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# Smart charging analysis for a service provider in mini parking lots by considering the V2V protocol

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**Abstract** — Smart charging of electric vehicles in the presence of renewable energy sources is a promising method that has recently received considerable attention. Therefore, various charging algorithms with specific objective functions have been proposed for different applications. In this paper, the smart charging prediction algorithm considering the vehicle to vehicle (V2V) protocol for a service provider in mini parking lots such as a restaurant, fast-food, or coffee shop is presented. In this regard, different scenarios are examined from the point of view of the parking owner, assuming two electricity prices. In addition, the impact of the applied scenarios on battery health is briefly discussed. Finally, it is concluded that the best scenario depends on the details of each case study. In other words, it is not possible to determine a definite scenario for smart charging. Therefore, the owner of the parking lot and the drivers will make the final decision optionally with full awareness.

**Keywords**—Battery health state, mini parking lot application, Plug-in electric vehicles, Smart charging prediction algorithm, Vehicle to vehicle protocol.

## I. INTRODUCTION

These days, thanks to extensive training and advertising, the challenges of internal combustion engine vehicles (ICEV) have become apparent to everyone. In fact, conventional vehicles with obvious disadvantages such as limited fossil fuel resources, environmental and noise pollution, and low efficiency, have been replaced by a new generation of vehicles with electric propulsion. Looking at the worldwide car sales and the offered products, the growing growth of electric vehicles, especially plug-in electric vehicles (PEVs), is understandable. However, it must be acknowledged that the generation transition in products like automobiles requires significant study, investments, and planning. Although this procedure has advanced to a large extent in the automotive production sector, research about the effects of a dramatic increase in the number of cars on the system is a fascinating topic at the moment [1].

For example, large-scale electric mobility development could bring extensive changes in energy demand. In fact, electric vehicles as high-consumption elements are usually connected to the grid at certain times of the day. According to the literature, it has been clarified that users would like to charge their vehicles after going to work or coming back home [2]. Therefore, by implementing a similar pattern for a huge volume of PEVs, two power peaks will be created in the

morning and evening. It should be noted that these peaks can be added to the usual grid peaks and create worse conditions for the grid. Therefore, the grid operator should try to improve the situation by using various schemes such as price changes, incentives, and investments for grid enlargement.

In this regard, in recent years, various smart energy management algorithms have been proposed that not only try to solve the aforementioned challenge, but also use the vehicle as a flexible load to improve the network structure [3]. In other words, by controlling the exchanged power of parked vehicles, the desired objective functions can be pursued. The energy scheduling algorithms can be classified into three main categories according to the type of application: residential [4], [5], workplace [6]–[8], and parking lots [9], [10]. In the residential application, depending on the house or apartment, the number of vehicles is different, the station owner and the vehicle owner are the same, and the parking time is usually long and is from the early hours of the night to morning. In the workplace application, the number of vehicles is usually more than the residential one, the owners of the station and the vehicle are different who usually know each other, and the parking time during the day allows for effective cooperation with PV arrays. However, the parking lot application, depending on the location, has the greatest variation in the number of vehicles, the length of the parking time, and the arrival time. Moreover, the station owner has no knowledge of the vehicle owner. For example, in airport or train station parking lots, the number of vehicles is very high, the length of the parking time is long and the arrival time is random. In this paper, the proposed smart charging algorithm is considered for a small parking lot in a restaurant, coffee shop, or fast food. In this structure, the number of vehicles is usually low with a short parking time. In this regard, different scenarios from the point of view of the station owner with different electricity prices (fixed and time-variable) are examined.

