Parking Lot operation management considering V2X and renewable generation

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João Maria Botelho Brum
Instituto Superior Técnico, Lisbon, Portugal

***Abstract*—The rapid growth of the electric vehicle (EV) market has emphasized the need for sustainable transport as one of the solutions to reducing carbon emissions and mitigating environmental impact. The goal of this thesis is to explore and evaluate the benefits of using a solar system and Vehicle-to-Everything (V2X) technology in a parking lot with EV charging.**

The goal is to improve park performance, reduce operational costs, and increase the efficiency of electric vehicle charging.The research begins with a review of the literature on current trends in the automotive industry, with a focus on the growing popularity of electric vehicles and the need for adequate infrastructure to support their use. In addition, the importance of solar energy as a renewable and sustainable source capable of providing clean electricity to yield the same or better results in the EV charging process, while reducing reliance on fossil fuels.

Aside from that, V2X technology will be explored, which allows for bidirectional communication between electric vehicles and electric infrastructure. It will be proposed to integrate V2X resources into the parking lot, allowing electric vehicles to be used as energy storage units capable of providing power to the network or to the park's facilities.

***Index Terms*—Electric vehicle charging; Solar power system; Renewable energy integration; Charging optimization; Discharge; Vehicle-to-Everything (V2X).**

I. INTRODUCTION

The electric vehicle (EV) market has grown rapidly as the world is trying to prioritizes lowering carbon emissions to reduce the impact on the planet. Thus the Greenplan 2050's was set in motion with the goal to lower carbon emissions by making electric cars a viable alternative to today's internal combustion engine cars. Scheduled or smart charging of EVs can considerably reduce peak demand for electricity and avoid local grid congestion. The use of smart charging strategies will reduce the cost of providing accessible and affordable EV charging stations. As a result, one of the most significant barries to EV adoption is the absence of accessible charging stations.

The ability of a plug-in hybrid electric vehicle (PHEV) to connect to the power grid and operate as a vehicle-to-grid (V2G) makes it a unique subject for studying how EVs connect to the power grid. PHEVs have a power cord that lets them connect to the utility grid. This means that they can not only get power from the grid, but they can also send power back to the grid. With this ability, V2G can help power buildings with enough energy from their battery, which can be charged at a different location, [1]. V2G helps the power grid by storing energy as a backup when its battery pack is used to meet demand and lower system overload. V2G will also improve the quality of the power by making it easier to control the voltage and reducing power outages. It will do this by adding reactive and active power to the grid and not having to build new power plants. Previous research conducted on V2G control such as an autonomous distributed V2G control of grid connected PHEV and EV by coordinating battery condition, use for vehicle, and power system state.

II. STATE OF THE ART

A. EV Charging in Parking Lots

Scheduled or smart charging of EVs can considerably reduce peak demand for electricity and avoid local grid congestion. The use of smart charging strategies will reduce the cost of providing accessible and affordable EV charging stations. As a result, one of the most significant barries to EV adoption is the absence of accessible charging stations. Smart charging can help increase the penetration of renewables in the mobility sector by aligning EVs charging with the availability of locally produce renewable energy (such as local energy provided by solar photovoltaics). Knowledge of future electricity demands and renewable energy production is required for EV charge scheduling schemes that aim to educe local peak demand and congestion.

The ability of a PHEV to connect to the power grid and operate as a V2G makes it a unique subject for studying how EVs connect to the power grid. PHEVs have a power cord that lets them connect to the utility grid. This means that they can not only get power from the grid, but they can also send power back to the grid. With this ability, V2G can help power buildings with enough energy from their battery, which can be charged at a different location, [1]. V2G helps the power grid by storing energy as a backup when its battery pack is used to meet demand and lower system overload. V2G will also improve the quality of the power by making it easier to control the voltage and reducing power outages. It will do this by adding reactive and active power to the grid and not having to build new power plants. Previous research conducted on V2G control such as an autonomous distributed V2G control of grid connected PHEV and EV by coordinating battery condition, use for vehicle, and power system state.

B. EV management in parking lots

Several publications on the management of EVs have recently been published. Recently, in [2], an assessment of the vehicle-to-everything mode of operation of EVs was provided, which examined the integration of vehicles in electric grids, households, and between vehicles. However, there is no mention of parking lot integration or management. *Kuran et al.* [3], a framework for managing EVs in a parking lot is provided, taking into account the high degree of information shared between the EVs and the parking lot management system. The major purpose of the architecture proposed in [3] is to optimise the energy supplied to EVs based on their needs (energy for next travel). Parking lot management is also addressed in [4], which proposes three different methods: 1) first-come, first-served [5], 2) priority based on departure timetable [6], and 3) the authors' decision-making algorithm The choice is made using two decision levels: arrival time and an EV scoring system based on the difference between the necessary and actual level of SOC. In comparison to [3–6], the approach given in this study differs from those proposed in prior studies since the parking lot management system lacks information on departure time and energy requirements. This is an important aspect because this knowledge is not available in the real world. Parking lot management considers parking lot operator (PLO) participation in electricity markets with the primary goal of profit maximisation [7]. According to [8], the real-time availability forecast method uses a combination of current (on-line) and historical data to anticipate parking facility availability in real time. This research employs an algorithm that works with both actual and simulated data.

C. Solar System in Parking EV Charging

Solar power is clean, free, and sustainable. Solar plants produce no greenhouse gases during their lifetimes. Photovoltaic (PV) technology also develops new applications. These upgrades let utilities diversify their energy portfolios with a lot of renewable electricity. Ground-mounted PV, rooftop PV, building-integrated PV (BIPV), and parking-shaded PV are some PV usage. Unfortunately, solar energy harvesting has various drawbacks that worry utilities, investors, and regulators. Thus, solar radiation inadvertences prevent widespread utilisation. Another solar energy obstacle is photovoltaic efficiency. Grid-connected PV system efficacy has been studied [9, 10]. Renewable energy can supply increased electricity demand while protecting the environment. Thus, the falling cost of PV panels is increasing the use of this solar-dependent technology, which decarbonizes the entire electrical sector [11].

