Research on Vehicle-to-Building Charging Strategy in Microgrid

Yali Liu[1], Xudong Wang[1], Xiaohui Hu[1], Yujun Liu[2,a,*], Cheng Hu[2]

[1]State Grid Tianjin Electric Power Company Electric Power Research Institute, Tianjin, China

[2]School of Electric Engineering, Southeast University, Nanjing, China

[a] liuyujun0713@126.com

Keywords: Bi-level Optimization, Building Load, Electric Vehicles, Charge and Discharge, Load Aggregator.

Abstract: Large parking location and plenty of residence time of EVs in building provide the spatial space and temporal convenience for energy interaction, so the precisely control of EVs' charging and discharging can be realized through the vehicle-to-building (V2B) technology. This paper studies the optimization method of EVs charge- discharge mode. At firstly, a multi-type building energy system model with EVs is established. Then, this paper establishes a bi-level optimal model for EVs' charging and discharging. The objective function of the outer level is to reduce the valley-to-peak difference of the equivalent load curve of building during the period of V2B. The objective function of inner level is to minimize the building operation cost paid by load aggregators which can be solved through CPLEX. The simulation results show that the proposed strategy can significantly reduce the valley-to-peak difference of buildings' load and the operating cost paid by load aggregators.

1. Introduction

Modern buildings, including residential buildings, office buildings, and commercial buildings, are usually equipped with large parking lots with a large number of EV s, which is an ideal place for charging and discharging management of EVs. Therefore, the refined management of charging and discharging of EV s can be realized through the interactive technology between EV and buildings (V2B) [1].

This paper studies the optimization of EVs charging and discharging management in typical multi-type buildings. Firstly, this paper analyzes and builds the model of multi-type building energy system. Then, an optimized two-layer model for charging and discharging electric vehicles is established. The objective function of the outer layer is to reduce the peak-to-valley difference of the building equivalent load curve during the V2B period. The objective function of the inner layer is minimizing the building operation cost paid by the building load aggregators. The charging/discharging strategies in each period are determined according to the power arrangement obtained by the outer layer optimization.

2. Analysis and modeling of multi-building energy system

2.1 Analysis of building load characteristics

Building loads mainly include air conditioning system, lighting equipment, etc. But different types of buildings differ in terms of their properties, and therefore in terms of power consumption structure and peak load, leading to different load characteristic curves of buildings [2]. According to living experience and field investigation, the electricity consumption time characteristics of three types of buildings can be roughly obtained, as shown in the following table:

  DOI: 10.25236/acete.2019.135

Table 1 Load time characteristics of different buildings in typical day

Building Type	Power Consumption Period	Peak Load Period
residential	all day	7:00-8:00, 20:00-23:00
office	8:00-19:00	9:00-11:00, 14:00-17:00
commercial	10:00-22:00	12:00-14:00, 18:30-21:00

2.2 Analysis of travel characteristics of EV users

According to the data analysis of Beijing's 2015 travel report [3], it can be found that urban residents mainly stay in three places in most of working days: residential buildings, office buildings and commercial buildings. Most EV users leave their homes in the morning to go to work in an office building or commercial building, and choose to go home after work or to the commercial building for leisure and entertainment before returning home. Its main travel routes include the following:

(1) Residential building→ office building→ residential building;

(2) Residential building→ commercial building→ residential building;

(3) Residential building → office building→ commercial building→ residential building.

2.3 Description of building system

We consider a micro-grid consisting of multiple high-rise buildings, DG, and EVs. The system architecture is shown in Figure 1.

