Research on Peak Load Shifting Operation Strategy of Small-Scale Mobile Energy Storage Device in Distribution Network

JianMing Chen¹,a, Ruijin Dai¹,b, Yilin He¹,c, Tiancheng Chen²,d, Weimin Chen²,e*

¹ Zhejiang Huayun Information Technology Co. Ltd, Hangzhou, China
² College of Mechanical and Electrical Engineering, China Jiliang University, Hangzhou, China
³ email: 494313948@qq.com, ⁴ email: dairuijin@hyit.com.cn, ⁵ email: heyilin@hyit.com.cn, ⁶ email: 1005934793@qq.com, ⁷ email: cwm@cjlu.edu.cn
*Corresponding author e-mail: cwm@cjlu.edu.cn

Abstract: This paper studied two methods of using energy storage (ES) to achieve peak load shifting by charging and discharging. In different distribution network transformer power supply areas, the time of peak and valley of load is not identical. The small-scale mobile ES device was commanded to deliver energy at the peak of the power supply area to reduce the supply pressure of the power system by central control units (CCU), and while the load is at the valley, the ES charges and absorbs power to enhance the utilization rate of energy in the system. Currently, the control methods of peak load shifting for ES device (Constant Power Control and Threshold Control) were studied, and the operation results in power system were analyzed with their involvement, which provided the substantial supports for CCU to dispatch. Ultimately, the results showed the methods proposed were feasible and effective by simulation.

1. Introduction

With the continuous prosperity of economy and the persistent enhancement of people’s living conditions, the maximum workload in the power supply area multiplies gradually, the peak-valley difference of load tends to expand, and the maximum load utilization hours are also decreasing year by year[1-3]. These problems may lead to the imbalance between supply and demand of power system, reduce the effective utilization of power, waste resources and greatly enlarge the cost of production and living. To alleviate these effects mentioned above, it is imperative to configure more power regulation capacity and standby capacity in the power supply network[4-5]. The battery energy storage (ES) system can absorb and store the excess power in the grid during the valley, and feed power to network when the power peak comes, which can effectively narrow the peak-valley difference between day and night and smooth the load curve, and it is beneficial to solve the issue of having to broaden the construction of transmission and distribution lines due to the increase of peak load[6-7].

Moreover, the operation of ES system will be directly or indirectly good for economy, which is also one of the purposes of peak shaving in distribution network. As the battery ES matures, the distributed ES system has been practical and the proportion of ES system participating in peak load shifting will gradually rise in the future[11]. This paper studied the small-scale ES device installed in the transformer power supply area of the distribution network. In fact, it provides power to the load at the
peak, and absorbs power at the valley to stabilize the peak-valley difference.

2. The working mode of small-scale mobile ES
As shown in Figure 1, the circuit topology of small-scale mobile ES device contains the following elements; Central control units (CCU) is used to manage the location as well as charging and discharging time of ES. Tr0 converts the voltage of medium voltage transmission line to 10kV. There are N 10/0.4kV transformers connected to 10kV grid, and the secondary side of transformer is connected to user load. At the same time, CCU collects the information of Tr1 to TrN, and these data will be used to predict the daily load tendency there.

![Figure 1. Topology of small-scale mobile ES device in distribution network](image)

Assume that CCU predicts that the peak load of Tr1 is from 8:30 a.m. to 9:30 a.m. and that of TrN is from 5:30 p.m. to 6:30 p.m., and Tr2 is in the load valley from 1:00 p.m. to 4:00 p.m. At the beginning, CCU commands the mobile ES device to connect to the public connection point (PCC1) before 8:30 a.m. and release battery energy to provide power for the place from 8:30 a.m. to 9:30 a.m. Then CCU commands device to move to PCC2 at 2:30 p.m. and begin charging. Last, CCU send a command to the device, requiring it to move to PCCN before 5:30 p.m. and discharge from 5:30 p.m. to 6:30 p.m. Ideally, the device can give full play to the maximum efficiency, realize the peak load shifting for power in this area, maintain the stability of the demand for energy, and reduce the peak-valley difference.