Turan et al. [12] examines the use of renewable energy in parking lot management. In this scenario, parking lot management is linked with solar generation from a rooftop PV system. The problem is examined from the standpoint of a distribution system, with the parking lot serving as a flexible load. Scheduling of EV charging and discharging with consideration for the influence on the distribution network is also examined in [13] , which proposes a decentralised management algorithm. *Sadeghi et al.* [14] presents optimal scaling of hybrid renewable energy systems with EVs using two algorithms: multi-objective particle swarm optimisation (MOPSO) and multi-objective crow search (MOCS). *Jiang and Zhen* [15] also includes an examination of a parking lot with a PV system with the goal of evaluating the solar energy potential in parking lots and maximising the usage of the energy generated by the PV system to charge the EV batteries.

D. Solar System Economic Analysis

Solar photovoltaic installations are considered an unexplored prospect in numerous parking lots worldwide. The parking lot shaded photovoltaic system (PLSPVS) exhibits superior efficiency compared to the conventional ground-mounted system, and its performance remains unaffected by the shading of its surroundings. In [16], the utilisation of solar shading in parking lots is a space-efficient approach that can be implemented in various locations within load centres, including but not limited to workplaces, shopping malls, hospitals, airports, industrial halls, and universities. As per the literature, the utilisation of parking spaces for solar shading is a productive strategy that enables the generation of electricity and provision of shade simultaneously [11].

E. Vehicle-to-Everything (V2X) approaches in parking lots

V2X is the capability of the EVs exchange energy (consume and supply energy) with the environment were is connected. As environment, it is possible to refer, houses, buildings, energy communities, parking lots and directly with distribution network. According to [17], V2G is an optimization problem. The objective of the V2G scheduling is to minimize total running cost which includes mainly fuel cost and startup cost. In order to accomplish this some constraints have to be satisfied during the optimization process such as: charging-discharging frequency, system power balance, state of charge, efficiency and ramp rate.

The authors [18] presented a comprehensive analysis of vehicle-to-anything (V2A) operations. They proposed a detailed framework and mathematical models for vehicle-to-home (V2H), V2G, and vehicle-to-vehicle (V2V) operations. The utilisation of V2H, V2G, and V2V operations can effectively achieve objectives such as minimising costs, reducing power losses, mitigating peak loads, and providing reactive power support. *Shafie-khah et al.* [19] investigated the optimal operation of electric vehicle parking lots (EVPLs) through the utilisation of price-based and incentive-based demand response (DR) programmes. The researchers employed a stochastic programming approach in their analysis.

Wang et al. [20] presented a V2V coordination approach aimed at facilitating energy transfer among mobile electric vehicles. EVs that have surplus energy and those that require charging were consolidated through aggregators. The objective of the study referenced as [20] was to reduce the charging expenses incurred by EVs requiring energy while simultaneously increasing the revenue generated by EVs that supply energy. However, the study did not take into account the potential contributions of PV systems and V2G technologies. *Chacko and Sachidanandam* [21] designed a charging station that incorporates solar panels and backup batteries in order to address the adverse effects of EVs on the power grid, while taking into account V2V communication. The study was formulated as a multi-objective optimisation model with the aim of minimising the expenses associated with electric vehicle charging, maximising the revenue generated by electric vehicles, and mitigating the emissions produced by plug-in hybrid electric vehicles.

III. PROPOSED METHODOLOGY

A. Previous Study

Given that this thesis bases itself upon a prior case study [22], it is imperative to present the initial values and proposed methodology in order to enhance comprehension of the present work.

B. Parking lot constraints

All charging stations should have less power than the parking lot's capacity. The power transformer, cable thermal restrictions, or contractual capacity determine this capacity. Charging stations CS first apply the power limit to EVs.

$$\sum_{CS=1}^{N_{CS}} \frac{P_{maxCS(CS,T)}}{\eta_{CSt(CS)}} \leq P_{maxPark(t)} \forall t \in \{1,...,T\} \tag{1}$$

1) Charge Stations constraints: The charging station power should be lower than its maximum capacity (technical constraint) and lower than the upper-level energy management system's maximum power (particularly if integrated with buildings management). $X_{Place(EV,CS,t)}$ indicates if the EV is connected to the CS in period *t*. Since the same car might be linked to different charging stations, this value can be dynamic. In period *t*, the EV is not connected to a CS, hence its power charge is 0. Charging stations have many outlets. Each plug provides the charging station's whole power. Modelling outlets requires no further limitations. $X_{Place(EV,CS,t)}$ is 0 for all periods when charging stations are unavailable due to technical reasons.

$$\begin{gathered}\sum_{EV=1}^{N_{EV}} P_{ch(EV,T)} \leq P_{maxCS(CS,t)}.X_{Place(EV,CS,t)} \\ \forall CS \in \{1,...,N_{CS}\}; \forall t \in \{1,...,T\}\end{gathered} \tag{2}$$

2) Electric Vehicles constraints: The power charge should be less than each EV's maximum power Eq 3. The EV also prohibits power charges below Eq 4. This figure can vary by EV and battery SOC. If the parking lot or charging station's power is less than the EV's minimal power ($P_{minCh(EV,t)}$), the variable $X_{Ch(EV)}$ will be 0, preventing infeasible solutions. The power charge is restricted by the energy needed by electric car batteries Eq. 5 to reach 100% SOC. Time Factor (TF) represents the power-energy relationship between one hour and each period *t*. TF is 1/60 for 1 min. Each EV's energy should be updated based on its prior condition (*t*-1) and the power charged in period t. Batteries should have less energy than the maximum. The system receives SOC data when the EV arrives at the parking lot (*t* = 0). Because the parking lot management system has no EV journey history.