## II. DESIRED STRUCTURE DESCRIPTION

As mentioned in the previous section, this paper focuses on the energy management of a small parking lot in a restaurant, coffee shop, or fast food. In this situation, people have different parking periods depending on various parameters such as individual or family visits, meal or drink, workday or weekend, etc. Besides, a small percentage of the new car global market sales are plug-in passenger cars, for example, 2.5%, 4.6% and 9% in 2019, 2020 and 2021, respectively [11]. With this argument, a limited number of PEVs are randomly present in the parking charging station. In

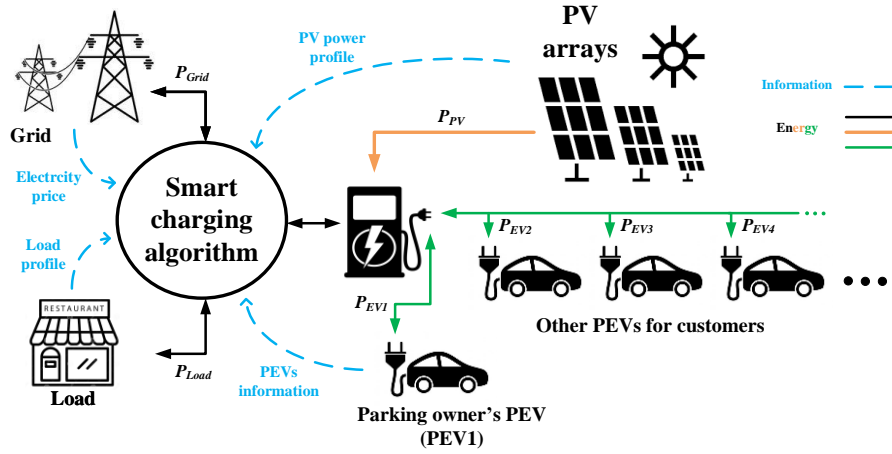


Fig. 1. Schematic description of the desired charging station structure.

general, the main electrical components of this station are shown in Fig. 1, which include:

#### A. Utility grid

The utility power grid is an inevitable element in microgrids with uncertain power generation sources. Therefore, the electricity network exist in the desired structure due to the urgent need for electricity ( $P_{Grid}$ ). The main task of the grid is to compensate for the power difference between resources and consumers. When the load power demand is more than the produced power of distributed generation sources, the power difference is provided by the grid. Also, when the produced power is more than the existing power consumption, the power difference is injected into the grid. It should be noted that the cost of energy exchanged with the grid can be calculated with fixed or time-variable electricity prices. The fixed price set for home and small business subscribers typically has two or three price levels for peak, medium, and low loads. However, time-variable price is mainly related to electricity markets, which reflect the real price of electricity. Applying both electricity prices to different scenarios reveals different aspects of the interests of the actors involved.

#### B. Photovoltaic arrays

The use of renewable energy sources, especially PV panels, has grown exponentially in recent years due to its unique benefits and government or international support. In addition, the effective cooperation of PV arrays and PEVs with the help of intelligent energy management has been proven in the literature [12]. In this regard, the uncertainty of distributed generation sources and the high energy demand of electric vehicles are covered. Therefore, PV arrays are another key element in PEV charging stations that usually try to operate at maximum power with the help of the maximum power point tracking (MPPT) algorithm. PV production capacity ( $P_{PV}$ ) is used in the first priority for local loads and in the next priority for injection into the utility grid. It should be noted that PV power generation is one of the uncertainties of the system and is usually predictable by using various algorithms. Here, it is assumed that the PV output power is well predicted. However, the proposed method compensates for some of the uncertainty using a predictive model and real-time controller.

#### C. Local load demand

The desired place, like any other electricity subscriber, has a consumption profile that must be fully supplied by

production sources. Load demand ( $P_{Load}$ ), like PV power generation, suffers from uncertainty, which can be compensated by the techniques described in the previous subsection.