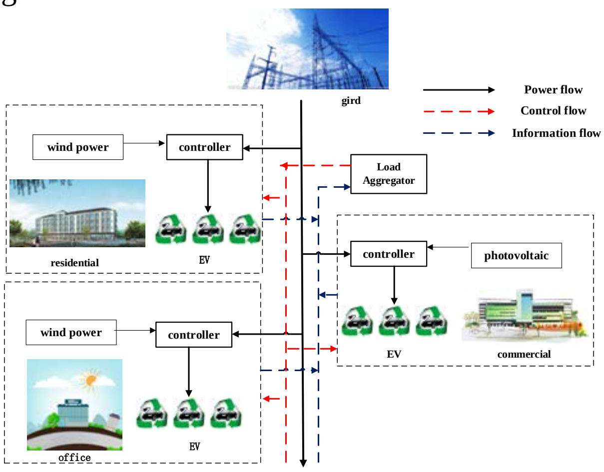

Figure 1 System Architecture

In this system, the buildings' DG with power generation capacity is used to provide the internal load of the building and electric vehicles with electricity, so as to satisfy the consumption of real-time load and charging service of electric vehicles as much as possible. Meanwhile, the output and load characteristics of DG are different between different buildings.

3. Charging and discharging optimization model for EV

Based on the multi-building energy system build in Section 2, this section establishes a two-layer optimization model for EV charging and discharging. [4-5] The aim is to improve the contour of the building equivalent load curve by optimizing the charging and discharging of electric vehicles participating in V2B from the perspective of building load aggregators. At the same time, the operating expenses of the aggregator expenditure are minimized, and the economical optimization is achieved.

3.1 Objective function

3.1.1 Outer optimization

Through EVs involved in peaking and filling the valley, the main idea is discharging at peak and charging at valley to reduce the peak and valley difference. Therefore, the minimum peak-valley difference of building equivalent curve is an important index to measure the performance of peak shaving and valley filling. The objective function is set up as follows:

$$\min F_1 = \frac{\max(P_{load} - P_{DG} + P_{EV}) - \min(P_{load} - P_{DG} + P_{EV})}{\max(P_{load} - P_{DG} + P_{EV})} \tag{1}$$

Where, P_{load} is the building load curve, P_{DG} is the output curve of buildings' DG, P_{EV} is the charging and discharging power curve of EVs connected to buildings.

3.1.2 Inner optimization

As intermediary of grid and users participating in the electricity market, building load aggregators has not yet have clear standard guidelines about benefits from the business. As a simplified here, this paper only considers expenses and income situation in the process of optimization: f_{grid} is the cost of purchasing electricity. f_{EVD} is the cost paid to the EV users who discharged their cars when participated in V2B mode. And f_{EVC} is the profits earning from EV charging. The minimum overall cost of these three parts represents the maximum benefit to the building load aggregator, so the following objective function is established:

$$\min\ F_2 = f_{grid} + f_{EVD} - f_{EVC} \tag{2}$$

$$f_{grid} = \sum_{t=1}^{T} e(t) \cdot (P_{load}(t) - P_{DG}(t) + \sum_{i=1}^{N} P_{EV,i}(t)) \tag{3}$$

$$f_{EVD} = \sum_{t=1}^{T} \frac{C_B}{cyc} \cdot \frac{\sum_{i=1}^{N} \min(0, P_{EV,i}(t))}{E} \tag{4}$$

$$f_{EVC} = \sum_{t=1}^{T} \alpha \cdot e(t) \cdot \sum_{i=1}^{N} \max(0, P_{EV,i}(t)) \tag{5}$$

Where, $P_{load}(t)$ is the load power of building at time t. $P_{DG}(t)$ is the output power of buildings' DG at time t. $P_{EV,i}(t)$ is the charging-discharging power of EV i connected to buildings at time t, where positive value represents charging and negative value represents discharging. $e(t)$ is time-of-use price at time t. C_B is price of EV battery. cyc is the maximum cycle times of charging and discharging of EV battery. α is the charging subsidy coefficient of the building load aggregators to attract EV users to participate in V2B mode, and α=0.9. All of the above calculations will take place during the period when electric vehicles are involved in V2B mode.

4. Case study

4.1 Model and parameters setting

This paper selects representative buildings in a certain area as the research object, including two residential buildings, one office building and one commercial building. The corresponding load curve in typical day is shown in Fig. 3. Considering that the main application scenario studied in this paper is 10kV low-voltage distribution network. And slow charging mode is preferred for electric vehicles.

