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Optimal Strategy of Efficiency Power Plant with Battery Electric Vehicle in Distribution Network

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Abstract. With the popularity of electric vehicles (EVs), such as plug-in electric vehicles (PHEVs) and battery electric vehicles (BEVs), an optimal strategy for the coordination of BEVs charging is proposed in this paper. The proposed approach incorporates the random behaviours and regular behaviours of BEV drivers in urban environment. These behaviours lead to the stochastic nature of the charging demand. The optimal strategy is used to guide the coordinated charging at different time to maximize the efficiency of virtual power plant (VPP). An innovative peer-to-peer system is used with BEVs to achieve the goals. The actual behaviours of vehicles in a campus is used to validate the proposed approach, and the simulation results show that the optimal strategy can not only maximize the utilization ratio of efficiency power plant, but also do not need additional energies from distribution grid.

1. Introduction

After stepping into the 21st century, the world's energy shows a situation of "multi-polarized" and diversity. This is an opportunity for the development of China [1]. But as an energy-imported country, China should pay more attention to the safety problem of energy [2]. Thus, it is necessary to assure the sustainable development of energy supplement and to propose a sustainable strategy for energy safety [3].Meanwhile, it is a common sense that we should improve the energy environment and minimize the carbon emission [4]. The transportation sector is not only a large proportion of energy consumption, but also an important breakthrough in energy saving and emission reduction. Ref [5-7] reviews the development of electric vehicles (EVs) and the planning problem of charging infrastructure, and they concluded that it is an optimal way to develop EV to solve the problem of energy minimization and to reduce the dependence on traditional energy issues. Thus, compared with the development of EV in other countries, the necessity and the key factors of EV development in China were reviewed [8] from the aspect of energy-saving and power supplement.

However, there will be great impacts of EV random integration on distribution grid. Ref [9-12] analyzed the impacts of charging load on power grid with further study, and there are some conclusions. The impacts of charging load on power quality are voltage drop, harmonic pollution and voltage imbalance [9]. Considering the EV behaviors, the uncoordinated charging demand can not only increase the peak on the peak situation [10], but also increase the peak load capacity [11] and power generation capacity [12]. Thus, coordinated charging is a promising way to mitigate the impacts

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of EV stochastic charging load. Efficiency power plant (EPP), as a way of demand-side management (DSM) and a kind of virtual power plant (VPP) [13], is a promising way to use electricity properly, which provides an opportunity for coordinating.

The development of EPP in China were reviewed [14-16], some conclusions are drawn that EPP can not only improve terminal consumption efficiency [14], optimize incentive policy [15], but also provide a low cost, zero-emission scheduling approach [16] and resource combination optimized approach [17]. Based on the wide spread of EPP, operation mechanism is analyzed in [18], and operation mode of EPP is proposed in [19]. These will lead to the fast development of EPP. With the integration of EVs, efficiency power plant with EV aggregation (E-EPP) is proposed to evaluate the vehicle-to-grid (V2G) response capability with different charging strategies during a whole day [20].

In this paper, an optimal strategy of virtual power plant is proposed to consume the capacity of E-EPP. Some necessary information is acquired for variable charging level decision. Based on the estimated EPP capacity, the system will estimate the proper charging level with distributed hash table (DHT). V2G will be used if the estimated capacity is not enough. The rest of the paper is organized as follows. The massive behaviors of vehicles are analyzed and the V2G capacity is presented in Section 2. Then the model development, which includes EPP capacity, DHT establishment and the proposed strategy, is presented in Section 3. The case study and simulation results are shown in Section 4. At last, this paper is concluded in Section 5.

2. Assessment of BEV behaviours

To assess the stochastic behaviour of BEVs, all probabilistic variables those specify the charging demand of BEVs in a 24h period of time in the campus should be defined. Hence, the actual samples in the campus are collected to simulate the behaviours.

2.1. Probabilistic Variables of the Problem

Three probabilistic variables should be regarded for BEV's operation: the charging start time of BEV (t_s), the leaving time of BEV (t_e) and the initial charging stage of charge (SOC). The Monte-Carlo method is used to estimate the probability density of battery electric vehicles on weekdays.