#### D. PEVs

As the last element but not least important, plug-in electric passenger vehicles are connected to the rest of the system by charging points. Typically, the main purpose of energy management systems is the control or manipulation of the exchanged power of electric vehicles ( $P_{PEV}$ ) as the most flexible element of the system. In other words, PEVs, in addition to their natural need for charging, can be used as a secondary storage system. Therefore, it has the ability to release its excess energy at peak consumption and store excess system energy at low load. In this application, according to the length of the parking time, PEVs can be divided into two categories. The first category is vehicles owned by the restaurant owner or workers, which their parking periods are obviously equal to the working hours of the restaurant. It should be noted that the standalone battery can also be mentioned as a representative of the first category. The second category is customers' vehicles, which have a shorter random parking time. The restaurant customer may have come to the parking lot only for parking. However, offering attractive scenarios such as free charging of PEV or partial deduction of the payment slip can persuade them to participate in smart charging. In the next section, the proposed smart charging algorithm for this structure will be presented.

### III. PROPOSED SMART CHARGING ALGORITHM

In this section, the proposed predictive charge control algorithm is briefly presented. The general structure of the proposed algorithm, which is shown in Fig. 2, is inspired by the previous work of the authors in [4]. In this paper, unlike the previous work in a residential application, the number of vehicles can be more than one and energy exchange can be done between them. In this regard, the main part of the proposed algorithm, i.e. predictive control based on linear programming, receives the necessary information from all elements of the system. This information should be commensurate with the time horizon of the predictive control, which is equal to ten hours according to the use of restaurant parking in this work. In addition, the time interval between time steps or algorithm update period ( $\Delta t$ ) is equal to 5 minutes. Therefore, the system is optimized based on the predicted information for the next 10 hours, and the algorithm output is applied to the system.

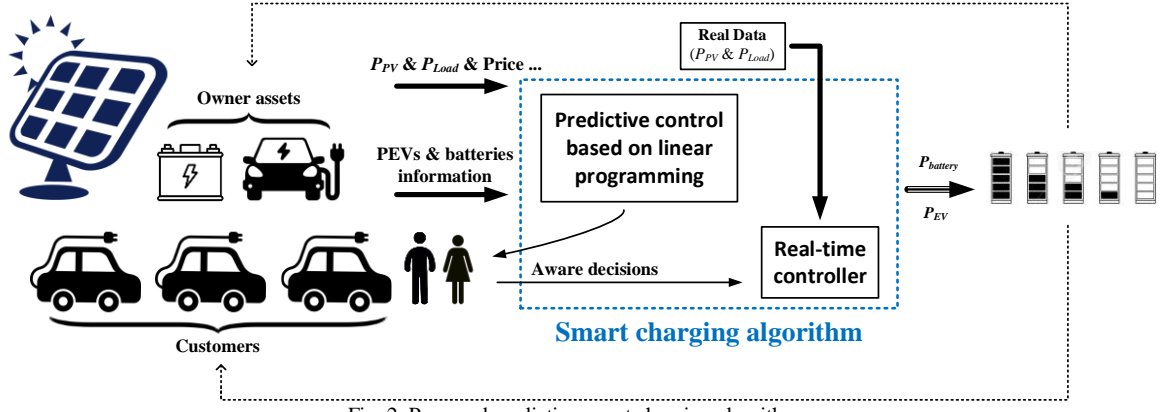


Fig. 2. Proposed predictive smart charging algorithm.

As shown in Fig. 2, the information received by the algorithm includes the predicted output power of the PV panels, the predicted or actual electricity price ( $EP_{Grid}$ ), the estimated local load consumption, and the specifications of the PEVs and individual batteries. Related to the PEVs subject, arrival time ( $t_{arr}$ ), initial charge ( $E_{init}$ ), estimated departure time ( $t_{dep}$ ), desired final charge ( $E_{final}$ ) and power and energy ( $SOC_{PEV}$ ) constraints are received directly from the users or drivers. Here, only the departure time is estimated which may change in case of emergency. However, uncertainty about the departure time is greatly reduced. In addition, the driver can choose other scenarios like uncontrolled scenario when he/she feels an emergency. Most likely, PEVs owned by the station owner or restaurant staff will have a relatively long parking time according to the restaurant's working hours. However, customers' vehicles have a temporary parking time, which reduces the predicted time horizon.