$$\begin{gathered}P_{ch(EV,T)} \leq P_{maxCh(EV,t)}.X_{Ch(EV,t)} \\ \forall EV \in \{1,...,N_{EV}\}; \forall t \in \{1,...,T\}\end{gathered} \tag{3}$$

$$\begin{gathered}P_{ch(EV,T)} \geq P_{minCh(EV,t)}.X_{Ch(EV,t)} \\ \forall EV \in \{1,...,N_{EV}\}; \forall t \in \{1,...,T\}\end{gathered} \tag{4}$$

$$\begin{gathered}P_{ch(EV,t)} \leq (1 - SOC_{EV,t}).\frac{E_{max(EV)}}{TF} \\ \forall EV \in \{1,...,N_{EV}\}; \forall t \in \{1,...,T\}\end{gathered} \tag{5}$$

$$\begin{gathered}E_{(EV,t-1)} + P_{ch(EV,t)}.TF = E_{(EV,t)} \\ \forall EV \in \{1,...,N_{EV}\}; \forall t \in \{1,...,T\}\end{gathered} \tag{6}$$

$$E_{(EV,t)} \leq E_{max(EV)} \forall EV \in \{1,...,N_{EV}\} \tag{7}$$

3) Parking rules constraints: Chargers and parking lots can be used fairly with few restrictions. Weighted penalties establish the rules. Optimisation uses these penalization's. Minimum Power Charge penalty, Eqs. 8, 9 - The fundamental idea is to charge each EV with a minimal power at each instant *t*. Users (parking lot manager) can set this value for each car and period. If the energy needed to fully charge the EV is less than the minimum power, modify the value. The objective function will penalise the solution if the system cannot provide the minimal power charge. State of Charge level penalties the SOC-level penalization factors prioritise low-SOC EVs. Consider three levels. Critical is 0–50% SOC. EVs with SOCs below level 1 should be prioritised. Level 3 (80–90% SOC) is low priority. EVs with SOCs above 3 have ample energy for daily use.

Level 2 is between 1 and 3. Before optimisation, calculate each level's EV power. The optimisation value should be 0 if the SOC level is higher than required. The parking lot manager accepts premium subscriptions. In such instance, VIPs (extremely important people) with privileged contracts will have priority over other users with similar SOC levels. Because of this, the power factor restrictions and objective function can be penalised. Eq. 10 limits active power for the sum of the three levels. Eqs. 11, 12, 13 define SOC levels. The formulae define the charging power needed to reach each level based on present SOC and necessary SOC. Eq. 13 caps each level's charging power at the EVs maximum. Maximum power charge variation, Eq. 14, this penalty limits power charge changes in successive periods to prevent charging level fluctuations. Only charging power loss is limited.

Minimum SOC, Eq. 15,is the minimum SOC of all EVs in the parking lot is penalised to prioritise vehicles with lower SOC. The previous punishment factor was Power-based, whereas this one is percentage-based. When two EVs arrive at the parking at the same time, the system will prioritise the one with the lower SOC. This penalization complements the SOC level penalization that favours some EVs over others with the same SOC level.

This penalization element involves upper management (operational planning or real-time) setting a parking lot power operation setpoint. The upper level might be a complicated management tool or a basic specification of power operations levels based on electricity pricing. If the price exceeds a predefined figure, the maximum power setpoint, Eq. 16, can be lower than technical limits.

$$\begin{gathered} P_{MCP(EV,t)} - PF_{MCP(EV,t)} \leq P_{ch(EV,t)} \\ \forall EV \in \{1,...,N_{EV}\}; \forall t \in \{1,...,T\} \end{gathered} \tag{8}$$

$$\begin{gathered} P_{MCP(EV,t)} = \\ min\left(P_{minMCP(EV,t)}; (1 - SOC_{EV,t}).\frac{E_{max(EV)}}{TF}\right) \\ \forall EV \in \{1,...,N_{EV}\}; \forall t \in \{1,...,T\} \end{gathered} \tag{9}$$

$$\begin{gathered} P_{SocL1(EV,t)} - PF_{SocL1(EV,t)} + \\ P_{SocL2(EV,t)} - PF_{SocL2(EV,t)} + \\ P_{SocL3(EV,t)} - PF_{SocL3(EV,t)} \leq P_{ch(EV,t)} \\ \forall EV \in \{1,...,N_{EV}\}; \forall t \in \{1,...,T\} \end{gathered} \tag{10}$$

$$\begin{gathered} P_{SocL1(EV,t)} = \\ max(0; (P_{SocL1max(Ev,t)} + P_{VIPL1(EV,t)} - \\ SOC_{(EV,t)}).\frac{E_{max(EV)}}{t_{period}}) \forall EV \in \{1,...,N_{EV}\}; \\ \forall t \in \{1,...,T\} \end{gathered} \tag{11}$$

$$\begin{gathered} P_{SocL2(EV,t)} = \\ max(0; (P_{SocL1max(Ev,t)} + P_{VIPL2(EV,t)} - \\ SOC_{(EV,t)}).\frac{E_{max(EV)}}{t_{period}}) \forall EV \in \{1,...,N_{EV}\}; \\ \forall t \in \{1,...,T\} \end{gathered} \tag{12}$$

$$\begin{gathered} P_{SocL3(EV,t)} = max\left(0; SOC_{(EV,t)}.\frac{E_{max(EV)}}{t_{period}}\right) \\ \forall EV \in \{1,...,N_{EV}\}; \forall t \in \{1,...,T\} \end{gathered} \tag{13}$$

