	1	24	24	40
9	45	1	24	24	45
10	50	1	24	24	50

For this case, it is possible to analyse the variation of the SOC level for each EV or VIP. So, in this resume, it will only be presented the final values of SOC for this case of study. The Table 8 shows the final SOC values of the EVs for each hypothesis and the cases where VIPs do and don't exist.

From the observation of the following tables, it possible to observe that the first hypothesis presents the biggest increase, over 30%, of the energy of the EVs in case these are VIPs. Thus making the VIPs reaching SOC values close to 90% of the full battery capacity. On the contrary, the accelerated charging of the VIPs means that the remaining EVs receive substantially less energy hence the average SOC value of the remaining vehicles is 7% lower than the case where VIPs aren't considered. The other hypotheses show that the more centralized the chargers are, the better will be the performance of charging VIPs. This is due to the power available is much greater in this kind of hypothesis than for architectures with individualized chargers.

Table 8 - Final SOC values - 10 Spots



EV	Com VIP				Sem VIP			
	Hip. 1	Hip. 2	Hip. 3	Hip. 4	Hip. 1	Hip. 2	Hip. 3	Hip.4
1	89,36	72,66	59,26	48,68	59,00	50,66	46,79	44,00
2	47,20	41,82	41,60	40,88	59,01	50,66	46,79	44,00
3	47,20	42,08	42,08	46,71	61,51	50,66	46,79	46,71
4	57,66	65,00	65,73	87,88	62,18	64,25	65,73	87,88
5	59,58	88,97	81,04	59,58	60,00	89,44	81,04	65,40
6	93,80	83,93	58,36	69,42	58,93	50,66	46,79	63,20
7	47,20	43,20	41,79	45,98	58,93	54,95	48,41	46,00
8	52,78	53,33	61,50	61,33	60,51	53,33	61,50	61,33
9	57,78	58,33	66,50	58,33	60,51	58,33	66,50	58,33
10	57,67	61,54	74,16	76,91	58,93	71,81	74,16	77,20
Média dos Evs	53,38	56,78	59,30	59,70	60,20	61,68	61,36	60,86

	Hip. 1	Hip. 2	Hip. 3	Hip. 4
Δ Média	6,82	4,90	2,06	1,16
Δ VIP N1	30,36	21,99	12,48	4,68
Δ VIP N2	34,87	33,26	11,58	6,21

From the commercial management point of view, the option of premium users is very interesting since it allows to raise the revenue without raising the maximum capacity associated with the parking lot. Nevertheless, this option should take into account that the presence of VIPs affects the overall performance of the EVs charging.

3.3. Case Study 3

In the last case study, the proposed method will be applied with the intention to optimize the charging of EVs in a parking lot with a higher degree of complexity, thus evaluate the effectiveness of the model.

In this case and for any simulation, the car park has 100 places that are occupied by EVs that respect the following indications. First, the EVs must represent the market shares of each vehicle model. Second, each EV will respect a daily usage profile. Third, the simulation starts at midnight and lasts 576 periods of 5 minutes each. It is possible to see below the usage profiles considered:

1) 3% of the EVs don't leave the parking lot during the simulation;
2) 70% of the EVs leave between 6:40 and 8:30am and return between 5:30 and 8:30pm;
3) 17% of the EVs exhibit random behaviour;
4) 10% of the EVs leave between 6:30 and 8:00am, return between 00:30 and 01:30pm, leave between 01:30 and 02:00pm and return between 06:30 and 09:00pm.

Therefore, Table 9 presents the list of EVs studied during this case study. In particular, the 3 EVs that represent Profile 1 have battery capacities well above the current values in order to raise the complexity of the problem.

Table 9 - EVs description - 100 Spaces

Quota de Mercado	Modelo	Capacidade [kWh]	Perfil 1	Perfil 2	Perfil 3	Perfil 4
16%	Nissan Leaf	40	0	12	3	1
13%	Tesla Model 3	75	0	10	2	1
10%	BMW i3	42	0	7	2	1
10%	Renault ZOE	41	0	7	2	1
9%	Jaguar I-Pace	90	0	6	2	1
8%	Mercedes E300	13,5	0	6	1	1
8%	BMW 530e	12	0	6	1	1
7%	Mini Countrymen	7,6	0	6	1	0
6%	Hyundai Kauai	39	0	4	1	1
5%	Mitsubishi Outlander	12	0	3	1	1
5%	Smart Fortwo	17,6	0	3	1	1
3%		200	3	0	0	0

Initially, it was studied the impact of the penalizations and the rules of the parking. The study was made by changing the combinations of values for the limits of each level on battery that the controller assumes, then varied the weight of the penalizations of the levels. According to the data retrieved, for long simulations, these variations don't show any significant difference.

