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Evaluation of the reliability of the deregulated radially distribution network with consideration of vehicle to grid

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Abstract. The necessity of reducing fossil fuels and environmental pollutants has led to consideration of Electric Vehicles (EVs). EVs can participate as a manufacturer in the electricity market through Vehicle to Grid (V2G) technology. This greatly improves the reliability of distribution systems. Therefore, it is necessary to plan the charging and discharging processes in the parking lot. This paper investigated different strategies for planning the charging and discharging processes of EVs considering the random and unpredictable nature of various parameters, as well as the limitation of the power exchange between the distribution system and parking, to evaluate the impact of V2G-equipped parking lots on reliability. An appropriate strategy is the strategy that increases the owner's interest in the parking. Therefore, the strategies are designed independent of the duration of EVs presence in the parking and considering the limitations of power exchange with the distribution system. In addition, the improvement of the reliability of the distribution system and the economic benefits of V2G are examined simultaneously. The results indicate that V2G and charge-discharge strategies increase the parking revenue by an average of 21.6% and improve reliability (System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Average Service Availability Index (ASAI), and Energy Not Supplied (ENS) indices) of the distribution network by 8.8%.

1. Introduction

The need to reduce fossil fuels and urban pollutants has made Electric Vehicles (EVs) an alternative to domestic combustion engines [1,2]. When EVs connect to the grid, there are two significant modes: the charging mode, called Grid to Vehicle (G2V), in which the EV is considered a load for the grid [3,4]; and the discharging mode, called Vehicle to Grid (V2G), in which the EV supplies energy to the power grid. V2G-equipped EVs offer a variety of benefits, such as active power regulation, reactive power support, load modulation, flow harmonic filtering, and peak load correction. Also, EVs with V2G technology provide a support source for renewable resources. These features provide support services including spinning reserve and voltage and frequency control. These factors enhance the efficiency

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and reliability of the system. Furthermore, vehicles can participate in electricity markets and provide many economic benefits to their owners and the grid [5]. The V2G concept, as well as paying attention to the behavior of EVs owners to park their vehicles most of the time, has raised the idea of constructing and planning EV parking [6–8].

It should be noted that the benefits of V2G depend on how the charging and discharging of EVs are performed [5]. If the charging process is not controlled, charging times will interfere with the peak load of the system and the distribution network will encounter problems such as over-supply, excessive loss of power, and voltage limitations [9–11]. The following section investigates studies on EV charging and discharging scheduling, as well as studies on improving the reliability of the system in the presence of V2G.

In [9], the Vehicle to Home (V2H) capability to schedule charging and discharging levels at any time step was evaluated. The purpose of this scheduling is to minimize the costs of interruptions and payment costs from the customer's point of view. By using this method, like home planning, the start and end times of the grid connection are predicted. However, it is not possible to determine the arrival and departure times of Plug-in Hybrid Electric Vehicles (PHEVs) when planning to charge and discharge in public parking spaces. Also, due to the increase in the number of PHEVs, parking may run into a problem providing the same energy required for PHEVs.

In [11], an Online Adaptive Cloud Structure (OACS) was used to plan the EV charging process while meeting the grid constraints. The limitations of the flow rate of the distribution line, the capacity of the Low Voltage (LV) transformer, the feeder voltage, and the busbar voltage unbalance are considered as the main constraints of the distribution grid. However, in these schedules, there is no time step for the EV battery discharge and V2G capability. In [12], a two-step method was employed for EVs charge scheduling to minimize the effects of EVs on distribution network equipment. In [13], an algorithm was proposed to optimize the process of charging a number of PHEVs in a parking lot. The objective of this algorithm is to maximize the average State of Charge (SoC) of the battery for all vehicles at a later time stage.

In [14], a control strategy was proposed to optimize the charging process, as well as the process of discharging EVs in the presence of renewable resources. The purpose of the control strategy is to plan the charging and discharging processes so that the power imbalance in the grid can reach the lowest level. The results show that the control strategy reduces the power imbalance in the grid. However, the economic aspects of this problem have not been investigated in this strategy.

In [15,16], the EV charging load model was obtained with the aim of improving the reliability of the power system. However, the generation model of EVs in the discharge mode was not studied.

In [17], the battery exchange method was employed to charge EVs. In this case, the reliability of the power system was evaluated. The results indicate that the use of a battery exchange method can improve the reliability of the power system. The negative point in this assessment is the charge and discharge evaluation, because the predicted strategy can only improve the reliability of the power system in the event of interruption. In addition, it is not possible to use EVs in other areas, such as peak load correction and participation in electricity markets.

In [18], the well-being analysis of generating systems in the presence of EVs was presented. However, the distribution and production system in the above cases can only take advantage of V2G for a continuous period of interruption and there is no possibility of using this feature in several discrete interruptions.

In [19], the reliability of the distribution network in the presence of EVs was evaluated. For each point of the load, two topologies of concentrated and dispersed charging are considered. The results show that using V2H and V2G capabilities will improve the reliability of the system.

In these studies, the random and unpredictable nature of the duration of EVs presence in the parking lot, the limitation of the distribution system in the exchange of energy with the parking lot, as well as the economic benefits of V2G have not been considered.

As mentioned, V2G technology improves the reliability of the distribution system, but it should always be kept in mind that the parking lot can improve system reliability if charging and discharging strategies are properly designed. On the other hand, parking lot contributes to the transmission of power to the grid where the perceived profit is appropriate; therefore, in the first stage, the charging and discharging strategy should be designed to incentivize parking lots to contribute to improving the reliability of the distribution system while ensuring suitable profits for the parking lot.

This paper has investigated the reliability (SAIFI (System Average Interruption Frequency Index); SAIDI (System Average Interruption Duration Index); ASAI (Average Service Availability Index); and ENS (Energy Not Supplied)) of a radial distribution network in the presence of EVs. Accordingly, first, novel strategies are proposed for scheduling the charging and discharging process of EVs in a V2G-equipped parking lot, aiming to maximize the profit of parking. Restrictions on the amount of power exchange between the parking lot and the distribution network are studied. Moreover, the random and unpredictable nature of the quantities such as the times of arrival and departure of the EVs to the parking lot and their SoC while arriving the parking lot in the proposed strategies, have been considered. Therefore, charging and discharging strategies are designed independent of the duration of EVs presence in the parking lot while considering the limitations of power exchange with the distribution system. In addition, the improvement of the reliability of the distribution system and the economic benefits of V2G are examined simultaneously.

The rest of the article is organized as follows. In Section 2, the functions of the parking profit are presented. In Section 3, charging-discharging strategies are presented in order to increase the parking cost according to the grid constraints. In Section 4, parking profit and distribution network reliability indexes are analyzed in each of the strategies; finally, section 5 provides the conclusions.

2. Parking profit function and requirements

The reliability of the distribution network depends on the energy exchanged between the parking lot and the distribution network. The amount of energy exchanged depends on which charging and discharging strategy the parking lot chooses to implement. Definitely, the owner of the parking lot will choose a strategy that reaps great profits through charging and discharging. In the first stage, in order to determine the parking profit in each of the strategies, it is necessary to introduce a function to calculate the parking profit.

2.1. Parking profit function

The parking profit with the maximum N_{ev} capacity of the vehicle operating at the time step [0-T] was calculated using Eqs. (1) to (8) [20]. The time step [0-T] is divided into t time steps of one hour.

$$W_{total} = C_p - C_n,$$

$$C_p = C_{gdch} + C_{park} + C_{ech},$$

$$C_n = C_{gch} + C_{edch} + C_{lim} + C_{sh}. \tag{1}$$

In Eq. (1), C_{gdch} denotes the total parking profit received from the grid for the sale of energy to the grid; C_{park} represents the total parking fee from the owners of the EV for parking the EV in the parking lot; C_{ech} is the total received cost by parking lot from EV owners for increase in vehicle battery when leaving the parking lot (perceived cost for selling energy to EV owner); C_{gch} denotes the total parking cost paid to grid for purchasing energy from the grid; C_{edch} is the total parking cost paid to EV owners for decreasing EV Battery Charge while departing the parking lot (cost of purchasing energy from EV); C_{lim} denotes the Total Parking Fee to EV Owners for failing to provide minimum EV cost (if agreed); C_{sh} is the total parking fee paid to the owners of EV for the share of the EV owner in the profit of the V2G (if there is agreement). In the following, the computational equations of the components of the parking profit function are presented.

$$C_{gdch} = \sum_{i=1}^{Nev} C_{gdch,i},$$

$$C_{gdch,i} = \sum_{t \in R_{EVi}} p_{dch}(t).price_{dch,t}, \tag{2}$$

$$C_{gch} = \sum_{i=1}^{Nev} C_{gch,i},$$

$$C_{gch,i} = \sum_{t \in R_{EVi}} p_{ch}(t).price_{ch,t}. \tag{3}$$

In Eqs. (2) and (3), $p_{dch}(t)$ is the actual power that the parking sends from the discharge point of the EV_i battery at time t to the grid; $p_{ch}(t)$ is the actual power that the parking receives from the grid for charging EV_i at time t, $price_{dch,t}$ and $price_{ch,t}$ is equal to the price of sales and purchases of energy at time t and R_{EVi} is equal to the presence time interval of EV_i in the parking lot.