$$\begin{gathered} P_{Ch(EV,t-1)} - P_{Ch(EV,t)} + \\ PF_{VarP(EV,t)} \leq \Delta P_{Ch(EV,t)} \\ \forall EV \in \{1,...,N_{EV}\}; \forall t \in \{1,...,T\} \end{gathered} \tag{14}$$

$$\begin{gathered} PF_{minSOC(t)} \leq SOC_{(EV,t)} \forall EV \in \{1,...,N_{EV}\}; \\ \forall t \in \{1,...,T\} \end{gathered} \tag{15}$$

$$\begin{gathered} \sum_{CS=1}^{N_{CS}} P_{maxCSt(CS,t)} - PF_{PParking(t)} \leq P_{ParkingSet(t)} \\ \forall CS \in \{1,...,N_{CS}\} \forall t \in \{1,...,T\} \end{gathered} \tag{16}$$

4) Objective Function: Each period *t*, the target function minimises parking lot rule penalties to charge electric automobiles in a fairway.

$$\begin{gathered} f(t) = min \sum_{EV=1}^{N_{EV}} [PF_{MCP(EV,t)} \times PW_{MCP(EV,t)} + \\ PF_{SocL1(EV,t)} \times (PW_{SocL1(EV,t)} + PW_{VL1(EV,t)}) + \\ PF_{SocL2(EV,t)} \times (PW_{SocL2(EV,t)} + PW_{VL2(EV,t)}) + \\ PF_{SocL3(EV,t)} \times (PW_{SocL3(EV,t)} + PW_{VL3(EV,t)}) + \\ PF_{VarP(EV,t)} \times PW_{VarP(EV,t)}] - \\ PF_{minSOC(t)} \times PW_{minSOC(t)} + \\ PF_{PParking(t)} \times PW_{PParking(t)} \end{gathered} \tag{17}$$

5) F-Index: The suggested model's fairness index (F-Index), described in Eq. 18, can be calculated as the average of the state-of-charge (SOC) of EVs at departure time (t_{last}). Given that the system lacks knowledge on the SOC required by the EVs, in an ideal world, all of the EVs would have 100% SOC and the F-Index would be 1. Only EVs with a lower fairness level (50%) will be evaluated to avoid the impact of EVs with low energy requirements. To emphasise the EVs with lower SOC, a second term that comprised only the 10% EVs with lower SOC was introduced. This means that the F-Index is a quadratic function of the SOC of the EVs leaving the parking lot with the lowest SOC (in percentage).

$$\begin{gathered} F - Index = \frac{\Sigma_{EV=1}^{0.5 \times N_{EV}} SOC_{(EV,t_{last})}}{N_{EV}} \times \\ \frac{\Sigma_{EV=1}^{0.1 \times N_{EV}} SOC_{(EV,t_{last})}}{N_{EV}} \end{gathered} \tag{18}$$

C. Solar System Implementation

In [23],the study evaluates the net value of installing PV panels on a solar parking lot over the lifetime of the panels, taking into account the presence or absence of energy storage. The analysis takes into account the expenses of purchasing PV panels and a battery, as well as the advantages of charging PEVs with free energy from PV panels.

To simplify the approach the following equation was implemented to approximately calculate the solar production of a solar system with $SolarPowerOutput$ being (kW):

$$SystemPower = PV_{Power} \times Efficiency \tag{19}$$

$$\begin{gathered} SolarPowerOutput(t) = SystemPower \times \\ \sin \frac{\pi \times t - dayStart}{dayEnd - dayStart} \quad \forall t \geq 1,...,T \end{gathered} \tag{20}$$

The following graph serves as a visual representation of the system implemented regarding that it only starts producing energy at sunrise and stops at dawn.

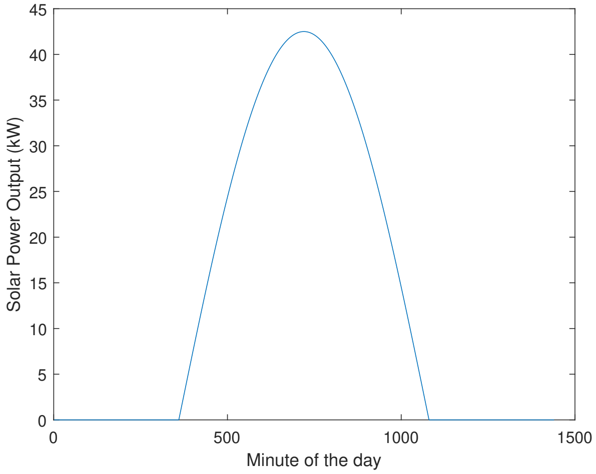

Fig. 1: Solar Curve implemented for a random $SystemPower(kW)$.

To test how much can the solar system can improve the park F-Index three tests were conducted with different System Powers of 50kWp, 100kWp, 150kWp, 200kWp, where all of them had 100 EVs.

D. Economical Study

To better evaluate if the solar system is reliable not only in terms of providing the charging capacity to the parking lot, it is proposed an economical study to evaluate the break-even point of installing a system like such.

Standard testing conditions (STC), were used to measure these criteria. The STCs are as follows: 1) 25°C cell temperature, 2) 1000 W/m^2 irradiance, and 3) an air mass of 1.5 spectrum.

As such here are the conditions of the proposed solar system, taking into account that the amount of panels will increase according to the case. Furthermore, it has been proposed that the PLSPVS be implemented as a fixed-tilt, non-tracking system oriented at a 20-degree southern tilt angle to optimise its ability to capture solar irradiance throughout the year, we have the following general configuration in Tables II and I.