In the following, the linear programming solves the problem in the desired time horizon with the help of the following objective function ( $C_{total}$ ) and the constraints.

$$\text{Minimize } C_{total} = \sum_t EP_{Grid}(t) \times \Delta t \times \left[ \underbrace{\frac{P_{Grid}(t) + |P_{Grid}(t)|}{2}}_{\text{first term-energy purchase}} + 0.9 \times \underbrace{\left( \frac{P_{Grid}(t) - |P_{Grid}(t)|}{2} \right)}_{\text{second term-energy sales}} \right] + \sum_i \sum_t EP_{Grid}(t) \times \left[ \underbrace{\left( \frac{P_{PEV_i}(t) + |P_{PEV_i}(t)|}{2} \right)}_{\text{third term-battery charging}} + 0.9 \times \underbrace{\left( \frac{P_{PEV_i}(t) - |P_{PEV_i}(t)|}{2} \right)}_{\text{fourth term-battery discharging}} \right] - \sum_i \lambda_i \times E_{PEV_i}(t_0 + \Delta t) \quad (1)$$

$$\text{Subject to } \sum_i P_{PEV_i}^{\min} \leq P_{PEV_i}(t) \leq P_{PEV_i}^{\max}, \quad (2)$$

$$\sum_i SOC_{PEV_i}^{\min} \leq SOC_{PEV_i}(t) \leq SOC_{PEV_i}^{\max}, \quad (3)$$

$$P_{Grid}(t) + P_{PV}(t) = P_{Load}(t) - \sum_i P_{PEV_i}(t), \quad (4)$$

$$\sum_i E_{PEV_i}(t) = \begin{cases} E_{init_i}; & t = t_{arr} \\ E_{PEV_i}(t - \Delta t) - P_{PEV_i}(t) \times \Delta t; & t_{arr} < t < t_{dep} \\ E_{final_i}; & t = t_{dep} \end{cases} \quad (5)$$

In the introduced objective function, the first term refers to the purchase of energy from the grid, the second term represents the sale of energy to the grid with a 10% drop in price for losses, the third and fourth terms refer to charging and discharging and the last term depends on the priority of PEV charging. In the first to fourth terms, it was observed that buying and selling energy for the grid and the vehicle at the same price is not logical. In other words, the prices of input and output energies to the grid or vehicle varies due to losses, maintenance costs and profits of market participants. Therefore, it is necessary to calculate the input and output energies separately. To obtain these parameters, the absolute values are needed. In this regard, due to the linearity of the optimization algorithm, the following linear constraints are added to the problem to calculate the absolute variables [3].

$$\begin{cases} +P_{Grid}(t) - |P_{Grid}(t)| \leq 0 \\ -P_{Grid}(t) - |P_{Grid}(t)| \leq 0 \end{cases} \quad (6)$$

$$\begin{cases} +P_{PEV_i}(t) - |P_{PEV_i}(t)| \leq 0 \\ -P_{PEV_i}(t) - |P_{PEV_i}(t)| \leq 0 \end{cases} \quad (7)$$

In fact,  $|P_{Grid}|$  and  $|P_{PEV}|$  are slack variables that presents the absolute values of grid power and PEV power, respectively.

Finally, the output of the predicted control will be information about different scenarios such as, unidirectional smart charging, bidirectional smart charging and uncontrolled charging. Then, with enough information, users make aware decisions that are appropriate to their situation. These decisions must be transmitted to the system components as a