According to the data available in [21], the time of EV's presence in the parking lot is a random quantity with an unbalanced dispersion. Therefore, the probability distribution of EV presence in parking lots is non-uniform. Due to the difference in the presence time of each EV in the parking lot, the cost for the EV parking lot will vary for each EV. Therefore, C_{park} is defined in accordance with Eq. (4):

$$C_{park} = \sum_{i=1}^{Nev} C_{park,i},$$

$$C_{park,i} = \begin{cases} at_{park,i} & t_{park,i} \leq t_0 \\ a(t_0 + \sum_{t=1}^{t_{park,i}-t_0} (1+bt)) & t_{park,i} > t_0 \end{cases} \tag{4}$$

In Eq. (4), $t_{park,i}$ is equal to the presence time of EV_i in the parking lot. If the EV is present in the parking lot for less than t_0, it shall pay a fixed charge per hour in the parking lot according to the coefficient of a; however, if the EV parking lot time exceeds t_0, it must pay a variable cost per hour, in addition to the preceding cost. This variable cost is determined by coefficient b.

The received and paid profits of parking for the sale and purchase of energy from the owner of EV are calculated using Eqs. (5) and (6):

$$C_{ech} = \sum_{i=1}^{Nev} C_{ech,i},$$

$$C_{ech,i} = R_1.(SoC_{out,i} - SoC_{in,i}), \tag{5}$$

$$C_{edch} = \sum_{i=1}^{Nev} C_{edch,i},$$

$$C_{edch,i} = R_2.(SoC_{in,i} - SoC_{out,i}). \tag{6}$$

In Eqs. (5) and (6), SoC_{in} and SoC_{out} indicate the SoC of the EV_i battery when arriving at and departing from the parking lot, respectively. R_1 and R_2 are also the sales and purchasing tariffs of the owner of the EV.

Parking is required to charge the EVs to the minimum specified capacity. If the SoC is less than the minimum specified capacity at departure and if there is agreement, the parking lot should be paid by the owner of the EV using Eq. (7):

$$C_{lim} = \sum_{i=1}^{Nev} C_{lim,i},$$

$$C_{lim,i} = R_3.(SoC_{lim,i} - SoC_{out,i}). \tag{7}$$

In Eq. (7), $SoC_{lim,i}$ represents the minimum capacity specified for SoC_i and R_3 represents the supply failure tariff of the $SoC_{lim,i}$.

Continuous charging and discharging affect the lifetime of the EVs battery. In order to compensate for this damage, parking should pay part of the benefit of the participation of the EV in the V2G process using Eq. (8) to the owner of the EV.

$$C_{sh} = \sum_{i=1}^{Nev} C_{sh,i},$$

$$C_{sh,i} = K.(C_{gdch,i} - C_{gch,i}). \tag{8}$$

In Eq. (8), the coefficient K determines the participation of the EVs in the profit earned.

2.2. Study period

All strategies are reviewed over an extended period of 48 hours (extended study period [19]). Thus, we will have 48 steps at a time of one hour.

2.3. Determination of the allowed charging and discharging time steps

Due to the change in grid consumption load over a day, energy prices change as a function of the load consumed per hour in a day; therefore, $price_{ch,t}$ and $price_{dch,t}$ will have different values at each time step. Obviously, as $price_{ch,t}$ decreases and $price_{dch,t}$ increases, the perceived profit from the parking lot will increase. Therefore, the first step in scheduling the charging and discharging processes in a parking lot is to determine the allowed charging and discharging time stages. The following are essential for determining allowed charging and discharging time stages.

2.3.1. Parking lot profit

Purchasing energy from the grid in time steps where the energy prices are lower and selling it to the grid at the time step when energy prices are higher will increase parking lot profit; therefore, in the range of $[0 - T]$, the allowed charge and discharge time steps must be determined such that $price_{dch}$ always has a higher value than $price_{ch}$. Therefore, the median index is used. The median index for energy price data is calculated over two consecutive days (48 hours). If the median index for energy price in two days is M, energy price in 24-time steps will be higher than M and the energy price in 24 other times will be lower than M.

2.3.2. The main task of the parking lot

The main task of the parking lot is to charge the EVs and increase their SoC when leaving the parking lot. Therefore, the number of allowed charging time steps must be greater than the number of allowed discharging times. Hence, the value of M increases to a minimum that increases the number of allowed charging time steps, R_{ch}, compared to the number of allowed discharging time steps, R_{dch}. R_{ch} consists of n discrete time steps for the charging process and R_{dch} consists of m discrete time steps for the discharge process, thus increasing the parking profit in the range of $[0 - T]$; the t allowed charge and discharge time steps should be determined such that pricedch is always higher than $price_{ch}$.

By using Eqs. (9) and (10), R_{ch} consists of n discrete time steps for the charging process, and R_{dch} consists of m discrete time steps m for the discharging process.

$$R_{ch} = \left[n_1, \quad ..., \quad n_j, \quad ..., \quad n_n\right], \tag{9}$$

$$R_{dch} = \left[m_1, \quad ..., \quad m_k, \quad ..., \quad m_m\right]. \tag{10}$$

Each discrete allowed charge and discharge time steps consist of continuous-time steps. In accordance with Eqs. (11) and (12), n_j consists of x continuous allowed charge time steps and m_k consists of y continuous allowed discharge time steps.

$$N_J = \left[t_{nj,1} \quad t_{nj,x}\right], \tag{11}$$

$$M_k = \left[t_{mk,1} \quad t_{mk,y}\right]. \tag{12}$$

2.4. Parking restrictions on power exchange with the distribution network

It is not possible to exchange power beyond the permissible limits ($P_{ch}^{\max}(t)$ and $P_{dch}^{\max}(t)$) for parking. Accordingly, the maximum number of vehicles that parking can charge or discharge at any time is determined using Eqs. (13) and (14):

$$M_{ch}(t)=\frac{P_{ch}^{\max}(t)}{p_{ch}(t)}, \tag{13}$$

$$M_{dch}(t)=\frac{P_{dch}^{\max}(t)}{p_{dch}(t)}. \tag{14}$$

2.5. Control filters

Control filters are defined as Eqs. (15) to (17):

$$g(x)=\begin{cases}0 & x<0\\ x & x\geq 0\end{cases} \tag{15}$$

$$s(x)=\begin{cases}0 & x<0\\ 1 & x\geq 0\end{cases} \tag{16}$$

$$y(x)=\begin{cases}0 & x\leq 0\\ 1 & x>0\end{cases} \tag{17}$$

3. Scheduling of the charging and discharging processes of EVs

The reliability of the distribution network depends on the energy exchanged between the parking lot and the distribution network. The energy exchanged depends on which processor or strategy for charging and discharging is considered by the parking. Definitely, the owner of the parking lot will choose a strategy that will generate more profits by charging and discharging. Determining the optimal strategy cannot be formulated. Therefore, like scenario-based approaches, we explore different strategies to adopt. In this paper, the charging-discharging strategy is taken as the control method that manages the charging and discharging processes in EV parking. There are 5 different strategies to schedule the charging and discharging processes of the EVs in the parking lot.

3.1. The first strategy

To meet the requirements of the parking facility owner, contribute to energy sales to the grid through V2G technology, and enhance the reliability of the system, it is necessary to allocate specific periods for discharging EVs' batteries. Therefore, it is not possible to charge EVs during the entire presence time in the parking lot. On the other hand, due to to restrictions on power transmission from the grid, the parking facility is unable to charge all EVs in the parking lot simultaneously. Hence, establishing a charging priority for EVs is crucial for maximizing the parking facility's profit. The charging strategy implemented at any given time determines the order in which EVs are charged.