The main purpose of electric vehicles is to travel between home and work, as well as shopping and entertainment. The departure time of electric vehicles from residential buildings in the morning obeys the normal distribution N(8:00 am,$(1h)^2$) while the departure time from the office building in the afternoon obeys the normal distribution N(6:00 pm, $(1h)^2$). The time to leave the business district at night obeys the normal distribution N(9:00 pm, $(1h)^2$). And the SOC of the electric vehicles obeys a normal distribution $N(0.7, (0.1)^2)$. In addition, suppose that the probability of EV users working in office buildings to go commercial building after work is 0.4, then their probability of going home is 0.6. EV users in the commercial building need working until they return home in the evening. At the same time, the normal distribution of different parameters can be used to simulate the driving time of EVs between different types of buildings, as shown in the Table 2.

Table 2 The driving time distribution between buildings

	office	Commercial
residential 1	$N(1,(0.5)^2)$	$N(1.5,(0.5)^2)$
residential 2	$N(1.5,(0.5)^2)$	$N(1.25,(0.5)^2)$
commercial	$N(0.5,(0.5)^2)$	

4.2 Results and analysis

The simulation of the travel situation of the EV in one day is carried out according to the parameters in Section 5.1. According to the outer layer optimization, the overall equivalent load curve of each building before and after the charging and discharging management period of EVs through the V2B mode is shown in Figure 2.

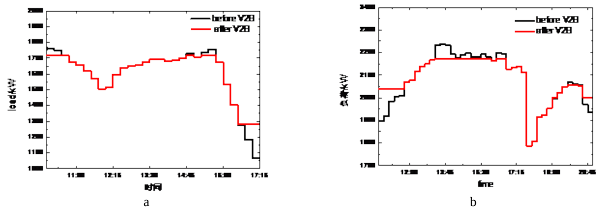

Figure 2 Equivalent load curves of buildings before and after V2B with the participation of EV (a. Office building; b. commercial building)

According to the total charging and discharging power arrangement of EVs by outer layer optimization, specific strategies for charging and discharging power of EVs connected to buildings in each period can be obtained respectively through CPLEX. The optimization results are shown in Figure 3. It can be found intuitively that the cost of building load aggregators is significantly reduced after the bi-level optimization proposed in this paper, which proves the correctness of this method.

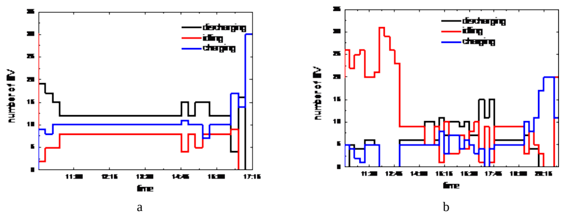

Figure 3 Charge-discharge strategy with the participation of EV (a. Office building; b. Commercial building)

5. Conclusion

This paper establishes a multi-building energy system model with the consideration of the characteristics of DG and load in different types of buildings. Then, the spatial and temporal distribution of EVs in the system in a typical day is determined by combining the travel chain. Finally, a bi-level optimization method is proposed to determine the charging and discharging control strategy for electric vehicle groups involved in the V2B process in buildings. The simulations show that the charge and discharge control strategy can meet the demand of load peak aggregator for load peaking and filling.

References

[1] Li Zhiwei, Zhao Shuqiang, Liu Yingmei. Control of Strategy and Application of Distributed Electric Vehicle Energy Storage [J]. Power System Technology, 2016, 40(2):442-450.

[2] Yang Y, Jia Q S, Deconinck G, et al. Distributed Coordination of EV Charging with Renewable Energy in a Microgrid of Buildings [J]. IEEE Transactions on Smart Grid, 2017, PP (99):1-1.

[3] Beijing traffic development center. 2015 Beijing Transportation Development Annual Report[R]. Beijing, 2015.

[4] SU Xiaoling, HAN Minxiao, ZHAO Zhengkui. Research on Maximum Capacity of Grid-Connected Distributed Generation in Distribution Network [J]. Power System Technology; 2012(10): 87-92.

[5] Lee T K, Bareket Z, Gordon T, et al. Stochastic Modeling for Studies of Real-World PHEV Usage: Driving Schedule and Daily Temporal Distributions [J]. IEEE Transactions on Vehicular Technology, 2012, 61(4):1493-1502.