TABLE I  
PEVS SPECIFICATIONS

	$t_{arr}$	$t_{dep}$	Parking time	$SOC_{init}$	$SOC_{final}$	$SOC_{min/max}$	$E_{EV}^{nom}$	$P_{EV}^{min/max}$
<b>PEV1</b> Renault Zoe	11:00	23:30	12:30	20%	75%	20%, 90%	44.1 kWh	-10 / 10 kW
<b>PEV2</b> Peugeot e-208	14:15	19:00	4:45	25%	80%	20%, 90%	50 kWh	-7.4 / 7.4 kW
<b>PEV3</b> Tesla Model 3	16:30	22:00	5:30	45%	90%	20%, 90%	50 kWh	-10 / 10 kW
<b>PEV4</b> Tesla Model 3	19:30	20:45	1:15	55%	75%	20%, 90%	50 kWh	-10 / 10 kW

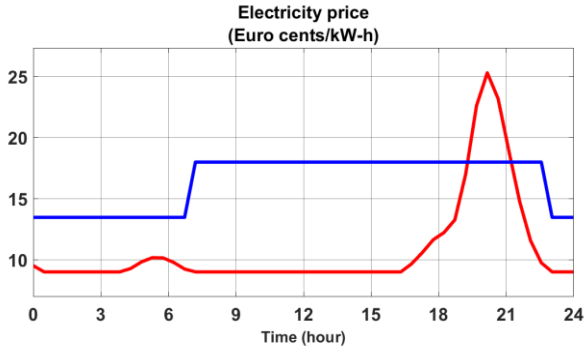


Fig. 3. Fixed and time-variable electricity prices.

control command. However, there is a real-time controller before sending the commands, due to uncertainties such as changes in PV power or load demand. It should be noted that this type of controller is typically used in real systems or real-time implementations. In this work, due to the simulation results and the stability of the received data, only the main predictive controller is sufficient.

On the other hand, battery health and its price drop is another important issue that needs to consider. For this purpose, the battery degradation model is calculated according to [13]. Obviously, the nonlinear structure of the battery model does not allow for linear programming. Therefore, in a separate structure, the cost of battery loss in Euros is calculated for different scenarios and added to the results. However, the main purpose of this paper was to examine different scenarios from the point of view of the charging station owner. In this regard, various scenarios can be defined, which will be mentioned here in six different cases. In the next section, the scenarios and their results will be presented.

#### IV. CASE STUDIES AND SIMULATION RESULTS

To evaluate the effectiveness of the smart charging control algorithm in the desired structure, first the whole system is simulated in MATLAB/Simulink software. Here, it is assumed that a photovoltaic system with a maximum power of 12 kW is connected to the grid along with local loads and electric vehicles. Also, PEVs specifications are presented in Table I. As it can be seen, it is assumed that during one working day, four electric vehicles go to the parking lot. The first PEV that has the longest parking time belongs to the restaurant owner or its staff, and the next vehicles belong to the customers. Depending on the working hours of the place and the first PEV parking time, the simulation time is considered between 10:00 AM to midnight. As mentioned earlier, the choice of the final charging scenario depends on the vehicle user. Depending on the proposed smart charging algorithm, the driver can choose unidirectional or bidirectional smart scenario. In the unidirectional smart charging scenario, the algorithm can only charge the vehicle at the best time and with the appropriate power according to the objective function. However, in the bidirectional smart charging scenario, the algorithm is also allowed to discharge the battery, which naturally leads to a decrease in battery health. However, the offer for a bidirectional smart charging can be attractive enough to offset the cost of battery loss. In this regard, in this paper, three different scenarios are considered. In the first scenario, all vehicles are participating in unidirectional smart charging. In fact, bidirectional smart control has no economic justification due to the high price of batteries or the constant price of electricity during parking

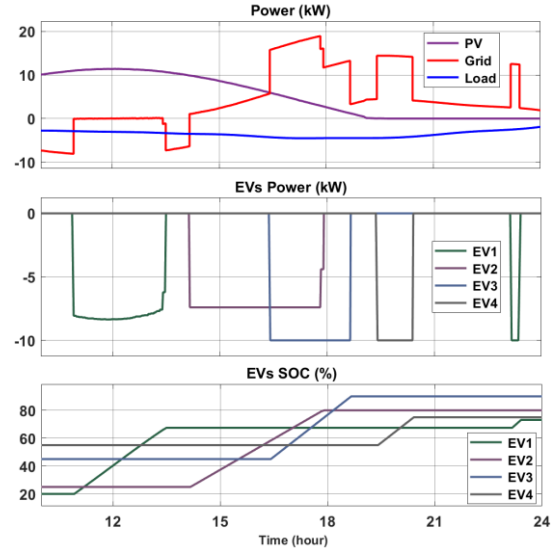


Fig. 4. Unidirectional smart charging results with fixed approved price.