In the final phase of the case study, it is intended to apply the scenario designed to possible charging architectures that may be applied in parking lots. For such infrastructure, several dimensioning issues arise to the installation of chargers. Thus, to evaluate the performance of the car park, is also needed to resort to economic parameters. The investment in a charger is divided into three main categories. The first is associated with the construction and adaption of space and installation of the charger, the second category corresponds to the price of the charging equipment being that the latter category is associated with the annual operating cost. Table 10 presents the cost of an individual charger that will be used in the following simulations.

Table 10 - Costs associated to Individual Chargers

Potência do Carregador	Instalação	Hardware	Custo Operacional Anual	Custo por Kilowatt
3,7kW	- €	300,00 €	- €	81,08€
7,2kW	300,00 €	600,00 €	- €	125,00€
10kW	600,00 €	1 000,00 €	300,00 €	190,00€
11kW	600,00 €	1 200,00 €	350,00 €	195,45€
22kW	1 500,00 €	2 100,00 €	600,00 €	190,91€
50kW	15 000,00 €	26 000,00 €	1 000,00 €	840,00€
350kW	25 000,00 €	75 000,00 €	2 000,00 €	291,00€

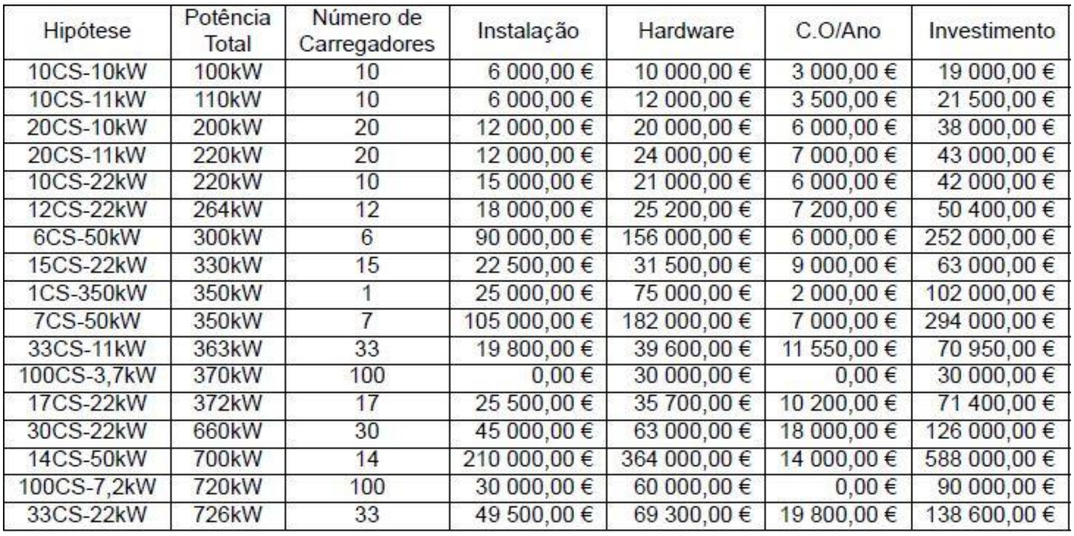
Taking into account the costs associated with the parking lot, it is intended to reach a compromise between the quality of service provided and a dimensioning of the loading architecture that allows the first criterion. To this end, several hypotheses were developed and the total investment of each option is presented in Table 11.

From the simulations of the hypotheses set out above, data were obtained regarding the charging of the EVs, the energy consumed by the car park and delivered to each group of EVs. After 576 periods, the final average SOC values for each group and profile are shown in Table 12.