The charge function of the first strategy, $J_{ch,1}(t)$, at each allowed charge time t determines the priority of charging EVs based on their SoC deficiency as compared to the capacity of the battery. In other words, in this strategy, the priority of charging EVs is determined by the free capacity of the battery. In the following, necessary equations for computing $J_{ch,1}(t)$ are presented.

$$\max J_{ch,1}(t)=\sum_{i=1}^{Nev(t)} n_i(t).F_i(t), \tag{18}$$

$$F_i(t)=E_s-SoC_i(t-1), \tag{19}$$

$$n_i(t)\in\{0,1\}. \tag{20}$$

In Eq. (19), E_s is equal to the capacity of the battery.

The charging strategy constraints are defined according to Eqs. (21) to (23):

$$0\leq SoC_i(t)\leq E_s, \tag{21}$$

$$SoC_i(t)=SoC_i(t-1)+n_i(t)p_{ch}(t), \tag{22}$$

$$0\leq\sum_{i=1}^{Nev(t)} n_i(t)\leq M_{ch}(t). \tag{23}$$

Restriction on the power sent from the parking facility at any time to the grid in the scheduling of the discharge process gives rise to further restriction on the number of EVs that can be discharged at each time step. Therefore, the priority should be set at each stage of the EV in order to increase parking profits. The first discharge function, $J_{dch,1}(t)$, determines the discharge priority according to the profit generated by the discharge of EVs at a time step t and the limitation on the power sent to the grid. In the following, necessary equations for calculating $J_{dch,1}(t)$ are presented:

$$\max J_{dch,1}(t)=\sum_{i=1}^{Nev(t)} n_i(t).F_i(t), \tag{24}$$

$$F_i(t)=C_{g,i}(t)-C_{lim,i}(t), \tag{25}$$

$$n_i(t)\in\{0,1\}. \tag{26}$$

In Eq. (25), $C_{g,i}(t)$ denotes the amount of power received by the parking facility from the grid for the power sent through EV_i at each time step t. $C_{lim,i}(t)$ is the cost paid for parking by the owner of EV for the non-supply of $SoC_{lim,i}$ at each time step t. The equations required for calculating $C_{g,i}(t)$ and $C_{lim,i}(t)$ are presented in this strategy:

$$C_{g,i}(t)=p_{dch}\ (t).price_{dch,t}, \tag{27}$$

$$C_{lim,i}(t)=s(SoC_{lim,i}-(SoC_i(t-1)-p_{dch}(t))).\ k_i(t). \tag{28}$$

As shown in Eq. (27), the parking cost for discharging EV_i at discharge time steps before the time period t

(previous discharge time steps) is not considered in calculating $C_{g,i}(t)$. Therefore, the parking price paid for non-supply of $SoC_{lim,i}$ in earlier stages of discharges should not affect the process of determining the priority of EV discharge at time step t. If the parking facility does not discharge EV_i in any of the previous discharge stages, $k_i(t)$ can be calculated using Eq. (29):

$$ki(t)=\left(SoC_{lim,i}-\left(SoC_i\left(t-1\right)-p_{dch}\left(t\right)\right)\right).R_3. \quad (29)$$

If EV_i was discharged by the parking lotin the previous discharge stage, the calculation of $k_i(t)$ requires first determining the costs incurred by the lot in the previous discharge stages. As mentioned earlier, the time step of EV_i presence in the parking lot consists of discrete charge time steps and discrete discharge time steps. If the EV_i passes through a discrete charge time before reaching the time step t, charging EV_i may partly compensate for the costs incurred during the early discharge stages. However, because of the constraint on M_{ch}, a part of this price is not compensated. Thus, $k_i(t)$ is calculated using Eq. (30):

$$k_i(t)=\left(SoC_{lim,i}-\left(SoC_i\left(t-1\right)-p_{dch}\left(t\right)\right)\right). \\ R_3-C_{n-s,i}(t). \quad (30)$$

In Eq. (30), $C_{n-s,i}(t)$ represents the price not compensated until the time period t. Eq. (31) is used to compute the value of $C_{n-s,i}(t)$. In Eq. (31), $t_{mk,1}$ is equivalent to the first continuous time period in the k-th discrete discharge time step.

$$C_{n-s,i}(t)=g\left(\sum_{t_i=t_{m_1,1}}^{t-1}C_{l,i}(t_i)-(p_{ch}(t_i).R_3)\right)+ \\ \ldots+g\left(\sum_{t_i=t_{m_k,1}}^{t-1}C_{l,i}(t_i)-(p_{ch}(t_i).R_3\right)+ \\ \ldots+g\left(\sum_{t_i=t_{m_m,1}}^{t-1}C_{l,i}(t_i)-(p_{ch}(t_i).R_3\right). \quad (31)$$

The constraints of the discharge strategy are defined using Eqs. (32) to (34):

$$0\leq SoC_i(t)\leq E_s, \quad (32)$$

$$SoC_i(t)=SoC_i(t-1)-n_i(t)p_{ch}(t), \quad (33)$$

$$0\leq\sum_{i=1}^{Nev(t)}n_i(t)\leq M_{dch}. \quad (34)$$

Eq. (26) and Eqs. (32) to (34) hold in all the discharging strategies.

3.2. The second strategy

In this strategy, the charge process is scheduled using the first strategy.

$$\text{Max} \quad J_{ch,2}=J_{ch,1}. \quad (35)$$

In the second discharge strategy, at any given time step, the parking price paid for EV discharging is compared with that obtained from the parking lot for EV discharge. In addition, If the price received from the parking facility is greater than the price paid, the EV can be discharged. In other words, the discharge function, $J_{dch,2}(t)$, in the the second strategy evluates what the parking lot gets when the EV is both discharged and not discharged.

In the following, the equations adopted for calculating $J_{dch,2}(t)$ are presented.

$$\text{Max} \quad J_{dch,2}=\sum_{i=1}^{Nev(t)}n_i(t).F_i(t). \quad (36)$$

In Eq. (36), $F_i(t)$ represents the difference between the parking income and its income loss (via EV_i) at a time step t. To compare the income earned by the parking facility and the potential income loss, it is necessary to determine, at time step t, the amount that the owner of the EV will either pay to the parking facility or receive from it. Payment and income by the owner of the EV are initially determined by comparing the battery energy status to that of $SoC_{in,i}$. Therefore, the battery energy status should be determined in the first step, especially if the EV is discharged at the time step t. Accordingly, $F_i(t)$ is defined using Eq. (37):

$$F_i(t)=s\left(\left(SoC_i(t-1)-p_{dch}(t)\right)-SoC_{in,i}\right).k_{i,1}(t)+ \\ y\left(SoC_{in,i}-\left(SoC_i(t-1)-p_{dch}(t)\right)\right). \\ k_{i,2}(t). \quad (37)$$

To calculate the costs paid by the parking lot to the owner of the EV at time step t, in case of an EV discharge where the battery power is still higher than $SoC_{in,i}$, it is necessary to consider the costs incurred due to lack the of $SoC_{lim,i}$. Therefore, $k_{i,1}$ is defined by Eq. (38).

$$k_{i,1}(t)=s\left(\left(SoC_i(t-1)-p_{dch}(t)\right)-SoC_{lim,i}\right).f_{i,1-1}(t) \\ +y\left(SoC_{lim,i}-\left(SoC_i(t-1)-p_{dch}(t)\right)\right). \\ f_{i,2-1}(t). \quad (38)$$

According to Eq. (38), in case $SoC_i(t)$ is still higher than $SoC_{in,i}$ and $SoC_{lim,i}$ despite the battery discharge, the parking profit is equal to $f_{i,1-1}(t)$. Eqs. (39) to (41) calculate $f_{i,1-1}(t)$:

$$f_{i,1-1}(t)=C_{i,g}(t)-C_{i,1}(t), \quad (39)$$

$$C_{i,g}(t)=p_{dch}(t).price_{dch,t}, \quad (40)$$

$$C_{i,1}(t)=p_{dch}(t).R_1. \quad (41)$$

If the battery energy content is less than $SoC_{lim,i}$ after the EV is discharged at time step t, the decrease in the value of $SoC_{lim,i}$ should be taken into account. Therefore, it is necessary to consider the value of $SoC_i(t-1)$ to determine the extent to which the discharge of EV at time t has affected the inability to supply $SoC_{lim,i}$. Accordingly, $f_{i,2-1}(t)$ is defined by Eq. (42):

$$\begin{aligned} f_{i,2-1}(t) =& s\left(SoC_i(t-1) - SoC_{lim,i}\right).h_{i,1-2-1}(t) \\ &+ y(SoC_{lim,i} - SoC_i(t-1)). \\ &h_{i,2-2-1}(t). \end{aligned} \tag{42}$$

