Vol. 8(28), Apr. 2018, PP. 3893-3900

Contents list available at IJMEC

International Journal of Mechatronics, Electrical and Computer Technology (IJMEC)

Journal Homepage: www.aeuso.org

PISSN: 2411-6173 - EISSN: 2305-0543

Charging and Discharging Coordination of Electric Vehicles In A Parking lot Considering The Limitation of Power Exchange With The Distribution System

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Abstract

With the extensive use of electric vehicles, the need to charge them has become one of the important issues in the distribution system. Also, these vehicles are able to play the role of energy-generating sources by utilizing vehicle-to-grid (V2G) capabilities. Therefore, coordination of the charging /discharging process of electric vehicle batteries is essential in order to optimally use these energy storage resources. In this paper, different strategies are proposed for charging /discharging electric vehicles regarding variable power costs, parking constraints for electric vehicles and the random and unpredictable nature of quantities, such as the entrance and exit of electric vehicles to the parking lot. Such strategies address the time and state of charge of vehicles in order to increase the profit of electric vehicle parking lot, because parking lot is the responsible of charging and discharging. The results show that different strategies have different profits for parking.

Keywords: *Electric vehicles, distribution systems, coordinated charging/discharging, vehicle-to-grid(V2G) capability*

1. Introduction

The reduction of fossil fuels and the need to reduce urban pollutants have made electric vehicles as an appropriate alternative to domestic combustion engines [5]. Electric vehicles can act as a source of energy by using vehicle-to-home (V2H) and vehicle-to-grid (V2G) capabilities. The V2G capability allows vehicles to act as a mobile storage device which can inject the storage energy into the grid [1]. The V2G capability allows for active power regulation, reactive power support, load modulation, flow harmonic filtering and peak charge correction. These factors provide services such as spinning reservations and voltage and frequency control for the power grid [10]. In addition to the aforementioned, electric vehicles can participate in electricity markets and provide many economic benefits to their power grid and owner via the correct implementation of the V2G [7]. However, it is important to note that the economic benefits of V2G capability depend on how to charge and discharge electric vehicles [8], [10]. If the charging process is not controlled, charging time periods will intersect with the peak load time of the distribution system [6], thereby increasing peak load [1], and the distribution system faces with problems such as overload, excessive loss of power and voltage violation [2]. Therefore, charging patterns should be designed in such a way to persuade users to transfer charge periods to off-peak periods [1]. The effects of the presence of plug-in hybrid electric vehicles (PHEV) have been studied in several articles. In [8], the reliability of the distribution system was evaluated with consideration of V2G. In [9], the well-being indicators of generating system have been evaluated with consideration of V2G. In these evaluations, in a 48-hour period, the network only has the ability to use

Article History:
Received Date: Jan.06, 2018
Accepted Date: Jun. 11, 2018
Available Online: June. 20, 2018

V2G in an interruption period, and there is no way to operate the V2G capability in several discrete periods. In [12], Particle Swarm Optimization (PSO) has been used to coordinate the charging of PHEVs. In this optimization, some constraints including energy costs, remaining battery capacity, and remaining time for charging have been considered. However, the accidental and unpredictable exit of PHEVs from parking is not included. In [11], a two-step method is proposed for charging coordination. This method guarantees that all vehicles are charged while limits the load on distribution and transmission systems. However, in this optimization, there is no time interval for discharging the battery and the possibility of the V2G capability has not been considered.

In [10], the effects of uncoordinated charging / discharging strategies (random charging and discharging) and coordinated charging / discharging strategies (charging at low loading hours and discharging in high loading hours) on the distribution system have been investigated. The coordinated charge / discharge strategy reduces daily electricity costs, voltage deviations, load waveforms in the transformer, and line currents. It also improves the technical performance of the distribution system in terms of sustainability, efficiency, and reliability. Therefore, the coordinated charging / discharging strategy is the most efficient and most valuable strategy for the owners of electric vehicles and network operators.

In this paper, various strategies for coordinating the charging/discharging of PHEVs are proposed in electric vehicle parking with V2G capability and the aim of increasing parking profits. The proposed strategies include constraints on the amount of power exchange between the parking lot and the distribution system, as well as the random and unpredictable nature of quantities, such as the entrance and exit of PHEV to the parking lot, and the state of charge for the PHEV when entering the parking lot. Finally, the impact of each strategy on the amount of parking dividend is analyzed.

In section 2 parking profit function is raised. Section 3 introduces charging/ discharging strategies. The results of each of the strategies are presented in section 4, and finally section 5 addresses the conclusion of this paper.