In a first analysis of Table 11, it is identified that the most expensive option is 14CS-50kW which requires an investment of 588 000€ while the most conservative hypothesis is 10CS10kW which invests 19 000€. The hypothesis 100CS-3,7kW is the only hypothesis that does not have extra installation costs (because they are traditional sockets). Besides this last combination of chargers, the hypothesis 100CS-7,2kW is the only that doesn't require maintenance throughout the year. In terms of installation, only the hypotheses with total power below 100kW and 100CS-3,7kW have installation costs lower than 10 000€ while the hypotheses with 20 chargers show values close to that limit. Additionally, it is noted that the three hypotheses that combine different numbers of 50kW chargers have the highest installation cost. From the point of view of the hardware, it is noted that every hypotheses has an expense equal or greater than 10 000€ while only the hypotheses with 50kW chargers present values over 100 000€. Regarding the annual operating cost, it is observed that for the hypotheses with semi-fast chargers and total power above 360kW, this value is always higher than 10 000€.

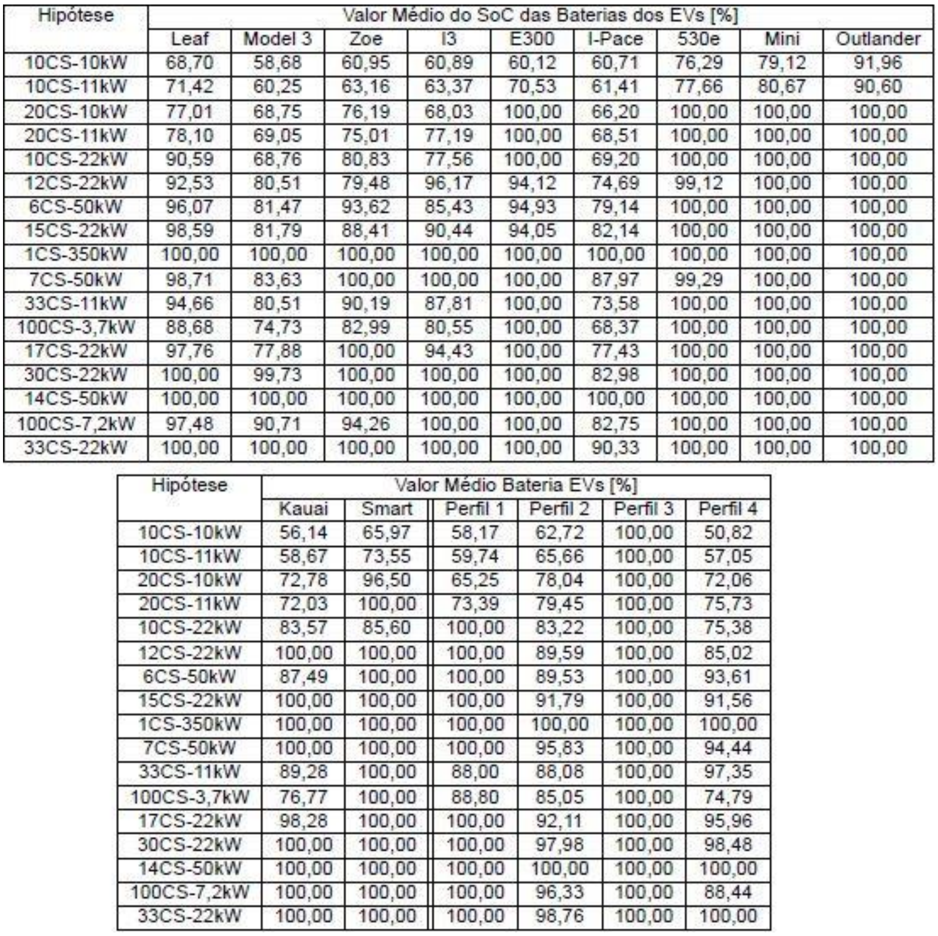
Table 12 shows that all EVs with random behaviour (Profile 3) present a full battery despite the architecture applied. This is due to extended parking intervals that allow the model to fully charge these EVs. Regarding Profile 1, it is identified that combinations of chargers with total power equal to or less 210kW are unable to fully charge these EVs as they reconcile two factors, each charger has several places to charge and the capacity of these chargers is low. Additionally, the simplicity of the hypothesis 100CS-3,7kW doesn't allow the model to perform any type of optimization leading to an average battery value of 88,8%. Regarding Profile 2, only 1CS-350kW and 14CS-50kW achieve full charging which represents the majority of the EVs in the parking lot. It is understood that the two factors that affect the most the final average SOC value are: the total power of