Despite the discharge of the battery, in cases where $SoC_i(t)$ is higher than $SoC_{in,i}$, but the EV discharge at time t causes the battery energy to be lower than the limit determined for $SoC_{lim,i}$, the parking profit is equal to $h_{i,1-2-1}(t)$. Eqs. (43) and (44) are utilized to calculate $h_{i,1-2-1}(t)$.

$$h_{i,1-2-1}(t) = C_{i,g}(t) - C_{i,2}(t), \tag{43}$$

$$\begin{aligned} C_{i,2}(t) =& p_{dch}(t).R_1 \\ &+ \left(SoC_{lim,i} - \left(SoC_i(t-1) - p_{dch}(t)\right)\right).R_3. \end{aligned} \tag{44}$$

Despite the battery discharge, in cases where $SoC_i(t)$ is higher than $SoC_{in,i}$, but the EV discharge at time t causes the battery energy to decrease more than the previous time steps compared with $SoC_{lim,i}$, the parking profit is equal to $h_{i,2-2-1}(t)$. Eqs. (45) and (46) are utilized to calculate $h_{i,2-2-1}(t)$.

$$h_{i,2-2-1}(t) = C_{i,g}(t) - C_{i,3}(t), \tag{45}$$

$$C_{i,3}(t) = p_{dch}(t).R_1 + p_{dch}(t).R_3. \tag{46}$$

In addition, it is necessary to consider cases where the EV discharge at time step t causes the battery energy to decrease by $SoC_{in,i}$. In the first step, if the EV is not discharged at time step t and there is enough battery energy content E_s and $SoC_i(t-1)$ to charge the EV in the future, the parking lot can benefit from purchasing energy at the lowest cost from the grid and selling it to the EV owner. In this case, $k_{i,2}(t)$ is defined by Eq. (47):

$$k_{i,2}(t) = \begin{matrix} y\left(\left(SoC_i(t-1) + p_{ch}\right) - E_s\right).f_{i,1-2}(t) \\ +s\left(E_s - \left(SoC_i(t-1) + p_{ch}\right)\right).f_{i,2-2}(t) \end{matrix}. \tag{47}$$

According to Eq. (47), the parking profit is equal to $f_{i,1-2}(t)$ in case the EV discharge at time step t reduces the energy of the battery compared to $SoC_{in,i}$; however, the non-discharge of the EV will result in not purchasing energy from the grid and not selling it to the owner of the EV. In this situation, the parking lot is obliged to pay the EV owner for the purchase of energy. Eqs. (48) and (49) are employed to calculate the value of $f_{i,1-2}(t)$.

$$f_{i,1-2}(t) = C_{i,g}(t) - C_{i,4}(t), \tag{48}$$

$$C_{i,4}(t) = p_{dch}(t).R_2. \tag{49}$$

Due to the costs of not supplying $SoC_{lim,i}$; $f_{i,2-2}(t)$ is defined by Eq. (50):

$$\begin{aligned} f_{i,2-2}(t) =& s\left(\left(SoC_i(t-1) - p_{dch}(t)\right) - SoC_{lim,i}\right). \\ &w_{i,1}(t) + y(SoC_{lim,i} - (SoC_i(t-1) \\ &- p_{dch}(t))).w_{i,2}(t). \end{aligned} \tag{50}$$

In case of EV discharge, at time step t, the battery energy relative to $SoC_{in,i}$ is reduced. However, in case of EV non-discharge, there will be an opportunity to purchase energy from the grid and sell it to the owner of the EV, in which case the parking profit will be equal to $w_{i,1}(t)$:

$$w_{i,1}(t) = C_{i,g}(t) - C_{i,5}(t). \tag{51}$$

In this situation, the parking lot is obliged to pay the cost of purchasing energy from the owner of the EV. In addition, the parking lot will lose the profit of purchasing energy to the owner of EV. This profit is calculated according to $p_{dch}(t).(R_1 - R_{\min})$. $R_{\min}$ is equal to the lowest cost of purchasing energy from the grid. Therefore, $C_{i,5}(t)$ is calculated using Eq. (52):

$$C_{i,5}(t) = p_{dch}(t).R_2 + p_{dch}(t).(R_1 - R_{\min}). \tag{52}$$

Due to the cost of not supplying $SoC_{lim,i}$, it should be considered that discharging at time step t causes a reduction compared to the $SoC_{lim,i}$ value; therefore, $w_{i,2}(t)$ is defined by Eq. (53):

$$\begin{aligned} w_{i,2}(t) =& s\left(SoC_i(t-1) - SoC_{lim,i}\right).w_{i,1-2}(t)+ \\ & y\left(SoC_{lim,i} - SoC_i(t-1)\right).w_{i,2-2}(t). \end{aligned} \tag{53}$$

In case the EV discharging at time step t, in addition to the reduction of battery energy with respect to $SoC_{in,i}$, causes the battery energy to be lower than the limit set for $SoC_{lim,i}$, the parking earned profit is equal to $w_{i,1-2}(t)$. Eqs. (54) and (55) are employed to calculate the value of $w_{i,1-2}(t)$:

$$w_{i,1-2}(t) = C_{i,g}(t) - C_{i,6}(t), \tag{54}$$

$$C_{i,6}(t) = \begin{bmatrix} p_{dch}(t).R_2 + p_{dch}(t).(R_1 - R_{\min})+ \\ \left(SoC_{lim,i} - \left(SoC_i(t-1) - p_{dch}(t)\right)\right).R_3 \end{bmatrix}. \tag{55}$$

In case EV discharging at time step t, in addition to reducing the energy of the battery as compared

Table 1. The second strategy.

Conditions				Equations
$SoC_{d,i}(t)=SoC_i(t-1)-p_{dch}$ $SoC_{d,i}(t)\geq SoC_{in,i}$	$SoC_{d,i}(t)\geq SoC_{\lim,i}$			$C_{i,1}(t)=p_{dch}(t).R_1$
	$SoC_{d,i}(t)<SoC_{\lim,i}$	$SoC_i(t-1)\geq SoC_{\lim,i}$		$C_{i,2}(t)=p_{dch}(t).R_1+\left(SoC_{\lim,i}-SoC_{d,i}(t)\right).R_3$
		$SoC_i(t-1)<SoC_{\lim,i}$		$C_{i,3}(t)=p_{dch}(t).(R_1+R_3)$
$SoC_{d,i}(t)<SoC_{in,i}$	$SoC_{c,i}(t)=SoC_i(t-1)+p_{ch}$ $SoC_{c,i}(t)>E_s$			$C_{i,4}(t)=p_{dch}(t).R_2$
	$SoC_{c,i}(t)\leq E_s$	$SoC_{d,i}(t)\geq SoC_{\lim,i}$		$C_{i,5}(t)=p_{dch}(t).R_2+p_{dch}(t).(R_1-R_{\min})$
		$SoC_{d,i}(t)<SoC_{\lim,i}$	$SoC_i(t-1)\geq SoC_{\lim,i}$	$C_{i,6}(t)=p_{dch}(t).(R_2+(R_1-R_{\min}))+(SoC_{\lim.i}-SoC_{d,i}(t)).R_3$
			$SoC_i(t-1)<SoC_{\lim,i}$	$C_{i,7}(t)=p_{dch}(t).(R_2+(R_1-R_{\min})+R_3)$

to $SoC_{in,i}$, causes a decrease in the battery energy over the previous time steps compared to $SoC_{lim,i}$, the parking earned profit is equal to $w_{i,2-2}(t)$. Eqs. (56) and (57) are used to calculate $w_{i,2-2}(t)$:

$$w_{i,2-2}(t)=C_{i,g}(t)-C_{i,7}(t), \tag{56}$$

$$C_{i,7}(t)=p_{dch}(t).R_2+p_{dch}(t).$$
$$(R_1-R_{\min})+p_{dch}(t).R_3. \tag{57}$$

Table 1 summarizes the $J_{dch,2}(t)$ equations.

