Load shifting and valley filling method with electric vehicles based on the area method

Yujun Liu[1,a,*], Yi Hong[1,a], Yali Liu[2], Shupeng Li[2] and Guodong Li[2]

[1] *Southeast University, Sipailou No.2, Nanjing, China*

[2] *Electric Power Research Institute of State Grid Tianjin Electric Power Company, Haitaihuakesilu No.8, Tianjing, China*

[a] *liuyujun0713@126.com*

**corresponding author*

Keywords: Area Method, Electric Vehicles, Peak Load Shifting, Valley Load Filling

Abstract: Load shifting and valley filling with Electric Vehicles (EVs) will be an important dispatchable strategy in the future. In this paper, a load shifting and valley filling (LSVF) method with electric vehicles is proposed. At first, the principle of LSVF with electric vehicles is analyzed. Then a strategy with electric vehicles based on the area method is proposed to manage the goal of LSVF. The simulation results show that large number of EVs is needed in order to change the peak-valley ratio of load curve.

1. Introduction

Peak load refers to the maximum possible load on an electrical system [1]. Electric power generators face peak load demands at those times when the greatest number of people use electricity [2-5]. An example of this is the late afternoon when most people return home from work and begin using electricity to power appliances, cook, and light their homes. However, the electric vehicles (EVs) for commuting, at the same time, become idle and constitute a large quantity of energy storage which can be used to deal with the problem of peak load through vehicle-to-grid technology [6-8].

In this paper, a load shifting and valley filling (LSVF) method with electric vehicles is proposed. At first, the goal of LSVF is confirmed based on the load profiles and area method. Then a strategy with electric vehicles is proposed to manage the goal of LSVF and we can know how many electric vehicles should be used to accomplish the goal of LSVF.

2. Peak-load Shifting with Electric Vehicles

Every time when an EV accesses to the grid, it has three choices for next time interval: charging, discharging or staying unused [9, 10]. If the EV chooses to charge, it will enhance the load of the grid and its SOC will rise. At the same time, the capacity which can be used for load shifting also rises. If the EV chooses to do nothing, the state of the EV will not change in the next interval. But since it remains connecting with the grid, the capacity of the EV are always ready for LSVF. What's more, if the unused state is changed from charging state by the aggregator, it will also lower the load of the grid just like load shedding and its effect can be remarkable. The last choice of discharging happens mainly in the situation of PLS. The EVs are used as batteries storages that can release energy to support the grid [11].

Figure 1 describes the three choices in one interval between t_1 and t_2 for one EV. Different choices will bring different load to the grid. The SOC curve will also respond accordingly. The red curves show the load and SOC of charging behaviors. The step value of AB is the slope value of A'B' which matches the power of charging. The blue curves are for discharging and the step value of AD (negative) is the slope value of A'D' which matches the power of discharging. The curves reveal the different tendency affected on the curves on load and SOC according to different choices.

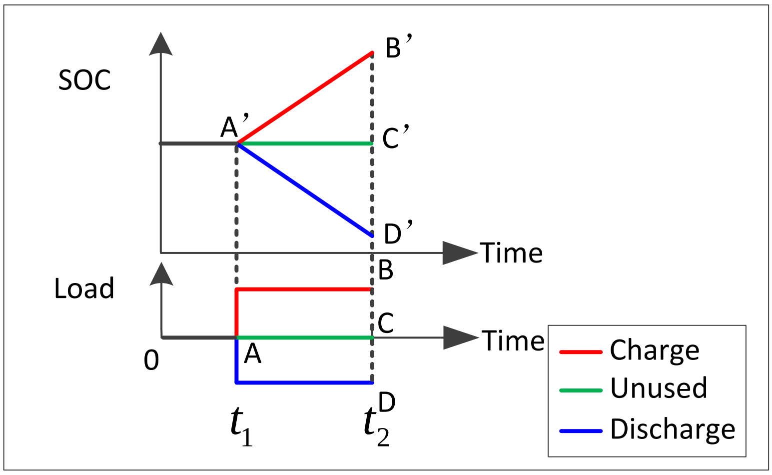

Figure 1 Three choices for aggregator in one interval

3. Load Shifting and Valley Filling Method based on Area Method

Peak load will usually last for several hours such as from 19:00 to 21:00 [12]. The phenomenon is often caused by the rise of residential load because most people have arrived home at that time. Then peak load will go down as night falls and form a valley load which needs to be filled. In order to shift peak load, EVs should be capable of maintaining certain amount of capacity during the whole time. EVs should be discharging during the peak load and charging during the valley load. For day-ahead LSVF, area method is used to confirm how much energy should be convert from valley time to peak time.