It is assumed that BEVs commence charging at different times with different probabilities. The probability density functions of t_s (arrival moment) and t_e (departure moment) are depicted in Fig .1, respectively. The probability density function of initial SOC is also depicted in Fig. 2.

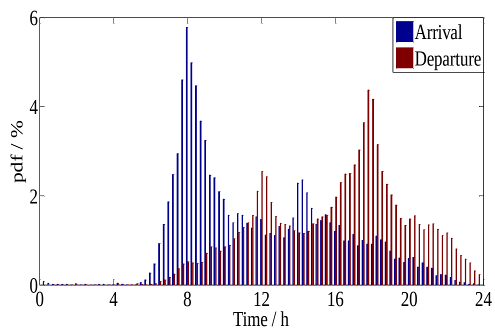

Figure 1. Probability density of arrival and departure.

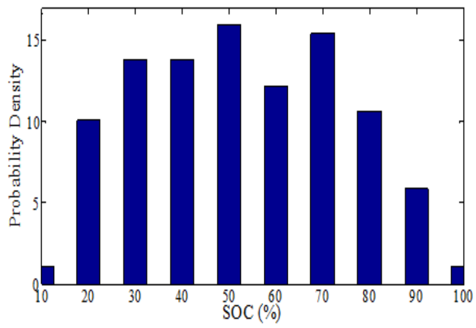

Figure 2. Probability density of initial charging SOC.

2.2. V2G Capacity Estimation

The nominal energy capacity and the consumption of BEVs are C_N = 25.6 kWh and r = 0.17 kWh/km, where CN is the nominal capacity of EV and r is the consumption rate of EV, respectively. The charging window (t_w) of each EV is obtained from (1).

$$t_w = t_e - t_s \tag{1}$$

Considering the degradation of battery packages [21] as well as the navigating distance [22] in Beijing, the charging end SOC_e is set as (2a). The available capacities for V2G (C_{v2g}) are obtained from (2b) and the result is shown in Fig. 3.

$$SOC_e = 0.8 \tag{2a}$$

$$C_{V2G} = \sum_{i=1}^{n} (0.8 - SOC_{i\_end}) \cdot C_N \tag{2b}$$

3. Optimal strategy development of E-EPP

3.1. Capacity estimation of EPP

As a special type of VPP [13], EPP generates electricity by load control to save energies, which is an opportunity for EV owners to charge their cars. The difference between the original load and the load with EPP is captured each minute. Based on these data, EPP capacity (P_{epp}) is estimated with Gray theory modified with data update [23], and it is depicted in Fig. 4.

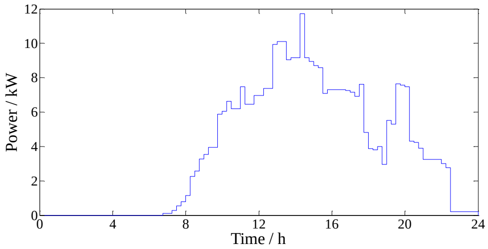

Figure 3. V2G capacity estimation

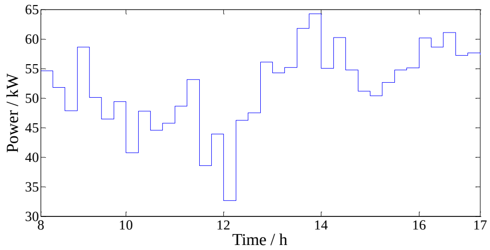

Figure 4.EPP capacity estimation

3.2. Distributed Hash Table development

A distributed hash table (DHT) is a class of a decentralized distributed system that provides a lookup service similar to a hash table: (key, value) pairs are stored in a DHT, and any participating nodes, namely EVs, can efficiently retrieve the value associated with a given key. Responsibility for maintaining the mapping from keys to values is distributed among the EVs, in such a way that a change in the set of participants causes a minimal amount of disruption. This allows a DHT to scale to extremely large numbers of nodes and to handle continual node arrivals, departures. An example of DHT is shown in Fig. 5.