3.3. The third strategy

All the equations involved in this strategy are in accordance with the second strategy, and the only difference is the use of $R_{\max}$ as the highest cost of purchasing energy from the grid. The third strategy assumes that EV will be charged in a time step when energy price is at its highest ($R_{\max}$) and then, provided by the parking lot to the EV owner.

3.4. The fourth strategy

In order to increase the participation of the EV in the discharge process in this strategy, a new constraint is added to the $C_{ech}(t)$ function. This constraint specifies that EV owner will only have to pay for SoC_{in} increase to SoC_{lim} and will not be charged any further. Consequently, $C_{ech,i}(t)$ is defined by Eq. (58):

$$C_{ech,i}(t)=\begin{cases} R_1.(SoC_{out,i}-SoC_{in,i}) \\ \quad SoC_{in,i}\leq SoC_{out,i}\leq SoC_{lim,i} \\ R_1.(SoC_{lim,i}-SoC_{in,i}) \\ \quad SoC_{in,i}\leq SoC_{lim,i}\leq SoC_{out,i} \end{cases} \tag{58}$$

In the following, the necessary equations for calculating the discharge function of the fourth strategy, $J_{dch,4}(t)$, are presented.

$$\max \quad J_{dch,4}(t)=\sum_{i=1}^{Nev(t)} n_i(t).F_i(t) \ . \tag{59}$$

In the first step of implementing this strategy, the energy status of a battery with respect to $SoC_{in,i}$ should be determined if the EV is discharged at the time step t. Therefore, $F_i(t)$ is defined by Eq. (60):

$$F_i(t)=s\left(\left(SoC_i(t-1)-p_{dch}(t)\right)-SoC_{in,i}\right).k_{i,1}(t)+$$
$$y\left(SoC_{in,i}-\left(SoC_i(t-1)-p_{dch}(t)\right)\right).k_{i,2}(t). \tag{60}$$

With the change of $C_{ech,i}(t)$ in the fourth strategy, it is essential to determine the energy status of the battery compared to $SoC_{lim,i}$ at first in the case of EV discharging. Therefore $k_{i,1}(t)$ is defined by Eq. (61):

$$k_{i,1}(t)=s\left(\left(SoC_i(t-1)-p_{dch}(t)\right)-SoC_{lim,i}\right).f_{i,1-1}(t)+$$
$$y\left(SoC_{lim,i}-\left(SoC_i(t-1)-p_{dch}(t)\right)\right).$$
$$f_{i,2-1}(t) \tag{61}$$

In case the battery energy is greater than $SoC_{in,i}$ and $SoC_{lim,i}$ despite the EV discharging, the benefit of the EV discharge will be equal to $f_{i,1-1}(t)$. Eqs. (62) to (64) deal with the calculation of $f_{i,1-1}(t)$:

$$f_{i,1-1}(t)=C_{i,g}(t)-C_{i,1}(t), \tag{62}$$

$$C_{i,g}(t)=p_{dch}(t).price_{dch,t}, \tag{63}$$

$$C_{i,1}(t)=0. \tag{64}$$

If an EV_i discharges at time t, it may result in a lower battery energy than the minimum $SoC_{lim,i}$. In such a situation, the reduction in energy relative to $SoC_{lim,i}$ caused by the discharging at time t should be determined first. Therefore, $f_{i,2-1}(t)$ is defined by Eq. (65):

$$f_{i,2-1}(t)=s\left(SoC_i(t-1)-SoC_{lim,i}\right).h_{i,1-2-1}(t)+$$
$$y\left(SoC_{lim,i}-SoC_i(t-1)\right).h_{i,2-2-1}(t). \tag{65}$$

In a certain case where $SoC_i(t)$ is higher than $SoC_{in,i}$ despite the discharge of the battery, but EV discharging at time step t causes the battery energy to be lower than the limit set for $SoC_{lim,i}$, the earned profit for the parking will be equal to $h_{i,1-2-1}(t)$. Eqs. (66) and (67) are used to calculate $h_{i,1-2-1}(t)$:

$$h_{i,1-2-1}(t) = C_{i,g}(t) - C_{i,2}(t), \tag{66}$$

$$C_{i,2}(t) = \left(SoC_{lim,i} - \left(SoC_i(t-1) - p_{dch}(t)\right)\right). (R_3 + R_1). \tag{67}$$

In cases where $SoC_i(t)$ is higher than $SoC_{in,i}$ despite the EV discharging and EV discharge at time t causes the energy of the battery to decrease over the previous time steps relative to $SoC_{lim,i}$, the earned profit for the parking will be equal to $h_{i,2-2-1}(t)$. Eqs. (68) and (69) are used to calculate $h_{i,2-2-1}(t)$:

$$h_{i,2-2-1}(t) = C_{i,g}(t) - C_{i,3}(t), \tag{68}$$

$$C_{i,3}(t) = p_{dch}(t).(R_1 + R_3). \tag{69}$$

According to the equations provided for calculating $C_{ech,i}(t)$, the parking profit varies in different cases, especially where the discharge of the EV leads to reduced battery energy with respect to $SoC_{in,i}$. In the first step, in case the EV is not discharged at time t and the values of E_s and $SoC_i(t-1)$ can be charged in a later stage, the parking lot can benefit by purchasing energy from the grid at the lowest price and selling it to the EV owner. Therefore, $k_{i,2}(t)$ is defined by Eq. (70):

$$k_{i,2}(t) = y\left((SoC_i(t-1)+p_{ch})-E_s\right).f_{i,1-2}(t)+ s\left(E_s-(SoC_i(t-1)+p_{ch})\right).f_{i,2-2}(t). \tag{70}$$

If discharging an EV at time step t reduces the battery energy compared to $SoC_{in,i}$, but not discharging the EV leads to purchasing energy from the grid and selling it to the owner of the EV, the parking lot's profit will be equal to $f_{i,1-2}(t)$. Eqs. (71) and (72) are employed to calculate $f_{i,1-2}(t)$.

$$f_{i,1-2}(t) = C_{i,g}(t) - C_{i,4}(t), \tag{71}$$

$$C_{i,4}(t) = p_{dch}(t).R_2. \tag{72}$$

Due to the costs of not supplying $SoC_{lim,i}$, the battery energy reduction relative to the value of $SoC_{lim,i}$ must be determined first due to discharging at time step t. Therefore, $f_{i,2-2}(t)$ is defined by Eq. (73):

$$f_{i,2-2}(t) = s\left((SoC_i(t-1) - p_{dch}(t)) - SoC_{lim,i}\right). w_{i,1}(t)+y(SoC_{lim,i} - (SoC_i(t-1)- p_{dch}(t))).w_{i,2}(t). \tag{73}$$

According to Eq. (73), if an EV discharges at time step t and the battery energy does not decrease below the minimum $SoC_{lim,i}$, the parking lot's profit obtained is $w_{i,1}(t)$.

$$w_{i,1}(t) = C_{i,g}(t) - C_{i,5}(t). \tag{74}$$

In this case, although the capacity of the battery allows the vehicle to earn profits by purchasing energy from the grid and selling it to the EV owner, if the parking lot chooses not to discharge the EV, it would forego that profit. However, since the value of SoC_i(t-1) is higher than $SoC_{lim,i}$, the parking lot would not be able to receive parking fees from the EV owner. Therefore, $C_{i,5}(t)$ is obtained through Eq. (75):

$$C_{i,5}(t) = p_{dch}(t).R_2. \tag{75}$$

Due to the costs of not supplying $SoC_{lim,i}$, it must first be determined how much energy reduction occurs compared to $SoC_{lim,i}$ value following the discharge at time step t. Therefore, $w_{i,2}(t)$ is defined by Eq. (76):

$$w_{i,2}(t) = s\left(SoC_i(t-1) - SoC_{lim,i}\right).w_{i,1-2}(t)+ y\left(SoC_{lim,i} - SoC_i(t-1)\right).w_{i,2-2}(t). \tag{76}$$

In case the EV discharge at time step t reduces the battery energy with respect to $SoC_{in,i}$ and $SoC_{lim,I}$, the parking profit is equal to $w_{i,1-2}(t)$.

$$w_{i,1-2}(t) = C_{i,g}(t) - C_{i,6}(t). \tag{77}$$

In case $SoC_i(t-1)$ is greater than $SoC_{lim,i}$, through EV charging, the parking lot will not be able to receive any cost from the EV owner. Therefore, $C_{i,6}(t)$ is obtained via Eq. (78):

$$C_{i,6}(t) = p_{dch}(t).R_2 + (SoC_{lim,i} - (SoC_i(t-1)- p_{dch}(t))).R_3. \tag{78}$$