3. The control strategy of ES device
The mobile ES device performs in peak load shifting with commands of CCU, whose essence is battery charging and discharging. Therefore, capacity is one of the major limited factors. The device must keep communication with CCU to feedback its status, which causes the operation strategy to dominant the dispatching effect.

3.1. Method of constant power control
The Constant power control strategy means the ES device exchanges energy with the grid at a constant power. It can clearly know the principle from figure 2 and figure 3.

1) Charging time and discharging time can be derived from battery capacity \( C \) and set power \( P_{ES} \).

\[
T_{ch\_disch} = \frac{C}{P_{ES}} \quad (1)
\]

2) Import predicted load, \( P_{max} \) and \( P_{min} \) are the maximum and minimum values of the load curve respectively. Make a horizontal line \( P_{low} = P_{min} + k \Delta P \) at the \( P_{min} \) and intersect the curve at two points at \( t_1 \) and \( t_2 \), and calculate the time difference between two points. If \( t \) is greater than or equal to \( T_{ch\_disch} \), stop the iteration to determine a reasonable time interval; If \( t \) is less than \( T_{ch\_disch} \), continue to iterate and move straight up in steps until a reasonable time interval is found. The discharge time interval can also be determined in the same way.
3) In the iterative process, if there are more than two intersections between the horizontal straight line and the load curve, as shown in Figure 3, determine the discharge time, judge the relationship between \( t \) and \( T_{ch\_disch} \), and continue to iterate with the above method to determine the discharge time interval if the former is less than the latter. The charging time process is the same.

![Diagram of constant power control](image1)

![Multi peak of constant power control](image2)

**Figure 2. Diagram of constant power control**

**Figure 3. Multi peak of constant power control**

### 3.2 Method of threshold control

Above all, calculate the mean of daily load based on predicted data. Then, set two thresholds, named discharging threshold and charging threshold, which can get a closed area formed by a threshold line and the load curve. It is noted that there is a certain relationship which the size of the area determines the energy provided by ES. Last, when the area formed by discharging threshold is close to the capacity of ES battery, CCU will send a command to smooth expected peaks it to according to the given power; Similarly, when the area formed by charging threshold is roughly equivalent to the capacity, CCU will command ES to smooth expected valleys. The method of calculating the charging and discharging time interval and power is as follows.

**Import predicted load data and draw curve.** \( P_{max} \) and \( P_{min} \) are the maximum and minimum values of the load curve respectively. Power iteration step \( \Delta P = 1 \) and initial value of iteration constant \( k = 0 \).

**Draw two lines \( P_{high} \) and \( P_{low} \) in figure 4.**

\[
P_{high} = P_{max} - P_{ES\_max}
\]

\[
P_{low} = P_{min} + P_{ES\_max}
\]

\( P_{ES\_max} \) is the maximum value of battery ES system power.

\[
S_{discharge} = S_2 + S_3 = \int_{t_1}^{t_3} (P_t - P_{high})dt + \int_{t_3}^{t_4} (P_t - P_{high})dt
\]

\[
= \sum_{i=2}^{m-1} (P_{t_i} - P_{high})\Delta t
\]

\[
S_{charge} = S_1 = \int_{t_1}^{t_2} (P_{low} - P_t)dt = \sum_{i=1}^{n-1} (P_{low} - P_{t_i})\Delta t
\]

\( P_t \) is continuous predicted load; \( P_{t_i} \) is discrete predicted load; \( m \) and \( n \) is the discrete number corresponding to \( t_1 \) and \( t_2 \); \( i \) and \( j \) is the discrete number corresponding to \( t_3 \) and \( t_4 \); \( \Delta t \) is the sampling interval.