The goal of LSVF is the ratio of peak-valley which can be calculated as the objective function

$$\frac{\max\left(L_i+P_i\right)-\min\left(L_i+P_i\right)}{\max\left(L_i+P_i\right)}. \tag{1}$$

Where, L_i is the load power at time period i; P_i is the power of EVs. Positive P_i means that the whole EV fleets are charging while negative P_i means discharging.

Step 1: set line $y=y_D$ with the load profile to get the energy E_D which needs shifting

$$E_{\mathrm{D}}=\int_{y_D}^{\max(P)}\int_{1}^{96}P_i\,di\,dy. \tag{2}$$

Step 2: set line $y = y_C$ with the load profile to get the energy E_C which needs filling

$$E_C = \int_{\min(P)}^{y_C} \int_{1}^{96} P_i didy \,. \tag{3}$$

Step 3: Adjust the value of y_C and y_D to satisfy the goal of LSVF.

Step 4: Calculate the number *N* of EVs needed through equation

$$\Delta E = E_C - E_D = N * \left(1 - \bar{Q}\right). \tag{4}$$

Where, $\bar{Q}$ is the average SOC of EVs' batteries.

4. Case study

The black curve in Figure 2 shows the typical load curve of an intelligent area in China. And the red curve shows the summation of typical load and charging load of assumed 25000 EVs. The original peak-valley ratio is about 34%.

Our goal is to change the peak-valley ratio of the load curve to 25%, 20% and 15% respectively. The shifting results based on the method of section 2 are also shown in Figure 2 through various lines of different colors. The results show that we only need to shift the load in one continuous time period and then fill in the valley. So most charging EVs only needs to change their state twice according to the EVs' aggregators.

To achieve the goal of LSVF, it is important to decide the number of EVs which needs to change their charging state. So we use 30000 and 28000 as the initial value to simulate the result of LSVF in Figure 3. The results are the same as 29186 which means the initial value has no impact on the result. The other results of different ratios are shown in Table 1.