In case $SoC_i(t-1)$ is less than $SoC_{lim,i}$, not discharging the EV will allow the parking lot to receive fees from the EV owner by purchasing energy from the grid and increasing the battery energy. The parking income for energy sales to the owner of EV depends on the value of $SoC_i(t-1)$. Thus, $w_{i,2-2}(t)$ is defined by Eq. (79).

$$w_{i,2-2}(t) = s\left((SoC_i(t-1)+p_{ch})-SoC_{lim,i}\right).v_{i,1}(t)+ y\left(SoC_{lim,i}-(SoC_i(t-1)+p_{ch})\right).v_{i,2}(t). \tag{79}$$

If the EV discharge at time step t reduces the battery energy with respect to $SoC_{in,i}$ and the difference between $SoC_i(t-1)$ and $SoC_{lim,i}$ is less than the rechargeable energy at a charge time step, the parking profit will be equal to $v_{i,1}(t)$:

$$v_{i,1}(t) = C_{i,g}(t) - C_{i,7}(t). \tag{80}$$

In this situation, given that the energy of the battery increases compared to $SoC_{lim,i}$ for a single charge stage, $C_{i,7}(t)$ is determined through Eq. (81):

Table 2. The fourth strategy.

Conditions					Equations
$SoC_{d,i}(t) = SoC_i(t-1) - p_{dch}$ $SoC_{d,i}(t) \geq SoC_{in,i}$	$SoC_{d,i}(t) \geq SoC_{\lim,i}$				$C_{i,1}(t) = 0$
	$SoC_{d,i}(t) < SoC_{\lim,i}$	$SoC_i(t-1) \geq SoC_{\lim,i}$			$C_{i,2}(t) = \left(SoC_{\lim,i} - SoC_{d,i}(t)\right).(R_1 + R_3)$
		$SoC_i(t-1) < SoC_{\lim,i}$			$C_{i,3}(t) = p_{dch}(t).(R_1 + R_3)$
$SoC_{d,i}(t) < SoC_{in,i}$	$SoC_{c,i}(t) = SoC_i(t-1) + p_{ch}$ $SoC_{c,i}(t) > E_s$				$C_{i,4}(t) = p_{dch}(t).R_2$
	$SoC_{c,i}(t) \leq E_s$	$SoC_{d,i}(t) \geq SoC_{\lim,i}$			$C_{i,5}(t) = p_{dch}(t).R_2$
		$SoC_{d,i}(t) < SoC_{\lim,i}$	$SoC_i(t-1) \geq SoC_{\lim,i}$		$C_{i,6}(t) = p_{dch}(t).R_2 + (SoC_{\lim,i} - SoC_{d,i}(t)).R_3$
			$SoC_i(t-1) < SoC_{\lim,i}$	$SoC_{c,i}(t) \geq SoC_{\lim,i}$	$C_{i,7}(t) = p_{dch}(t).(R_2 + R_3) + (SoC_{\lim,i} - SoC_i(t-1)).(R_1 - R_{\min})$
				$SoC_{c,i}(t) < SoC_{\lim,i}$	$C_{i,8}(t) = p_{dch}(t).(R_2 + (R_1 - R_{\min}) + R_3)$

$$C_{i,7}(t) = p_{dch}(t).R_2 + p_{dch}(t).R_3 + \left(SoC_{lim,i} - SoC_i(t-1)\right).(R_1 - R_{\min}). \quad (81)$$

In case the EV discharge at time step t reduces the battery energy with respect to $SoC_{in,i}$ and the difference between $SoC_i(t-1)$ and $SoC_{lim,i}$ is less than the rechargeable energy at a charge time step, the parking profit is equal to $v_{i,2}(t)$.

$$v_{i,2}(t) = C_{i,g}(t) - C_{i,8}(t). \quad (82)$$

In this situation, due to the single charge stage, the energy of the battery increases compared to $SoC_{lim,i}$ and $C_{i,8}(t)$ is determined using Eq. (83).

$$C_{i,8}(t) = p_{dch}(t).R_2 + p_{dch}(t).(R_1 - R_{\min}) + p_{dch}(t).R_3. \quad (83)$$

Table 2 summarizes $J_{dch,4}(t)$ equations.

3.5. The fifth strategy

All the equations in the fifth strategy are the same as those in the fourth strategy, except for the use of $R_{\max}$ as the maximum cost of purchasing energy from the grid. Accordingly, in the fifth strategy, it is assumed that EV is charged at a time step when the energy price is at its highest ($R_{\max}$) and then, it is provided by the parking lot to the EV owner.

4. Simulation results (Parking earned profit and distribution network reliability calculation)

The priority of charging and discharging EVs in each of the strategies is determined by optimizing $J_{ch,k}(t)$ and $J_{dch,k}(t)$ functions. Each strategy produces a certain amount of profit and load behavior. Therefore, distribution of the probability of consumption load and parking generation power in different strategies will be different. The probability distribution graphs are used to assess the reliability of the distribution network.

Due to the random nature of EV behaviors, parking profit and the load behavior of each strategy are of random nature. We use the Monte Carlo method to obtain the profit and determine the load behavior of each strategy. Figure 1 shows the calculation procedure for the parking profit and the reliability of the distribution network. In this study, the number of strategies is 5 ($S.N = 5$). Also, the number of iterations for each strategy is 100 (iteration = 100).

Price values were adopted from [22]. Parking status in different stages of time is shown in Table 3.

To increase the contribution of EVs to the transmission of power to the grid and improve the reliability of the distribution system, the tariffs of the EV owner on energy sales as well as the SoClim non-supply tariffs are determined in the following manner. According to Table 3, the energy price per hour is different. According to Table 3, the tariff on EV sales (EV charging) is considered to be the lowest energy sale tariff to the grid. Also, the tariff on not supplying SoClim and the purchase of energy from the EV owner (EV discharge) is equal to the minimum electricity purchase tariff from the distribution system. Since C_{park} calculation was not considered in previous studies, the coefficient was considered to be 70% of the highest energy price so that the values of the defined functions will not differ significantly. Therefore, the value of b is considered as 20%, as demonstrated by the statistical data.

According to [21], the following equation is used to calculate EV energy when entering a parking lot, SoC_{in}.

$$SoC_{in} = E_s - (d_d.C_{veh}). \quad (84)$$

E_s represents the EV battery capacity, d_d indicates the distance traveled by EV, and C_{veh} is the energy consumption rate per kilometer.

EVs use numerical results and equations in [21] for modeling driving patterns. The technical and economic