If \( S_{discharge} > C \), iterate as follows.

\[
P_{high} = P_{high} + k\Delta P
\]

\[
k = k + 1
\]
As shown in equation (4), calculate $S_{\text{discharge}}$ until $S_{\text{discharge}} \leq C$ stops iteration, and determine that the corresponding time $[t_3, t_4)$ is the discharging time interval of ES, and the power difference $P_{b,t}$ is the power of ES. When $P_{b,t}$ is greater than the maximum discharging power, replace it with the maximum value.

$$P_{b,t} = P_{\text{low}} - P_{\text{high}}$$  \hfill (6)

Similarly, if $S_{\text{charge}} > C$, iterate as follows.

$$P_{\text{charge}} = P_{\text{charge}} - k \Delta P$$
$$k = k + 1$$  \hfill (7)

Then, calculate $S_{\text{charge}}$ until $S_{\text{charge}} \leq C$ stops iteration, and determine that the corresponding time $(t_1, t_2)$ is the charging time interval. When $P_{b,t}$ is greater than the maximum charging power, replace it with the maximum value.

$$P_{b,t} = P_{\text{low}} - P_{\text{low}}$$  \hfill (8)

4. Simulation results and analysis

The load forecasting is based on the power data of a station in the new community of Hangzhou, China. Take the data of the day before 30 days as the model training data to predict new data, which is compared with the actual load data. The sampling interval $\Delta t$ is 15 minutes. Figure 5(a) shows the load curve on June 11, in which the line ○ is the prediction curve, the line △ is the actual curve, and figure 5(b) shows the absolute error of each prediction point, the root mean square error (RMSE) is 6.0819, and the average relative error is 9.4%.

In this project, the 30kW.h battery system is used as the mobile ES device to cut peaks in the way of two methods. First, after the load forecasting on June 11 and June 14, combined with the constant power method, the constant power is set to 8kW and the single working time is 225 minutes. The line ○ is both the raw data and predicted data, the line * is the data after optimization. The optimized curve is shown in figure 6 and figure 7, which can be seen that the time interval is distributed between peaks and valleys, which plays a great role in reducing the standard deviation of the curve.

Figure 8 and figure 9 are the optimization of threshold method. The peak and valley of the former are easy to identify so the result is satisfactory. The valley of the latter is unclear and the crest is so steep that the charging time is longer in contrast and the peak is not completely cut off.
5. Conclusion
This paper designs an application scenario based on the small-scale mobile ES device participating in peak load shifting of power grid. Under the control of CCU, the device can work flexibly in the appropriate power supply area so as to greatly alleviate the pressure of the whole power system; Then
it focuses on two methods of mobile ES control. The CCU can use these two methods to control the mobile ES device and make it run efficiently. This application design not only improves the utilization rate of ES device, but also reduces the investment cost.

![Figure 8. Optimization of threshold method on June 11th](image1)

![Figure 9. Optimization of threshold method on June 14th](image2)

References

[1] Setlhaolo D, Xia X. Optimal scheduling of household appliances with a battery storage system and coordination[J]. Energy & Building, 2015, 94: 61-70.

[2] Dufo-Lopez R. Optimisation of size and control of grid-connected storage under real time electricity pricing conditions[J]. Applied Energy, 2015, 140: 395-408.

[3] Ma G, Xu G C, Jiang L R, et al. Study on stored energy optimization method of the grid-connected wind power based on loss of power supply probability[J]. Renewable Energy Resources, 2015.

[4] Xu Q, Ding Y, Yan Q, Zheng A and Du P, "Day-Ahead Load Peak Shedding/Shifting Scheme Based on Potential Load Values Utilization: Theory and Practice of Policy-Driven Demand Response in China,"[J] in IEEE Access, vol. 5, pp. 22892-22901, 2017, doi: 10.1109/ACCESS.2017.2763678.

[5] Liu H T, Xu L, Hao S P, Zhang X L, Zhang C. Distributed hybrid energy storage optimization method based on distribution network zoning [J]. Power automation equipment, 2020, 40 (05): 137-145.
[6] Chen X L. Research on load forecasting and user side optical storage dynamic optimization strategy based on deep learning [D]. Beijing Jiaotong University, 2019.

[7] Niu W D. Research on Optimization Strategy of battery energy storage participating in power grid peak shaving and valley filling [D]. Harbin University of Technology, 2018.