2. Parking profit function

The parking profit function is defined as follows.

$$\begin{aligned} W_{total} &= C_p - C_n \\ C_p &= C_{gdch} + C_{park} + C_{ech} \\ C_n &= C_{gch} - C_{edch} - C_{\lim} - C_{sh} \end{aligned} \tag{1}$$

In (1), W_{total} is the profit received by the parking, C_{gdch}, the cost received by the parking from the grid for the sale of energy to the grid, as well as C_{park} and C_{ech} are the cost received by parking from the owner of the vehicle for parking and increase of vehicle battery when leaving the parking lot respectively. Also, C_{gch} is the cost paid by parking to the network for the purchase of energy from the network and C_{edch}, C_{lim} and C_{sh} are the cost paid by parking to the owner of the vehicle to reduce the charge of the vehicle battery when leaving the parking lot, not providing the minimum charge required and the owner's share from the profits V2G. In the following, the necessary relations are presented to calculate each of the above-mentioned functions.

$$\begin{aligned} C_{gdch} &= \sum_{1}^{t} C_{gdch}(t) \\ C_{gdch}(t) &= P_{gdch}(t).price(t) \end{aligned} \tag{2}$$

$$C_{gch} = \sum_{1}^{t} C_{gch}(t)$$
$$C_{gch}(t) = P_{gch}(t).price(t) \qquad (3)$$

$P_{gdch}(t)$ Is equal to the actual power that the parking lot sells to the grid, $P_{gch}(t)$ is the actual power that the parking lot receives from the network and price(t) is equal to the price of energy at time step t. According to [4], the duration of the presence of PHEVs in a parking lot is a random quantity with unbalanced dispersion. Hence, a two- criteria function is defined for the calculation of C_{park}.

$$C_{park} = \sum_{i=1}^{Nev} C_{park,i}$$
$$C_{park,i} = \begin{cases} at & t \le t_0 \\ at_0 + \sum_{1}^{t-t0} a(1+bt) & t > t_0 \end{cases} \qquad (4)$$

N_{ev} represents the number of PHEVs. a and b are Constant coefficients.

$$C_{ech} = \sum_{i=1}^{Nev} C_{ech,i}$$
$$C_{ech,i} = R_1.(SoC_{out,i} - SoC_{in,i}) \qquad (5)$$

$$C_{edch} = \sum_{i=1}^{Nev} C_{edch,i}$$
$$C_{edch},i = R_2.(SoC_{in,i} - SoC_{out,i}) \qquad (6)$$

In (5) and (6), SoC_{in} and SoC_{out} indicate respectively the state of charge of the vehicle battery when entering and leaving the parking lot. R_1 and R_2 are the energy exchange cost between the parking lot and the vehicle owner.

Charging and discharging continuously affect the battery life. Therefore, parking has to give some part of the V2G profit to the owner in accordance with (7). The amount of vehicle share in the profit is determined by K coefficient.

$$C_{sh} = \sum_{i=1}^{Nev} C_{sh,i}$$
$$C_{sh,i} = K.(C_{gdch,i} - C_{gch,i}) \qquad (7)$$

Parking is required to charge the vehicle battery to the minimum specified capacity, SoC_{lim}. If the PHEV conditions are such that there is no access to SoC_{lim}, the parking lot should charge the battery up to the maximum level.

$$C_{\lim} = \sum_{i=1}^{Nev} C_{\lim,i}$$
$$L_{1,i} = SoC_{\lim} - SoC_{out,i}$$
$$L_{2,i} = SoC_{\max,i} - SoC_{out,i}$$
$$C_{\lim,i} = \begin{cases} R_3.L_{1,i} & SoC_{out,i} \le SoC_{\lim} \le SoC_{\max,i} \\ R_3.L_{2,1} & SoC_{out,i} \le SoC_{\max,i} \le SoC_{\lim} \end{cases} \qquad (8)$$

In (8), SoC_{max} is the maximum possible charge of PHEV and R_3 is the SoC_{lim} non-supply cost.

3. Charging/ discharging strategies

3.1. Parking constraints

3.1.1. According to [8] and [9], all strategies are examined for an interval of 48 hours.

3.1.2. In this paper, as in reference [3], table I is used to determine the energy price. In order to increase profits, parking should, with regard to energy cost, select the permitted time intervals for the charging process as well as the permitted time periods for the discharging process.

3.1.3. Due to the limited power exchange between the parking lot and the grid, P_{chmax} and P_{dchmax}, the maximum number of vehicles that can be charged / discharged by parking, M_{ch} and M_{dch}, should be taken into account.

3.1.4. Each coordinated charging / discharging strategy includes a strategy for coordinating charging process and a strategy for coordinating the discharging process.