TABLE I: Solar Module Parameters

Peak Power (Wp)	500
Area (m^2)	2.58
Price per watt (€/W)	0.23

PV arrays often generate power output that is lower than their STC rating, primarily due to variations in real-world conditions that differ from those specified under STC. Possible real-world scenarios that may affect photovoltaic cell performance include elevated cell temperatures, reduced irradiance levels, and accumulation of dirt or other contaminants on the module surface. Upon factoring in the projected energy losses, it can be inferred that the photovoltaic system proprietor will experience an operational output of approximately 85% of the standard test conditions rating. Given the persistent nature of these losses, it is possible to oversize the PV array beyond the power rating of the inverter.

TABLE II: General PV System configuration

System Parameters				
Azimuth	180º			
Inclination	20º			
System Efficiency	85%			
Nº of Panels	115	230	345	460
Peak Power (kWp)	57.5	115	172.5	230
Output Power (kW)	50	100	150	200

Given that a single carport has the capacity to accommodate 100 modules and can provide parking space for 25 electric vehicles, it is proposed to augment the number of carports by one in each instance of peak power testing, which would result in an associated increase in cost.

In addition, in order to have a better understanding of the extent to which the park will profit from the installation of a solar power system, an analysis of how much energy the park was consuming daily was taken into account by simply summing the power used by each station through the day, as shown in Eq. 21.

$$DailyPowerConsumption = \sum_{CS=1}^{100} \frac{P_{ch(EV,t)}}{60} \quad \forall t \in 1, ..., T \tag{21}$$

Also we have to take into account the daily power generated by our solar system into consideration that it was set to have sun for 12h a day and that can be achieved in Eq. 22 using the results from Eq. II.

$$DailySolarProd = \sum \frac{SolarPowerOutput(t) \times 12}{60 \times 24} \quad \forall t \in 1, ..., T \tag{22}$$

To calculate the break-even point in Eq. 24 it was taken into the account that the electricity tariff is around 0.17€/kWh and the price per kWp for a solar system with carports would be around 1.1€/Wp. With this and using Eq. 23, we can calculate the yearly energy production from out solar system, in €.

$$YearlyProduced = DailySolarProduction \times 365. \tag{23}$$

$$BreakEven = \frac{TotalCost}{YearlyProd \times ElectricityPrice} \tag{24}$$

E. V2X Discharge Method

In this section it was implemented the method V2X discharge where the EVs could discharge their batteries to charged adjacent EVs charging in the park. To implement this method a few changes had to be made. First we have to check if the vehicles can discharge and that could only happen after having their SOC at least at 95%, then the vehicle could not discharge completely so a discharge threshold was set at 80% SOC. It is important to note that during the discharge process the vehicles cannot suddenly charge again, it can only discharge or charge, therefore when the SOC hits 80% the EV goes back to charging mode. As it is shown in Eq. 25

$$\begin{aligned} P_{maxDch(EV,t)} = \\ (SOC_{(EV,t)} - DischargeBoundary) \\ \times EV_{BatteryCapacity(EV,t)} \\ \forall t \in 1, ..., T \end{aligned} \tag{25}$$

It is important to understand that with this configuration in Eq. 25, the closer to 95% SOC, the faster the vehicle will discharge depending on his maximum charge/discharge rate and the closer it gets to the Discharge Boundary of 80%, the slower it discharges, until it stops.

Remember the goal is to optimize the F-Index result and have all the vehicles leave with higher SOC on t_{last}, which is the moment before leave the park.

1) Discharge Objective function: The objective function which we want to minimize on the model also changes to take into account the discharge of the vehicle in the optimization model, as shown in Eq. 26

$$\begin{aligned} f(t) = min \sum_{EV=1}^{N_{EV}} [PF_{MCP(EV,t)} \times PW_{MCP(EV,t)} + \\ PF_{SocL1(EV,t)} \times (PW_{SocL1(EV,t)} + PW_{VL1(EV,t)}) + \\ PF_{SocL2(EV,t)} \times (PW_{SocL2(EV,t)} + PW_{VL2(EV,t)}) + \\ PF_{SocL3(EV,t)} \times (PW_{SocL3(EV,t)} + PW_{VL3(EV,t)}) + \\ PF_{VarP(EV,t)} \times PW_{VarP(EV,t)} + \\ PF_{Dch(EV,t)} \times PW_{PDch(EV,t)}] - \\ PF_{minSOC(t)} \times PW_{minSOC(t)} + \\ PF_{PParking(t)} \times PW_{PParking(t)} \end{aligned} \tag{26}$$

This implementation of the objective function takes into account the penalization factor of the discharging EV in order optimize the charging for all EVs.

IV. NUMERICAL RESULTS

A. Base Study Results for comparison

In this section, we present the numerical results obtained from our study, utilizing the program developed in [22]. Our aim was to establish a baseline of comparison for evaluating the effectiveness of integrating solar energy and V2X discharge in parking lots. To ensure a fair assessment, we focused on analyzing the power capacity of the parking lots, limiting the grid power of the park to a maximum of 100 kW.

To ensure comprehensive analysis, we considered four distinct cases representing varying CS configurations. These cases are as follows:

1) Case 1: In this scenario, we examined a parking lot equipped with 100 charging stations, each capable of delivering a maximum output of 7.2 kW.
2) Case 2: The second case focused on a parking lot featuring 20 charging stations, each with a maximum output of 22 kW.
3) Case 3: We explored a scenario where the parking lot consisted of only three high-power charging stations, each capable of delivering a maximum output of 120 kW.
4) Case 4: Finally, we investigated a single charging station with a maximum output of 250 kW.

Figures **??** and 2, along with table III, serve as the foundational benchmarks for comparison in the subsequent sections. In these sections, we will provide a comprehensive analysis of the numerical results, emphasising the significant findings and implications for each case.