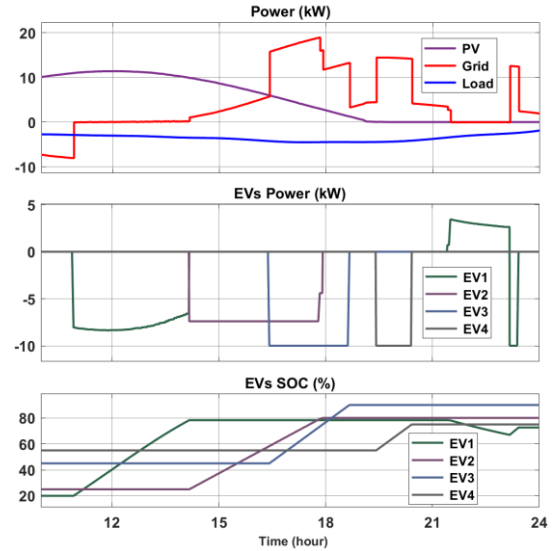


Fig. 5. Bi+Unidirectional smart charging results with fixed approved price.

time. In the second scenario, all the customer's vehicles are still in the unidirectional scenario due to insufficient information, short park time, etc., but the station owner's vehicle is in bidirectional smart charging for various reasons (Bi+Unidirectional scenario). The main reasons for station owner include greater awareness of smart charging, higher revenue, longer parking times, or better customer service. Also, as mentioned, this element can be an auxiliary battery instead of an electric vehicle. Finally, in the third scenario, it is assumed that all vehicles are participating in bidirectional smart charging. On the other hand, it should be noted that the electricity price has a major impact on the results. At present, the electricity price of small users in France is considered as two fixed steps in low load and high load [14]. However, the actual market price that may be applied to consumers in the near future has different results. Fixed standard and hypothetical time-variable actual electricity prices are shown in Fig. 3. Therefore, the following scenarios are presented for both electricity prices, respectively.

##### A. Fixed electricity price

As stated, in this section, various scenarios with approved prices of electricity in the domestic and commercial sectors of



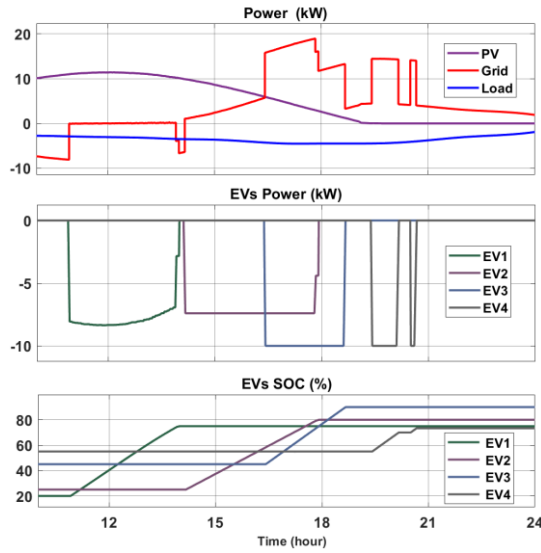


Fig. 6. Unidirectional smart charging results with time-variable price.