3.1.5. Parking control filters are defined as follows:

$$g(x) = \begin{cases} 0 & x < 0 \\ g(x) & x \ge 0 \end{cases} \qquad (9)$$

$$s(x) = \begin{cases} 0 & x < 0 \\ 1 & x \ge 0 \end{cases} \qquad (10)$$

$$y(x) = \begin{cases} 0 & x \le 0 \\ 1 & x > 0 \end{cases} \qquad (11)$$

3.2. The first charging / discharging strategy

The objective function of the charging strategy is defined as follows:

$$MAX \quad J_{ch,1} = \sum_{i=1}^{Nev(t)} n_i(t).F_i(t)$$
$$F_i(t) = S_i(t) + Y_i(t)$$
$$S_i(t) = s(SoC_{\max,i}(t) - SoC_{\lim}).k_{i,1}(t)$$
$$Y_i(t) = y(SoC_{\lim} - SoC_{\max,i}(t)).k_{i,2}(t)$$
$$k_{i,1} = E_s - \left[SoC_i(t-1) - SoC_{\lim} + \alpha(SoC_i(t-1))\right]$$
$$k_{i,2} = E_s - \left[SoC_i(t-1) - SoC_{\max,i}(t) + \alpha(SoC_i(t-1))\right] \qquad (12$$

In (12), SoCi (t-1) represents the state of charge of i-th PHEV at time step t-1 and also Es is equal to the capacity of the battery. In this strategy, the number of times that the vehicle is discharged, or not charged during the permitted time period is essential in determining the charge priority. The value of α is calculated as 0.0001.

Table 1: Parking State

	Time Step			
	1-9 33-25	10-14 34-38	15-19 39-43	20-24 44-48
Energy Price (€/MWh)	32-62	73-76	62-66	80-94
Parking State	charging	discharging	charging	discharging

The charging strategy constraints are as follows:

$$\begin{aligned}
&SoC_i(t) = SoC_i(t-1) + n_i(t)p_{ch}(t)\\
&0 \le n_i(t) \le 1\\
&0 \le SoC_i(t) \le E_s\\
&0 \le \sum_{i=1}^{Nev(t)} n_i(t) \le M_{ch}
\end{aligned} \tag{13}$$

names In (13), p_{ch} (t) is equal to the slope rate of the PHEV battery charge at time step t. This equation holds in all charging strategies. The discharging strategy is defined as:

$$\begin{aligned}
&MAX \quad J_{ch,1} = \sum_{i=1}^{Nev(t)} n_i(t).F_i(t)\\
&F_i(t) = S_i(t) + Y_i(t)\\
&S_i(t) = s(SoC_{\max,i}(t) - SoC_{\lim}).k_{i,1}(t)\\
&Y_i(t) = y(SoC_{\lim} - SoC_{\max,i}(t)).k_{i,2}(t)\\
&k_{i,1}(t) = s((SoC_i(t-1) - p_{dch}(t)) - SoC_{\lim}).f_{i,1}\\
&\quad + y(SoC_{\lim} - (SoC_i(t-1) - p_{dch}(t))).f_{i,2}
\end{aligned} \tag{14}$$

$$\begin{aligned}
&f_{i,1}(t) = E_S - \left[0 - \alpha(SoC(t-1))\right]\\
&f_{i,2}(t) = E_s - \begin{bmatrix} (SoC_{\lim} - (SoC_i(t-1) - p_{dch}(t))).R_3 \\ -\alpha(SoC_i(t-1)) \end{bmatrix}\\
&k_{i,2}(t) = E_s - \begin{bmatrix} (SoC_{\max,i}(t-1) - (SoC_i(t-1) \\ - p_{dch}(t))).R_3 - \alpha(SoC_i(t-1)) \end{bmatrix}
\end{aligned} \tag{15}$$

In (14) and (15), p_{dch} (t) is equal to the PHEV battery discharge slope rate at time step t. In this strategy, a vehicle that is charged more than other vehicles in authorized intervals has a discharging priority. Discharging strategy constraints in all strategies is described as follows.

$$\begin{aligned} & SoC_i(t) = SoC_i(t-1) - n_i(t)p_{dch}(t) \\ & 0 \le n_i(t) \le 1 \\ & 0 \le SoC_i(t) \le E_s \\ & 0 \le \sum_{i=1}^{Nev(t)} n_i(t) \le M_{dch} \end{aligned} \tag{16}$$

3.3. The second charging / discharging strategy

The objective function of the charging strategy is defined as follows:

$$\begin{aligned} & MAX \quad J_{ch,2} = \sum_{i=1}^{Nev(t)} n_i(t).F_i(t) \\ & F_i(t) = E_S - SoC_i(t-1) \end{aligned} \tag{17}$$