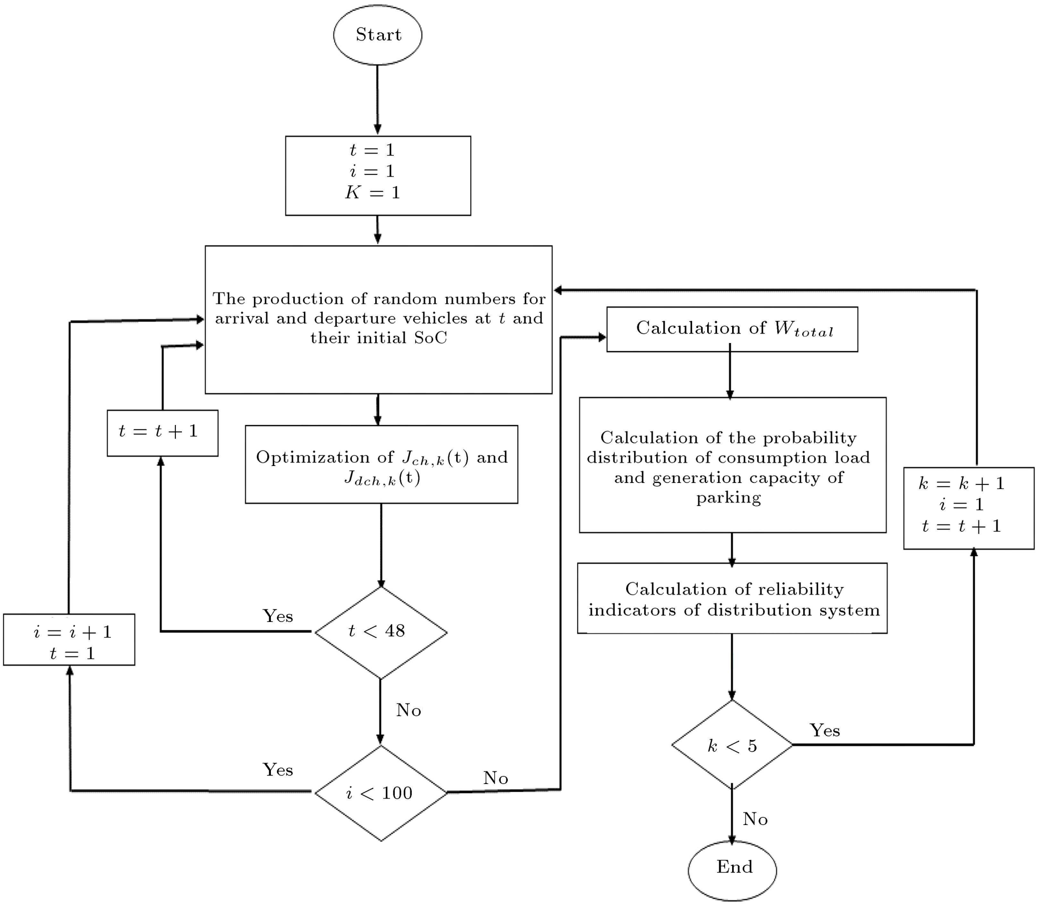

Figure 1. Calculation procedure for parking profit and distribution network reliability.

Table 3. Energy price and parking status during the study period.

	Time step			
	1–9 33–25	10–14 34–38	15–19 39–43	20–24 44–48
Energy price (€/kWh)	0.032 0.062	0.073 0.076	0.062 0.066	0.080 0.094
Parking state	Charging	Discharging	Charging	Discharging

Table 4. Technical and economic features of parking and EVs.

$p_{ch} = p_{dch}$ (kW)	E_s (kW)	$P_{ch} = P_{dch}$ (kW)	SoC_{lim} (kWh)	R_1 (€/kWh)	$R_2 = R_3$ (€/kWh)
3.2	32	192	24	0.073	0.03

features of EVs and parking are given in Table 4. The parking capacity of 100 vehicles is considered.

If the EV owner does not allow the parking lot to charge and discharge the EV, the parking lot is not able to earn money by buying and selling energy due to the lack of charging and discharging EV in the parking lot. Thus, the parking profit only includes the parking cost of EVs.

As observed in Table 5, the participation of EVs in the first strategy in the charging and discharging processes will increase the parking benefit by selling energy to the grid and selling energy to the owners of EVs. In the second strategy, considering the possibility of selling energy sales to the owner of EV in the scheduling process results in a reduction in the amount of energy sold to the grid compared to the amount of energy sold to EV owners. Furthermore, the decision not to discharge EVs results in a significant reduction in the amount of energy purchased from EV owners, as well as the amount of energy that is not supplied.

Table 5. The parking profit functions.

Function (€)	**Strategy**				
	The first	**The second**	**The third**	**The fourth**	**The fifth**
C_{gdch}	131.77	41.353	93.457	64.153	104.89
C_{park}	209.73	209.73	209.73	209.73	209.73
C_{ech}	57.69	82.134	76.049	61.468	60.512
C_{gch}	111.43	85.361	103.59	92.031	105.91
C_{edch}	5.4989	0.8486	3.8294	2.2416	4.8922
C_{lim}	8.4592	0.1511	3.0774	1.4114	4.3959
C_{sh}	4.4153	0.728	3.028	1.6728	3.5804
W_{total}	269.39	246.13	265.7	238	256.33

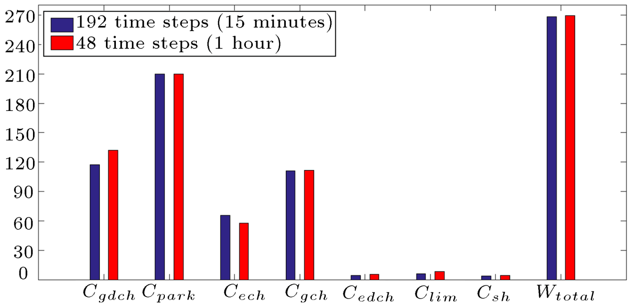

Figure 2. The parking profit functions in the first strategy.

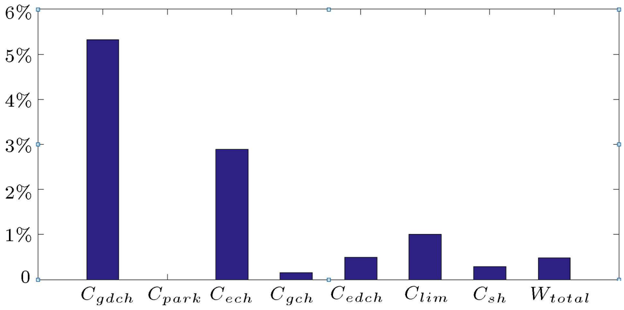

Figure 3. The percentage of changes in parking functions relative to W_{total}.

The third strategy attempts to encourage parking in favor of EVs discharge by changing $R_{\min}$ into $R_{\max}$. Table 5 shows that by increasing the participation rate of EVs in the discharge process, the parking profit from the sale of energy to the grid is more than the profits earned through the sale of energy to EV owners. In the fourth strategy, reducing the cost of selling energy to the EV owners increased the sales of energy to the grid, compared with the second strategy. However, changing the C_{ech} function led to a reduction in parking profits compared to the third one. In the fifth strategy, with a change in the value of $R_{\min}$, the amount of energy sold to the grid increased and the amount of energy sold to EV owners decreased. Increasing profits earned from energy sales to the grid led to an increase in parking profits, compared with the fourth strategy.

In order to increase accuracy and study the effect of the duration of each time step on the profit of parking, the duration of each time step was reduced from 1 hour to 15 minutes. The first strategy was reevaluated over a 48-hour time interval and over 192 time steps of 15 minutes. The study is also re-evaluated in 100 iterations. Figure 2 shows the values of the parking profit functions in the first strategy when the duration of each time step is 15 minutes (number of time steps equal to 192 time steps) and when the duration of each time step is 1 hour (number of time steps equal to 48 time steps). Figure 3 shows the percentage of changes in parking functions relative to W_{total} (269.39).

As shown in Figures 2 and 3, the amount of changes in parking functions is negligible. Most of the changes are related to C_{gdch}, which is reduced by 5.32%. On the other hand, a decrease in the amount of energy sold to the grid led to an increase in the amount of energy sold to homeowners, and C_{ech} increased by 2.89%. Wtotal remains almost the same in both states. Therefore, the parking profit is independent of the duration of each time step. For this reason, other strategies were not re-evaluated.

This section evaluates the reliability of the radial distribution network introduced in [23] under different strategies. The Load Duration Curve (LDC) introduced in [24] is used to determine the peak charge per hour. This article assumed that parking is located in Bus C. The studied distribution network is demonstrated in Figure 4.

Calculating the values of reliability indicators including ENS, ASAI, SAIFI, and SAIDI is very necessary in order to investigate the impact of each strategy on the reliability of the system, in cases where parking is not equipped with V2G technology and the process of charging the EVs in the parking lot is performed in a random and unplanned way. Figure 5 shows the mean values of ENS in charging conditions without scheduling and scheduled charging and discharging.

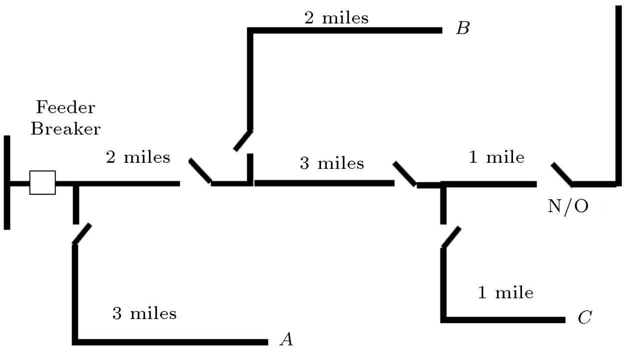

Figure 4. Radial distribution network.