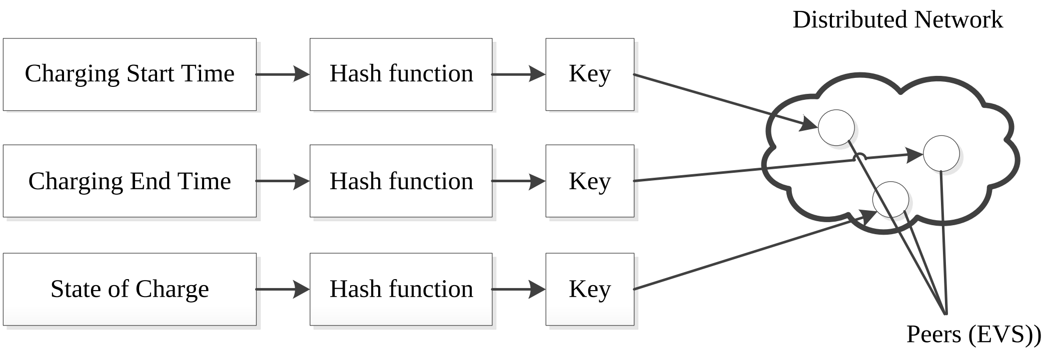

Figure 5. Outlet of DHT

In distributed network, each EV can search the key of other EVs, which results that EV can be charged based on the charging sources, EPP capacity (P_{epp}) and V2G capacity (C_{v2g}) included, and charging level can be derived from (3).

$$P_{ch} = \begin{cases} (P_{epp} + C_{v2g}) / n , & (P_{epp} + C_{v2g}) / n \le 7 \\ 7 , & (P_{epp} + C_{v2g}) / n > 7 \end{cases} \tag{3}$$

Considering the degradation mechanism of battery pack [21], the charging level is varied from 0 kW to 7 kW which is based on the charging number (n).

3.3. Constraints and objective function of the proposed method

The SOC constraint of each EV is considered by upper and lower limits to assure that each EV can complete a daily commute [22] and alleviate the degradation of battery package [21], and it can be express as (4).

$$0.7 \le SOC_{\_end} \le 0.8 \tag{4}$$

Where, $SOC_{\_end}$ stands for the capacity that EV leaves from charging pole.

The selected objective function is aimed at maximizing the utilization ration of EPP with V2G capacity, and it can be expressed as (5a).

$$F = \min(P_{epp}^{t} + C_{v2g}^{t} - P_{c}^{t}) \tag{5a}$$

$$P_{c}^{t} = n \cdot P_{ch}^{t} \tag{5b}$$

Where, P_c^t is the charging power at moment t, and P_{ch}^t is the charging level at moment t.

3.4. Proposed strategy of E-EPP

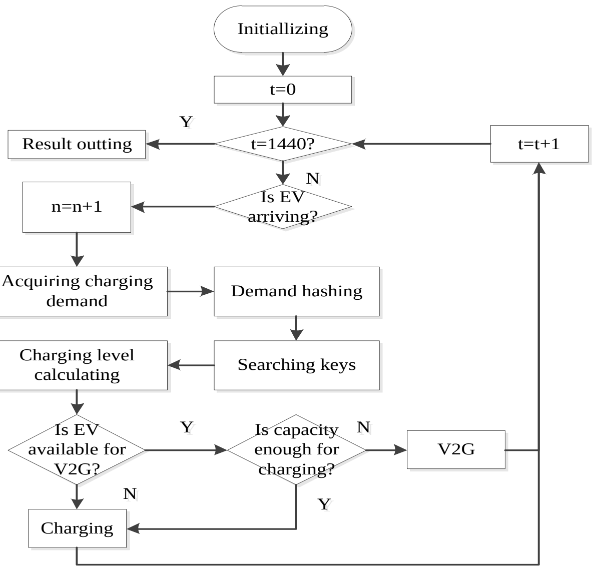

Figure 6. Proposed method of E-EPP

The proposed method, which is shown in Fig. 6, is validated during a 9-hour period from 8 am to 5 pm. Based on prediction technology, EPP capacity is input and hashed in the initializing stage. At the end of the whole day, optimal results are output. Charging numbers are counted when EV is arriving. Then, the charging demand, which includes charging start time (t_s), leaving time (t_e) and initial SOC, is acquired to be hashed. After demand hashing, the EPP capacity for charging is obtain as well as the V2G capacity. The charging level for each EV is evaluated by searching keys, and it can be expressed as (3) on the basis of charging numbers and the generating capacity. Afterwards, each EV is evaluated whether it can be used for V2G. If it can be used for V2G, the difference between charging demand and the whole available capacity for charging is estimated. If the whole capacity is not enough for charging, the EV will be discharge, and the discharge rate can be expressed as (6).