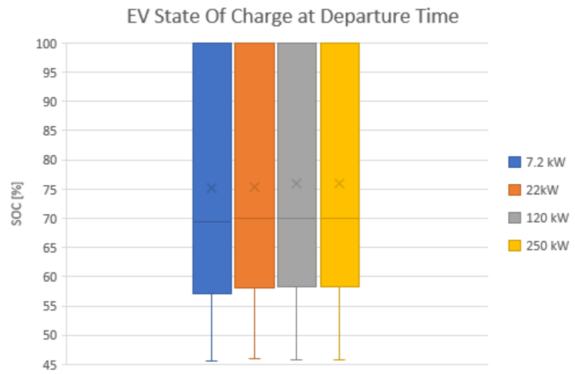

Fig. 2: EV State of Charge at Time of Departure

TABLE III: F-Index results for each base case

CS	F-Index
7.2 kW	0.2691
22 kW	0.2874
120 kW	0.2861
250 kW	0.2861

B. Solar System Implementation results

Four distinct solar power systems were implemented for each case, with varying capacities. The study under consideration analysed solar power capacities of 50 kW, 100 kW, 150 kW, and 200 kW. With this we can analyse the effects of varying solar power capacities on the charging performance, energy consumption, and grid interaction across different scenarios.

To better visualise the results we just obtained the following figures 3,4,5 and 6 shows the EVs state of charge at departure time for every single case mentioned with the 4 solar power implementations.

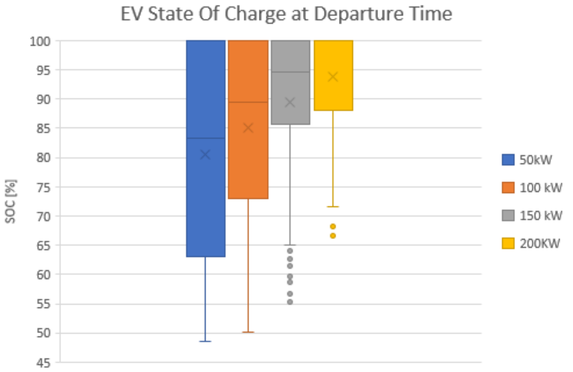

Fig. 3: EV State of Charge at Departure time for each solar system implemented for case 1

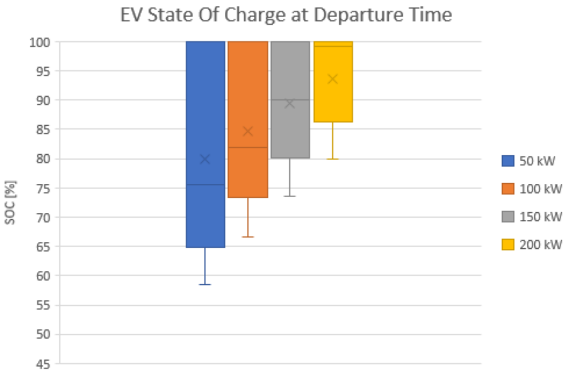

Fig. 4: EV State of Charge at Departure time for each solar system implemented for case 2

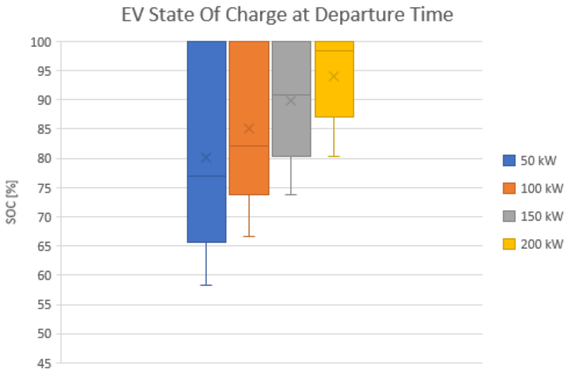

Fig. 5: EV State of Charge at Departure time for each solar system implemented for case 3

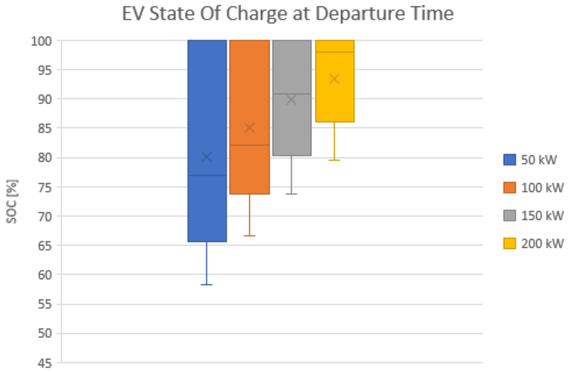

Fig. 6: EV State of Charge at Departure time for each solar system implemented for case 4

As such the results for F-Index evaluation each case are represented in table VI

TABLE IV: F-Index results for each case with the four implementations of solar power.

Solar Power (kW)	Case 1	Case 2	Case 3	Case 4
50	0.3320	0.3912	0.3911	0.3911
100	0.3968	0.4930	0.4972	0.4972
150	0.4735	0.5982	0.6030	0.6030
200	0.6457	0.7085	0.7158	0.7005

The results that are shown in table VI make one thing abundantly clear: the superiority of the outcomes is directly proportional to the rate at which the vehicle may be charged.

It stands to reason that the more power we add to the solar system, the better it will be. This is due to the fact that we will be able to accomplish fast charging much sooner if the energy is accessible (there is sun), and the station will be able to give it with relative ease.

C. Economic Evaluation

To calculate the break-even point we first need to know how much solar energy our system if going to produce. Accurately determining the appropriate size of a photovoltaic (PV) array for connection to an inverter necessitates the ability to forecast the power output that will be generated throughout a full year.