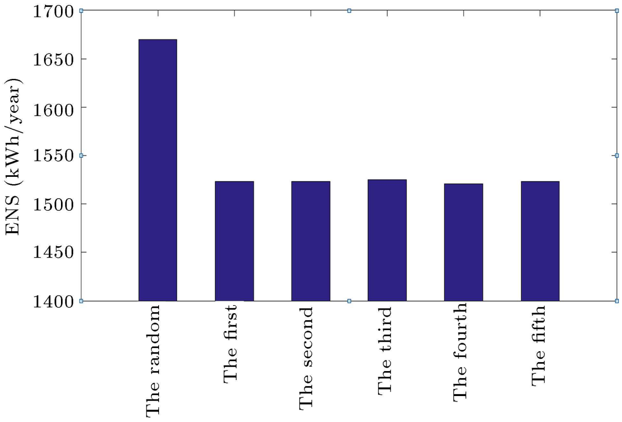

Figure 5. ENS average values in different conditions.

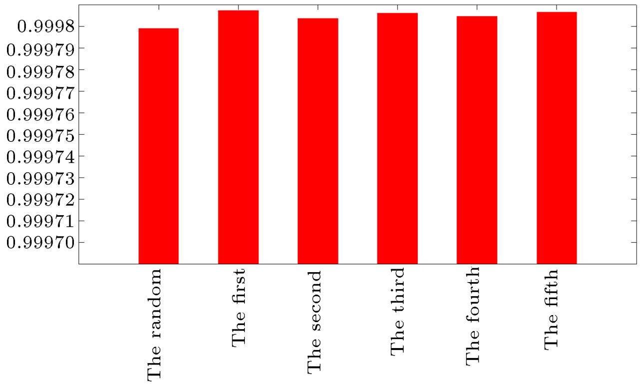

Figure 6. ASAI average values in different conditions.

As seen in Figure 5, the availability of V2G capabilities during high-load hours will reduce the amount of energy not supplied in the system.

Figure 6 shows the average ASAI values in charging conditions without scheduling and scheduled charging and discharging.

As observed in Figure 6, having a V2G capability and scheduling the charge-discharge process will increase the probability of system availability in all scenarios relative to the random and unscheduled mode. This is because with the power generated by the parking lot, a number of customers are fed on the C and B buses every hour and as a result, they will not be interrupted by the system interruption.

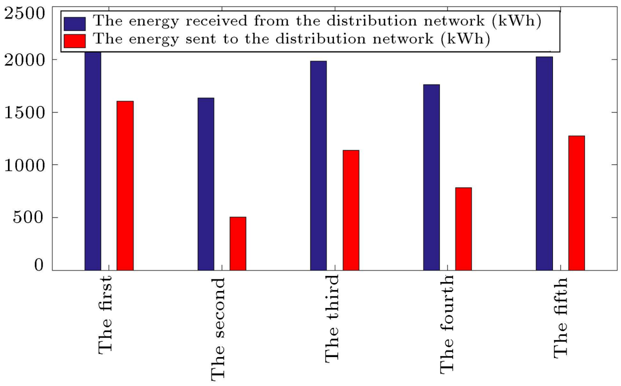

Figure 7. The energy exchange of parking and distribution network.

Table 6. The reliability indicators.

Strategy	SAIFI	SAIDI	ASAI	ENS
Without exchange	1.225	1.7375	0.9998	1473.25
The first	1.18866	1.68885	0.99981	1522.94
The second	1.20683	1.72215	0.9998	1522.94
The third	1.19445	1.6998	0.99981	1524.79
The fourth	1.20138	1.71163	0.9998	1521.09
The fifth	1.1923	1.69541	0.99981	1522.99

As noted above, in case the owner of the EV does not allow parking on the charge and discharge, no energy exchange with the distribution network is carried out (no-exchange status). Figure 7 shows the graphs of the energy received from the distribution network and the energy sent to the distribution network. Table 6 shows reliability indicators.

The parking was located on Bus C and the error rate was lower on this bus. Therefore, the improvement of the SAIFI index using the first strategy results from the addition of more load and more generation than other strategies. The SAIDI and ASAI indicators are enhanced using the first strategy due to the lower energy content provided for the EVs than other strategies. In the strategies 1–5, the parking has an electrical load nature unlike no-exchange status, and according to Figure 7, the parking load consumption is always higher than its generation. This increases the ENS using all the strategies as compared to the situation without exchange.

As shown in Figure 8, the first, third, and fifth strategies are the most profitable, because the profit in the first strategy through the sale of energy to the grid is more than the profits made using the fifth and third strategies. By the same token, the improvement rates of SAIFI, SAIDI, and ASAI indices achieved using this strategy surpass those in the fifth and third strategies.

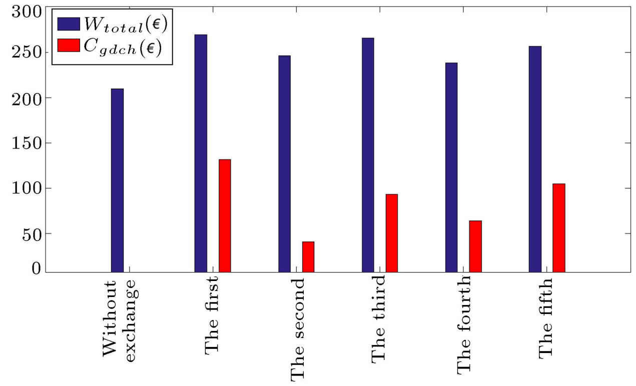

Figure 8. Parking profit and parking profit received from the grid for the sale of energy to the grid.

Accordingly, the improvement of the indicators in the fifth strategy is greater than that in the third strategy.

Increasing the energy received from the grid and reducing the energy sent to the grid will increase the ENS index. Based on Figures 7 and 8, the third strategy has a higher ENS index value than the other strategies due to the higher total amount of energy received from the grid and the lower amount of energy sent to the grid.

Tables 5 and 6, along with Figures 7 and 8, demonstrate that the first strategy, by increasing the participation of the EVs in the sale of energy to the grid, can result in a significant portion of the parking lot's profit generated through the sale of energy to the grid, despite the increase in parking costs. Moreover, this approach can improve the reliability of the distribution network.

5. Conclusion

Increasing parking profits is an important step towards enhancing parking satisfaction through participation in the Vehicle to Grid (V2G) process and improving the reliability of the distribution network. Accordingly, strategies for scheduling the charging and discharging processes were proposed in this paper, with initial consideration given to the receipt and payment of parking fees and the associated profit function. Planning the process of charging and discharging Electric Vehicles (EVs) in the design of strategies is subjected to limitations, namely the random and unpredictable nature of the time of arrival and departure of EVs and their energy content while arriving at the parking lot, and the limitation on the power sent from the system of distribution to the parking lot, and vice versa.

By using the first strategy, the contribution of EVs in the charging and discharging processes increased the parking lot benefit by selling energy to the grid and selling energy to EV owners. By using the second strategy, attention to the possibility of selling energy to the EV owner in the scheduling process reduced the amount of energy sold to the grid compared to the amount of energy sold to the EV owners. This reduced the parking lot benefit compared to the first strategy. In the third strategy, the contribution of the EV to selling grid energy increased due to the change from $R_{\min}$ to $R_{\max}$, resulting in increased parking lot benefit compared to the second strategy. In the fourth strategy, lowering the price of energy sales to EV owners increased the energy sales to the grid, compared to the second strategy. However, changing the cost function of the EV owner reduced the parking lot benefit compared to the second strategy. In the fifth strategy, due to the change of $R_{\min}$ to $R_{\max}$, the contribution rate of EVs increased in the grid energy sales and as a result, the parking lot benefit increased compared to the fourth strategy. The results indicated that the first, fifth, and third strategies outperformed other strategies in terms of improving the SAIFI index, because they increase the energy exchange between the parking lot and the grid. Also, the first, fifth, and third strategies improved SAIDI and ASAI because they caused the parking lot to send more energy to the grid than the energy perceived from the grid through V2G. The improvement rate of the ENS index in the third strategy was lower, because the total energy received from the grid and the energy delivered to the owners were greater than those in other strategies. Based on the information above, it can be concluded that the first strategy is the most effective in improving reliability indicators as well as parking lot profit because it increases the participation of EVs in the sale of energy to the grid.

The results of each of the implemented strategies demonstrate that utilizing V2G technology and scheduling the process of charging and discharging EVs in the parking lot can improve the reliability indices of the distribution network. Moreover, the strategies that generate profits through the sale of energy to the grid can simultaneously enhance parking revenue and the reliability of the distribution network.

It is essential to take advantage of the strategies proposed in order to improve the reliability of the distribution network because it increases the profit of the parking owner and encourages the owner of the parking lot to participate in the electricity market.

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