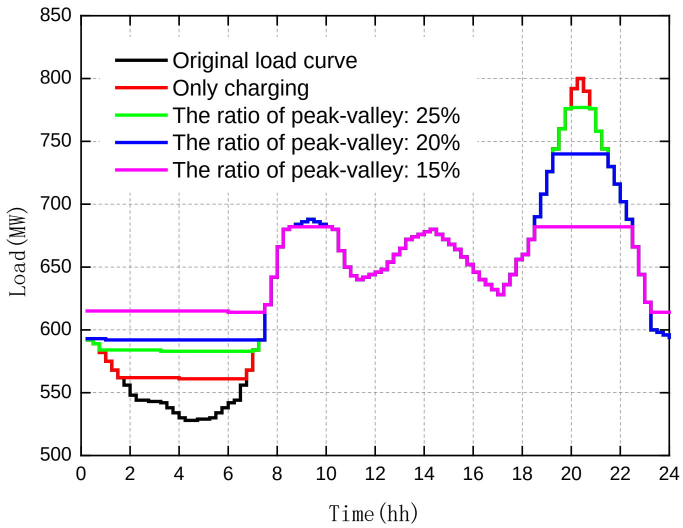

Figure 2 Load curves and the shifting results

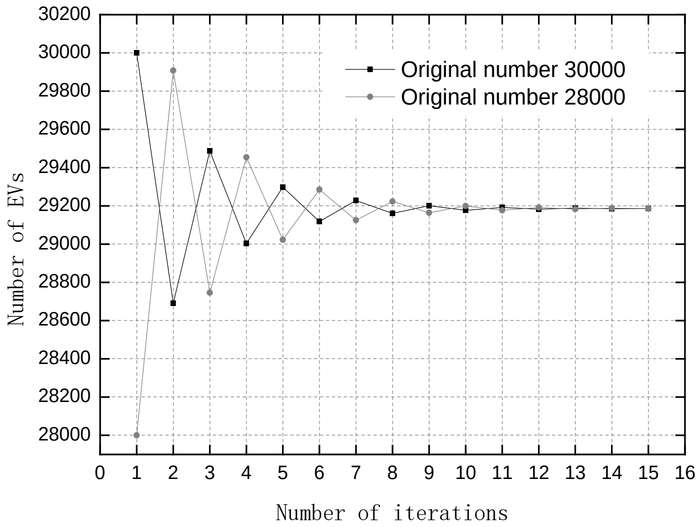

Figure 3 Iteration results of EVs needed with different initial values

Table 1 The number of EVs needed in different peak-valley ratios

Peak-valley Ratio		The number of EVs needed
Goal	Result	
Original Value	34.00%	0
30%	29.88%	25000
25%	24.97%	29186
20%	20.00%	46582
15%	15.00%	63874

5. Conclusion

Load shifting and valley filling with EVs will be an important dispatch strategy in the future. This paper proposes LSVF method based on the area method which can calculate the number of EVs needed in the LSVF. The results show that large number of EVs is needed in order to change the peak-valley ratio of load curve.

Acknowledgements

This paper is funded by Science and Technology Project of State Grid Tianjin Electric Power Company (kj17-1-02).

References

[1]. Huang, Y., Liu, J., Li, C., and Gong, W. (2012). Considering the electric vehicles in the load frequency control. 1-4.

[2]. Takagi, M., Yamamoto, H., and Yamaji, K. (2011). Evaluation of expanded allowable capacity of wind power in power systems by charge control for plug‐in hybrid electric vehicles. Electrical Engineering in Japan, 178(4), 39-48.

[3]. Shimizu, K., et al., Shimizu, K., Masuta, T., Ota, Y., and Yokoyama, A. (2010). Load Frequency Control in power system using Vehicle-to-Grid system considering the customer convenience of Electric Vehicles. International Conference on Power System Technology. 1-8.

[4]. Kempton, W., Perez, Y., and Petit, M. (2018). Public policy for electric vehicles and for vehicle to grid power. Revue Déconomie Industrielle, 148(148), 263-290.

[5]. Tomić, J., and Kempton, W. (2007). Using fleets of electric-drive vehicles for grid support. Journal of Power Sources, 168(2), 459-468.

[6]. Almeida, P. M. R., Lopes, J. A. P., Soares, F. J., and Seca, L. (2011). Electric vehicles participating in frequency control: Operating islanded systems with large penetration of renewable power sources. PowerTech, 2011 IEEE Trondheim. 1-6.

[7]. Datta, M., and Senjyu, T. (2013). Fuzzy control of distributed PV inverters/energy storage systems/electric vehicles for frequency regulation in a large power system. IEEE Transactions on Smart Grid, 4(1), 479-488.

[8]. Masuta, T., Shimizu, K., and Yokoyama, A. (2012). Load frequency control by use of a number of both heat pump water heaters and electric vehicles in power system with a large integration of renewable energy sources. IEEJ Transactions on Power and Energy, 132(1), 23-33.

[9]. Ramírez, P. J., Papadaskalopoulos, D., and Strbac, G. (2016). Co-optimization of generation expansion planning and electric vehicles flexibility. IEEE Transactions on Smart Grid, 7(3), 1609-1619.

[10]. Xu, Q., Liu, Y., Ding, M., Zeng, P., and Pan, W. (2014). Research on the performance of electric vehicles in peak load shifting. Journal of Applied Mathematics, 2014(14), 1-7.

[11]. Pavić, I., Capuder, T., and Kuzle, I. (2015). Value of flexible electric vehicles in providing spinning reserve services. Applied Energy, 157, 60-74.

[12]. Kádár, P., and Lovassy, R. (2012). Spatial load forecast for Electric Vehicles. IEEE International Symposium on Logistics and Industrial Informatics. 163-168.