France are examined. According to Fig. 3, the price is constant at the restaurant during working hours between 11:00 AM and 11:00 PM and is equal to 17.99 euro cents. After 11:00 PM, the price of electricity will be reduced to 13.46 euro cents, which the restaurant owner's vehicle will be only present during this period for half an hour. As the first simulation, the results for unidirectional smart charging are shown in Fig. 4. As it can be seen, before the arrival time of the first PEV, the power generated by PV arrays supplies the local load and the excess energy is injected into the grid. As soon as the vehicle arrives, the energy exchange with the grid stops and the PEV is charged with the available solar energy. It should be noted that the price of electricity after working hours is less than the selling price of PV energy produced per day. Therefore, some demand of the first PEV is charged at the end of the interval. In the following, solar energy is not enough to charge the next PEVs. Therefore, the second to fourth PEVs are charged with maximum power with the help of utility grid and PV arrays. It is also observed that the desired final charge is obtained for all vehicles and the station owner has to pay 10.70 Euros to the grid for energy exchanged on this working day.

In the second scenario, only the first PEV participates in bidirectional smart charging, which its results are shown in Fig. 5. In this regard, the first PEV uses the extra solar energy available to charge more than it needs before the second PEV arrives. In other words, the extra solar energy is stored in the first vehicle instead of being injected into the grid. Then at the end of the period, the extra energy of the first PEV is used to feed the local loads. In this scenario, with the help of the first vehicle, the energy exchange with the grid is a little reduced and the station owner's payment bill for this day will be 10.57 Euros. However, considering the decline in battery health, the cost difference with the previous scenario will be even smaller. Therefore, assuming the above conditions, this scenario, despite some benefits for the utility grid, will not be very attractive to the restaurant owner.

In the last scenario with the fixed price, all PEVs participate in bidirectional smart charging. However, the results are quite similar to the previous scenario because the electricity price is constant during the parking times of the second to fourth PEVs. In other words, despite the possibility of charging and discharging vehicles, the best mode is unidirectional smart charging.

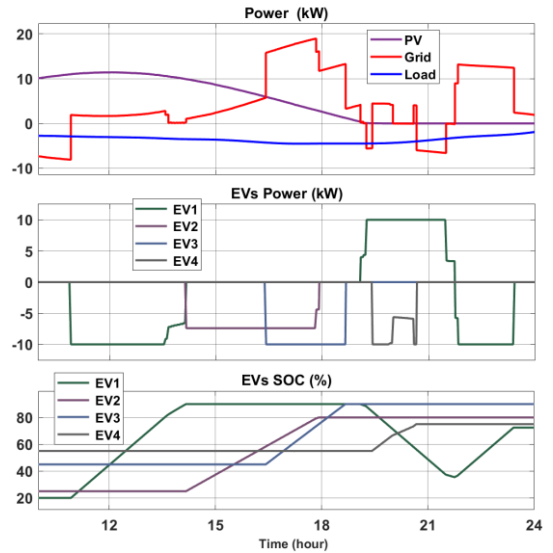


Fig. 7. BI+Unidirectional smart charging results with time-variable price.

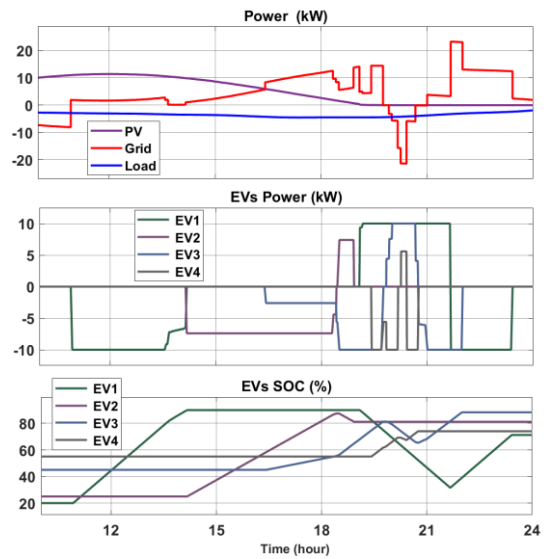


Fig. 8. Bidirectional smart charging results with time-variable price.