In this case, the charge priority is determined based on the vehicle's SoC. The objective function of the second discharging strategy is (18).

$$\begin{aligned} & MAX \quad J_{dch,2} = \sum_{i=1}^{Nev(t)} n_i(t).F_i(t) \\ & F_i(t) = C_{g,i}(t) - C_{e,i}(t) \end{aligned} \tag{18}$$

$$C_{g,i}(t) = \begin{cases} (t-9).p_{dch}(t).price(t) & 10 \le t \le 14 \\ (t-19).p_{dch}(t).price(t) & 20 \le t \le 24 \\ (t-33).p_{dch}(t).price(t) & 34 \le t \le 38 \\ (t-43).p_{dch}(t).price(t) & 44 \le t \le 48 \end{cases}$$

$$C_{e,i}(t) = R_3.g(SoC_{\lim} - SoC_i(t-1))$$

In this strategy, the total profit from discharging is compared with a fine paid to the owner of the vehicle due to lack of consideration of SoC_{lim}. Vehicles are assumed to have been discharged in previous permitted periods in order to make vehicles conditions more uniform.

3.3. The third charging / discharging strategy

Equation (19) shows the objective function:

$$\begin{aligned} & MAX \quad J_{ch,3} = J_{ch,2} \\ & MAX \quad J_{dch,3} = J_{dch,1} \end{aligned} \tag{19}$$

4. Results

A parking with a capacity of 100 vehicles has been considered for the study of proposed strategies. The time of arrival and departure of vehicles and the vehicle's state of charge when entering the parking lot have been considered in Accordance with [4]. Parking and PHEV specifications are in accordance with Table 2 The results of each of the strategies are shown in tables 3 and 4 For example, in table III, the SoC value of a vehicle with SoC_0 = 16.9190 kilo Watt hour and the arrival time of t = 12 has been calculated. In t= 25, the SoC of the first and third strategies is equal but since the discharging number of this vehicle is Higher than other vehicles, in the first strategy, the vehicle was charged at the final stage (t=26).

Table 2: Technical And Economic Parameters

$p_{ch=dch}$ (kW)	E_s (kWh)	$P_{ch=dch}$ (kW)	R_1 (€/kWh)	$R_2=R_3$ (€/kWh)	SoC_{lim} (kWh)	a (€/h)
3.2	32	192	0.073	0.03	24	0.0658

Table 3: State of Charge

Time Step	**State of Charge (Kwh)**		
	The first	The second	The third
12	13.7190	13.7190	13.7190
13	10.5190	10.5190	10.5190
14	7.3190	7.3190	7.3190
15	10.5190	10.5190	10.5190
16	13.7190	13.7190	13.7190
17	16.9190	16.9190	16.9190
18	20.1190	20.1190	20.1190
19	23.3190	23.3190	23.3190
20	23.3190	20.1190	23.3190
21	20.1190	16.9190	20.1190
22	20.1190	13.7190	20.1190
23	16.9190	13.7190	16.9190
24	13.7190	10.5190	13.7190
25	16.9190	13.7190	16.9190
26	20.1190	16.9190	16.9190

Table 4: Amount of functions

Cost(€)	**Sterategy**		
	The first	The second	The third
C_{gdch}	138.9	136.3	138.9
C_p	209.7	209.7	209.7
C_{ech}	53.01	56.58	55.82
C_{gch}	113.3	112.8	114.6
C_{edch}	5.24	5.8	5.46
C_{lim}	9.71	9.03	8.9
C_{sh}	4.21	4.54	4.31
W_{total}	269.2	270.4	271.2

In contrast, because SoC of this vehicle is in a good position compared to others, the vehicle charging will be discarded at the last stage. Also SoC is the same in the second and third strategy until the 19th stage. But in Step 20(t=20), the second strategy decides to discharge due to the fact that the amount of loss paid to the owner is small. In contrast, the third strategy ignores discharging because of the fact that the number of its discharging is more than others. By comparing the results of table 4, the SoC's alignment of vehicles in the charging phase, as well as the share level of vehicle in discharging time intervals, will result in more profits for parking lot.

CONCLUSION

This paper presents various strategies for coordinating charging/discharging of electric vehicles in the parking lot, with the aim of increasing parking profits. For this purpose, a V2G-equipped parking lot with limited power exchange and a capacity of 100 vehicles was considered. The results of various strategies showed that the alignment of energy consumption of vehicles in the charging phase and paying attention to the level of participation of vehicles at the discharging stage would increase the profit of the parking lot.

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