$$P_{id} = \frac{(0.8 - SOC_{i\_end}) \cdot C_N}{t_e - t} \quad (6)$$

4. Case study and results discussion

4.1. Assumptions
Some parameters are set to verify the proposed method. 1) The Monte Carlo method is used to simulate the driving behaviours of 54 BEVs on the basis of the actual data of cars. 2) All drivers are subordinated to the orders from SLM. 3) The charging ending SOC of EV is set to 80%, which incorporates the degradation of battery packages [21] and is enough to ensure the navigating distance of whole day [22]. 4) Advanced ICT system is assumed to be acquired. 5) Constant charging power is 3 kW. 6) EPP is installed for air conditioner controlling. There are 20 air conditioners in this case. The power of each air conditioner is 4 kW.

4.2. Simulation results
Two scenarios are compared in this paper. One is constant charging power without optimization (CCP); the other is variable charging power with DHT (VCPD). The simulating results of CCP and VCPD are shown in Fig. 7.

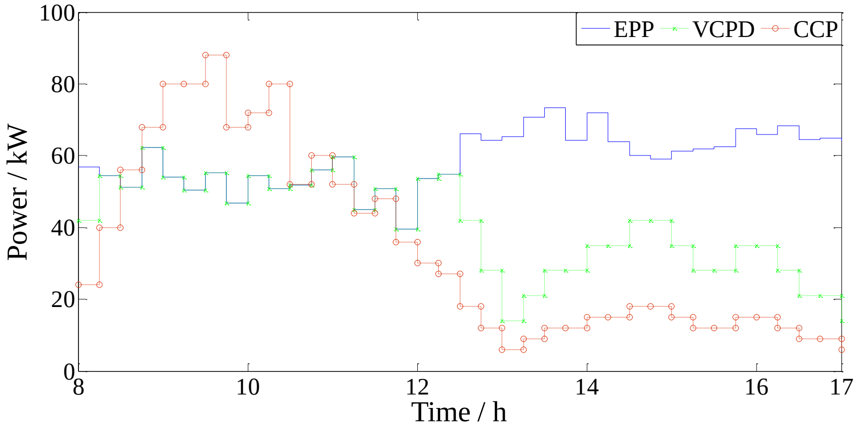

Figure7. Simulating result of CCP and VCPD

The utilization ratio of EPP can be expressed as (7).

$$u = \frac{\int_8^{17} [P_{ch}^t \cdot m + P_{EPP}^t \cdot (1-\mathrm{m})]\mathrm{d}t}{\int_8^{17} P_{EPP}^t dt} \cdot 100\%, m = \begin{cases} 1, P_{ch}^t < P_{EPP}^t \\ 0, P_{ch}^t > P_{EPP}^t \end{cases} \quad (7)$$

Some key parameters are shown in table 1.

Table.1. Key parameter comparison

	Utilization ratio u (%)	Additional capacity (kWh)	Charging Peak (kW)
CCP	49.1	42.75	88
VCPD	68.3	0	62

4.3. Result discussion
According to Fig. 7 and TABLE. I, some conclusions are drawn. 1) With the use of the proposed method, utilization ratio u increases by 19.2%. 2) Compared to VCPD (E-EPP), 42.75 kWh is additionally demanded from distribution grid in Scenario CCP, which will have an additional impact on distribution network. 3) Compared with CCP, the charging peak of VCPD decreased by 29.5%.

5.Conclusion

The problem of the stochastic charging of EV can be solved by the proposed strategy. Regarding the stochastic behaviours of EVs in urban areas, all current probabilistic information which is need for the strategy is considered. The maximization of EPP utilization ration employs a DHT over 9h time period. The simulation results show that the proposed strategy can successfully maximize the utilization ratio of EPP and the additional demand from distribution grid are unnecessary.

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