As a result, the input rating of the solar power inverter was selected to be equivalent to that of the PV array in order to ensure secure and effective operations for the grid-tied PV system. On table V it represents the daily energy production of sun with each type of implementation.

TABLE V: Solar Energy Production

Solar Power (kw)	Daily(kWh)	Yearly (kWh)
50	142	51.830
100	416	151.840
150	624	227.760
200	821	299.665

As a consequence of this, in order to determine the point at which each scenario becomes profitable, and since we concluded that the required energy for every case is mostly the same it will only be considered case one, which leads to the following results:

TABLE VI: Break-Even Point for each case for a system power.

System Power (kW)	Cost (€)	Break-Even (years)
50	55.000	3.12
100	110.000	2.16
150	165.000	2.16
200	220.000	2.16

According to the example presented and the data in table VI, it appears that the break-even point stabilises. However, it should be noted that this analysis does not take into account the decreasing prices as the kWp installed increases, which would likely result in a faster break-even point. Moreover, the analysis fails to account for the partial absorption of energy by the park, as there exist periods during the day when the energy is not exclusively allocated towards charging electric vehicles, but rather directed towards the grid.

D. V2X discharge and Solar Power

1) V2X discharge Without Solar Power: Prior to examining the outcomes pertaining to the solar system, it is imperative to inspect the impact of V2X discharge on the SOC of the vehicles. It is noteworthy to reiterate that the park maximum power is presently set at 100kW for the entire day. Nevertheless, it should be noted that the aggregate energy consumption may still increase, given the incorporation of localised solar energy into the park's energy supply as opposed to relying solely on grid-based sources.

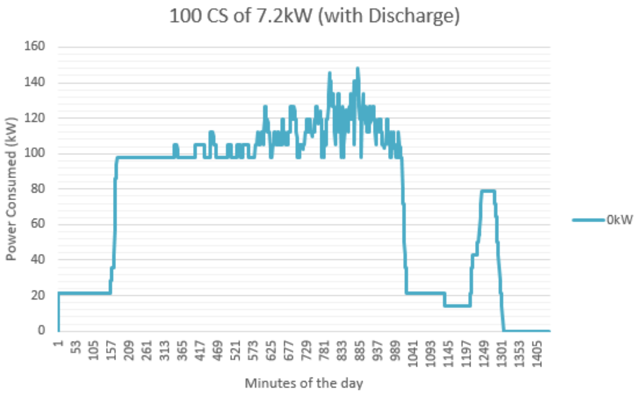

Fig. 7: Power Consumed for one hundred 7.2kW CS with V2X discharge.

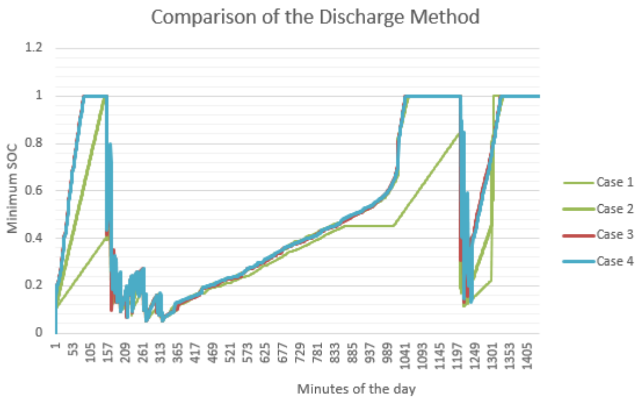

Fig. 8: Comparison between the 4 cases of V2X discharge without any solar power added.

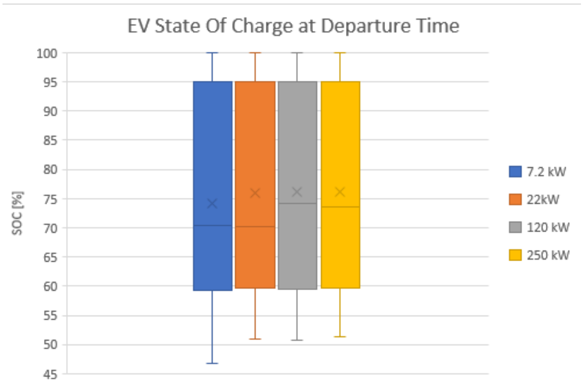

Fig. 9: Comparison between the 4 cases of V2X discharge without any solar power added.

TABLE VII: F-Index results for each case of V2X discharge without solar power.

Case	F-Index
1	0.2859
2	0.3210
3	0.3231
4	0.3258

As illustrated in figure 8, the utilisation of the V2X discharge method in Case 1, as shown in figure 7, did not yield satisfactory results. This can be attributed to the insufficient power supply of the charging stations, resulting in prolonged charging times that prevent EVs from reaching full 100% SOC. Consequently, these EVs cannot discharge as they are superseded by other vehicles with higher charging priority.

2) V2X discharge With Solar Power.: In our study, we incorporated V2X discharge capabilities in conjunction with the solar power systems for each case examined. The investigation was conducted to examine the impact of V2X discharge on the overall performance of the EV charging infrastructure and the utilisation of solar energy.

Again to better visualise the results we just obtained the following figures 10, 11,12 and 13, shows the EVs state of charge at departure time for every single case refered with V2x discharge and the 4 solar power implementations.

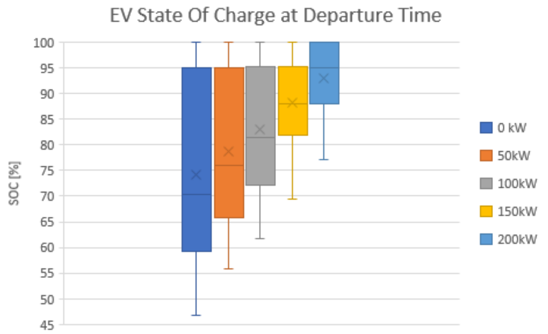

Fig. 10: EV State of Charge at Departure time for each solar system implemented and V2X discharge for case 1.