### B. Time-variable electricity price

In this section, the electricity price is closer to the real market, in which the price of each kilowatt-hour of electricity varies with time and has a sharp price peak at the peak of electricity consumption at 20:00 o'clock. In this regard, the results of the first scenario, i.e. unidirectional smart charging of PEVs, are shown in Fig. 6. As it can be seen, the first vehicle is fully charged by PV arrays. After that, the second and third PEVs will be charged with the maximum power at a lower price to reach the desired amount. However, the fourth PEV is in the peak price range. Due to the short parking time and the need to charge, it experiences a small charge stop only at the highest price. Here, all the PEVs reach their desired final energy at the lowest cost again, and the station owner has to pay 10.02 Euros to the grid at the end of the day.

In the second scenario, the first PEV operates alone on bidirectional smart charging, which the results are shown in Fig. 7. According to this figure, the first vehicle is charged with maximum power by means of grid and PV arrays to reach the maximum SOC because it is in a reasonable price range. Next, the second and third PEVs are charged similarly to the previous scenario, but the fourth PEV is charged by the V2V protocol from the first PEV as well as the grid. It is observed

TABLE II  
COMPARISON OF DIFFERENT SCENARIOS

	Fixed electricity price			Market electricity price		
	S1	S2	S3	S1	S2	S3
Energy exchange cost with grid (€)	10.70	10.57	10.57	10.02	7.47	4.68
V2V capability	no	no	no	no	yes	yes
Effective grid support	no	no	no	+	++	+++
Attraction for station owner	+	no	no	+	++	+++

that the first PEV is discharged at the peak price to get the most revenue. Then, when the electricity price decreases, the first PEV is charged again to the final desired SOC. Here, the station owner is required to pay 7.47 Euros for the whole day, which can also compensate for the loss of battery health.

In the last scenario, all PEVs participate in bidirectional smart charging, which the results are presented in Fig. 8. Here, all vehicles intend to save energy at the minimum price in order to have benefits for themselves and the grid by selling at a higher price. The first PEV behaves similarly to the previous scenario because it was on bidirectional smart charging in both of them. The second PEV is charged approximately to  $SOC_{max}$ , but due to the early departure time, it is discharged at a lower price than the peak. In the following, the third PEV and even the fourth PEV assist the grid at peak load by stored energy. In addition, the V2V protocol is clearly between EV2 and EV3, between EV1, EV3 and EV4, and between EV3 and EV4. In this scenario, the station owner would have to pay 4.68 Euros to the grid, with a significant reduction in price.

Finally, the results obtained from the above simulations are summarized in Table II. As it can be seen, in the case study with fixed electricity price, the first scenario (S1) is the best scenario for the restaurant owner while it cannot help the grid. But considering the time-variable market price, all the members move toward the third scenario (S3). In this case, not only the cost of PEV charging will be reduced, but it will also have the highest efficiency for the station owner. At the same time, there is the most cooperation with the grid to balance the load. Therefore, it is predicted that in the near future, considering a significant number of PEVs, power grids will seek to realize time-variable electricity prices and will use many incentives to implement the third scenario.

## V. CONCLUSION

In this paper, a smart charging prediction algorithm for mini parking lots was presented. The charging station was characterized by a small number of electric vehicles with short parking times. In this regard, various scenarios from the point of view of the station owner were examined for fixed and time-variable electricity prices. Also, the V2V protocol was considered for energy exchange between vehicles. It should be noted that it is a fact that the best-case scenario varies for different case studies depending on the system parameters. According to the results, at a fixed price, the station owner uses the unidirectional scenario to keep the batteries healthy. In this case, there is no effective cooperation between PV arrays, PEVs, and the grid. However, for an example time-variable price, all the elements involved may also participate in the bidirectional smart charging scenario. Therefore, it is predicted that with the new generation of measurement and

communication devices in the near future, the real price will be considered for electricity consumption.

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