Table 11- Investment for the Development of each Architecture



Hipótese	Potência Total	Número de Carregadores	Instalação	Hardware	C.O/Ano	Investimento
10CS-10kW	100kW	10	6 000,00 €	10 000,00 €	3 000,00 €	19 000,00 €
10CS-11kW	110kW	10	6 000,00 €	12 000,00 €	3 500,00 €	21 500,00 €
20CS-10kW	200kW	20	12 000,00 €	20 000,00 €	6 000,00 €	38 000,00 €
20CS-11kW	220kW	20	12 000,00 €	24 000,00 €	7 000,00 €	43 000,00 €
10CS-22kW	220kW	10	15 000,00 €	21 000,00 €	6 000,00 €	42 000,00 €
12CS-22kW	264kW	12	18 000,00 €	25 200,00 €	7 200,00 €	50 400,00 €
6CS-50kW	300kW	6	90 000,00 €	156 000,00 €	6 000,00 €	252 000,00 €
15CS-22kW	330kW	15	22 500,00 €	31 500,00 €	9 000,00 €	63 000,00 €
1CS-350kW	350kW	1	25 000,00 €	75 000,00 €	2 000,00 €	102 000,00 €
7CS-50kW	350kW	7	105 000,00 €	182 000,00 €	7 000,00 €	294 000,00 €
33CS-11kW	363kW	33	19 800,00 €	39 600,00 €	11 550,00 €	70 950,00 €
100CS-3,7kW	370kW	100	0,00 €	30 000,00 €	0,00 €	30 000,00 €
17CS-22kW	372kW	17	25 500,00 €	35 700,00 €	10 200,00 €	71 400,00 €
30CS-22kW	660kW	30	45 000,00 €	63 000,00 €	18 000,00 €	126 000,00 €
14CS-50kW	700kW	14	210 000,00 €	364 000,00 €	14 000,00 €	588 000,00 €
100CS-7,2kW	720kW	100	30 000,00 €	60 000,00 €	0,00 €	90 000,00 €
33CS-22kW	726kW	33	49 500,00 €	69 300,00 €	19 800,00 €	138 600,00 €

Table 12- Final Average SOC Values for each group and profile - 100 Spots



Hipótese	Valor Médio do SoC das Baterias dos EVs [%]								
	Leaf	Model 3	Zoe	I3	E300	I-Pace	530e	Mini	Outlander
10CS-10kW	68,70	58,68	60,95	60,89	60,12	60,71	76,29	79,12	91,96
10CS-11kW	71,42	60,25	63,16	63,37	70,53	61,41	77,66	80,67	90,60
20CS-10kW	77,01	68,75	76,19	68,03	100,00	66,20	100,00	100,00	100,00
20CS-11kW	78,10	69,05	75,01	77,19	100,00	68,51	100,00	100,00	100,00
10CS-22kW	90,59	68,76	80,83	77,56	100,00	69,20	100,00	100,00	100,00
12CS-22kW	92,53	80,51	79,48	96,17	94,12	74,69	99,12	100,00	100,00
6CS-50kW	96,07	81,47	93,62	85,43	94,93	79,14	100,00	100,00	100,00
15CS-22kW	98,59	81,79	88,41	90,44	94,05	82,14	100,00	100,00	100,00
1CS-350kW	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
7CS-50kW	98,71	83,63	100,00	100,00	100,00	87,97	99,29	100,00	100,00
33CS-11kW	94,66	80,51	90,19	87,81	100,00	73,58	100,00	100,00	100,00
100CS-3,7kW	88,68	74,73	82,99	80,55	100,00	68,37	100,00	100,00	100,00
17CS-22kW	97,76	77,88	100,00	94,43	100,00	77,43	100,00	100,00	100,00
30CS-22kW	100,00	99,73	100,00	100,00	100,00	82,98	100,00	100,00	100,00
14CS-50kW	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
100CS-7,2kW	97,48	90,71	94,26	100,00	100,00	82,75	100,00	100,00	100,00
33CS-22kW	100,00	100,00	100,00	100,00	100,00	90,33	100,00	100,00	100,00