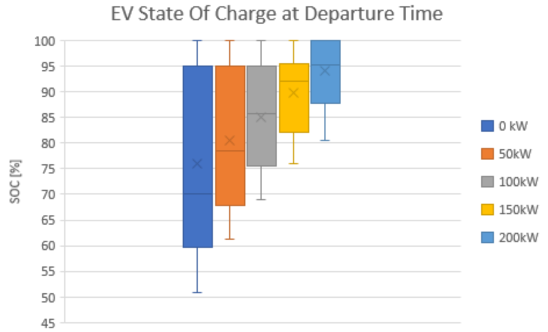

Fig. 11: EV State of Charge at Departure time for each solar system implemented and V2X discharge for case 2.

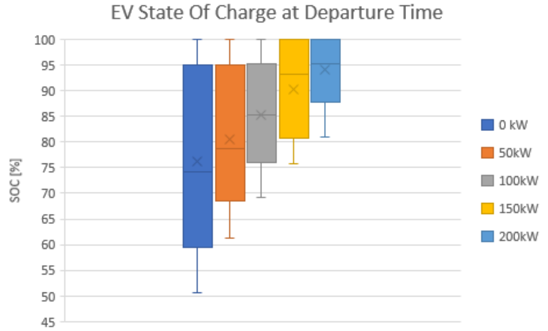

Fig. 12: EV State of Charge at Departure time for each solar system implemented and V2X discharge for case 3.

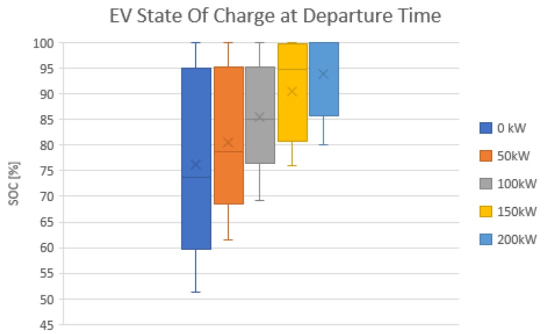

Fig. 13: EV State of Charge at Departure time for each solar system implemented and V2X discharge for case 4.

TABLE VIII: F-Index results for each case of V2X discharge with the four implementations of solar power.

Solar Power (kW)	Case 1	Case 2	Case 3	Case 4
0	0.2859	0.3210	0.3231	0.3258
50	0.3865	0.4247	0.4277	0.4296
100	0.4718	0.5280	0.5340	0.5337
150	0.5800	0.6354	0.6336	0.6350
200	0.7159	0.7353	0.7393	0.7090

It should be noted that the discharge capability of vehicle batteries has resulted in earlier vehicles receiving greater benefits from charging alongside with the solar charging, even with a robust 200kW solar system, compared to the results shown in table VI, vehicles that remain parked for extended periods of time do not experience significant improvements in their f-index value.

The evaluation of the f-index optimisation for the scenario without solar power exhibited a decline in performance, as indicated in table VII, owing to the occurrence of V2X discharge, which is in contrast to the outcomes presented in table VIII. As anticipated, the incorporation of solar power resulted in a marginal increase in the f-index.

Interestingly Case 2 and 3 present very similar results all across tables VI and VIII, this shows that having fewer CS with higher power can lead to better power management through the park, but on the other hand case 4, that is one CS of ”only” 250kW does not manage well with this much power, as expected.

In the forth scenario, the 250kW CS is being utilised to its maximum capacity. However, the excessive implementation of solar power with V2X discharge proves to be counterproductive and fails to yield significant benefits. This is particularly evident when comparing the index values of case 3 and 4 of table VIII, as they exhibit minimal differences.

Thus, it can be inferred that an excessive amount of local power generation does not provide substantial benefits. It should be noted that the system consistently draws the maximum power of 100 kW from the grid. Decreasing the income value has the potential to significantly decrease monthly billing expenses. However, it is also crucial to consider the necessity of this value. In comparison to the f-index value presented in table VII, relying solely on V2X discharge is insufficient.

V. CONCLUSIONS

This thesis shows that electric vehicle charging rates affect results. EVs charge faster and reach full charge faster, proving that charging rate affects charging outcomes.

Solar system electricity increases charging results. A larger solar system speeds charging during solar energy availability, making the station's energy supply easier. Thus, charging outcomes improve. The economic research shows that at 100 kW, the cost of establishing a solar power system equals its savings. Power increases may not be beneficial until the park's energy usage rises. However, this approach ignores energy returned to the grid when vehicles are not charging.

V2X discharge without solar power shows inefficient charging and long charging times, preventing electric vehicles from fully charging. Solar electricity and reverse charging improve performance. Case 4, with three 120 kW solar-powered charging stations, had the best results. This time, the F-Index score is higher, indicating less penalization and a closer SOC to 100% for electric vehicles. To charge electric vehicles efficiently, the study recommends considering charging rate, solar power, and charging station power capacity. To optimise charging outcomes, minimise charging time, and increase efficiency, these aspects must be considered throughout charging infrastructure design and deployment.

VI. FUTURE WORK

Future research could involve the assimilation of Smart Grid Technologies. The investigation of the amalgamation of smart grid technologies that has the potential to facilitate improved synchronisation and correspondence among the charging infrastructure, solar power generation, and the electrical grid. The implementation of this approach can potentially enhance load management, demand response, and grid balancing tactics, thereby resulting in heightened efficacy in the utilisation of solar energy, decreased peak demand, and enhanced stability of the grid.

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