Hipótese	Valor Médio Bateria EVs [%]					
	Kauai	Smart	Perfil 1	Perfil 2	Perfil 3	Perfil 4
10CS-10kW	56,14	65,97	58,17	62,72	100,00	50,82
10CS-11kW	58,67	73,55	59,74	65,66	100,00	57,05
20CS-10kW	72,78	96,50	65,25	78,04	100,00	72,06
20CS-11kW	72,03	100,00	73,39	79,45	100,00	75,73
10CS-22kW	83,57	85,60	100,00	83,22	100,00	75,38
12CS-22kW	100,00	100,00	100,00	89,59	100,00	85,02
6CS-50kW	87,49	100,00	100,00	89,53	100,00	93,61
15CS-22kW	100,00	100,00	100,00	91,79	100,00	91,56
1CS-350kW	100,00	100,00	100,00	100,00	100,00	100,00
7CS-50kW	100,00	100,00	100,00	95,83	100,00	94,44
33CS-11kW	89,28	100,00	88,00	88,08	100,00	97,35
100CS-3,7kW	76,77	100,00	88,80	85,05	100,00	74,79
17CS-22kW	98,28	100,00	100,00	92,11	100,00	95,96
30CS-22kW	100,00	100,00	100,00	97,98	100,00	98,48
14CS-50kW	100,00	100,00	100,00	100,00	100,00	100,00
100CS-7,2kW	100,00	100,00	100,00	96,33	100,00	88,44
33CS-22kW	100,00	100,00	100,00	98,76	100,00	100,00

the car park and the number of spaces associated with each charger. The latter is directly linked with the proposed method since the distribution of power for different EVs is at the base of this controller. Regarding the fourth profile, 3 hypotheses show a full charging of the 10 EVs belonging to this group. Since its parking periods are very short, these vehicles are highly dependent on the distribution of power. In percentage terms, EVs with greater capacity (Tesla Model 3 and Jaguar I-Pace) are vehicles with less charged batteries at the end of the simulation because more energy is needed for your full load. On the contrary, hybrid vehicles with the lowest battery capacities obtain better performances.

Through a deep analysis of the performance and economic weight of each hypothesis, also according to the proposed power management and distribution methodology, the hypotheses recommended for construction and installation in the large-scale adoption of EVs are: 15CS-22kW, 1CS-350kW, 17CS-22kW as they guarantee the good charging of the vehicles while minimizing the economic effort associated with the application of the scenario.

For the 15CS-22kW and 17CS-22kW hypotheses, was studied the possibility of having VIP vehicles as the 1CS-350kW presents a full charging for any EV in that car park. From this study, firstly, the premium option presents less impact for a park of this size because, on average, they show increases lower than 10% of the EVs battery. Second, centralized architectures have again better performances. In this case, 15CS-22kW presents gains up to 8% of the EV battery, while 17CS-22kW shows increases of less than 5% even though it has 2 more chargers with 22kW

Lastly, it is identified that the proposed model is capable of optimizing the charging of EVs in parking lot independently of the charging architecture except for the cases where there are only individual chargers. In those cases, due to its simplicity, it is impossible to optimize the distribution of energy.

6. Conclusions

The increasing integration of EVs in the power network has created new challenges that put at risk the stability of the grid. In this work, it is proposed a controller for the EVs charging that optimizes the distribution of energy. Although the model only has technical goals, an economic assessment was made into the charging stations costs to complete the applicability of the methodology. The proposed model helps to minimize the integration impact of electric vehicles through the development of charging architectures that present good performance while minimizes the investment. Through the simulation of different scenarios, it was possible to reach that this model has a better performance when applied to charging architectures that have centralized chargers. Although the premium users seem to be an important decision to increase the revenue of the parking lot, it has shown that for long parking duration, its impact is reduced. The last case study shows that the model is capable of optimizing the charging of EVs despite the scenario presented. It also shows that during the simulation, the complexity diminishes allowing faster-charging solutions.

Therefore, it is possible to conclude that the mode of optimization and control of the charging system for parking lots is capable of providing an intelligent distribution of power to minimize the impact of EVs integration

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