

Optimization Strategy of Constant Power Peak Cutting and Valley Filling for Battery Energy Storage System Based on Variable Smoothing Time Constant

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Abstract: The intermittence and fluctuation of wind energy have brought adverse effects to large-scale grid-connection of wind power. Installing energy storage system at the outlet of wind farm can effectively adjust the rate of change of grid-connection power and improve the stability of grid-connection operation of wind farm. This paper takes energy storage grid-connected inverter and its optimal control as the research object. Starting from considering the smoothness of grid-connected power and prolonging the service life of energy storage system, an optimal control method based on variable smoothing time constant and power limiting is proposed. The protection of battery energy storage system is realized by adjusting the smoothing time constant and power limiting in real time. Taking one day as the time scale and energy storage system electricity balance as the criterion, the problem of excessive peak valley difference in distribution network is effectively improved. At the same time, the uncertain change of battery capacity caused by other control functions of energy storage system caused by power grid disturbance is solved by online correction. The experimental results verify the effectiveness and feasibility of the proposed optimal control method, which can avoid the overcharge, overdischarge and overload of the battery energy storage system.

1. Introduction

Due to the great fluctuation of wind farm output affected by weather and geographical conditions, wind power output has a great impact on the safety and stability of the power system, especially the impact of large-scale wind farm integration on the stability and power quality of the system cannot be ignored [1]. An energy storage system with a certain capacity and power is arranged at the outlet of the wind farm, which can effectively smooth the fluctuation of wind power and improve the stability of the power system [2]. For power grid operators, the reduction of peak load is conducive to delaying equipment capacity upgrading, improving equipment utilization rate, saving equipment renewal costs and reducing power supply costs. For power users, the difference between peak and valley electricity prices can be used to obtain economic benefits. The traditional means of peak load regulation has been difficult to meet the demand of power grid development. In order to alleviate the contradiction between power supply demand and economy, it is necessary to adopt more efficient and reliable means of load transfer [3]. Based on the typical daily load curve and the variable smoothing time constant, this paper proposes a load side peak load and valley load control strategy based on the battery energy storage system, and analyzes the low-level charging and peak discharge of the battery energy storage system, that is, the cost and benefit of each participant under the action of peak load and valley load. At the same time, a specific control algorithm of the bottom layer of the grid connected energy storage inverter is proposed to avoid the undervoltage and overvoltage operation of the battery. In the end, experiments are carried out under different control methods and different energy storage systems. The experimental results verify the superiority of the proposed method.

2. The design of the control strategy of battery energy storage system (BESS)

2.1 BESS optimal control based on constant smoothing time constant

The charging and discharging power of BESS can be changed quickly and flexibly without considering the climbing rate constraint. Neglecting the internal loss of the battery pack, the battery can be regarded as a constant voltage source model [4]. According to the load curve and battery usage. Considering that too many times of charging and discharging will affect the service life of the battery, the battery can be charged and discharged once a day. Figure 1 shows a typical wind power system based on BESS, which is connected to the power grid through an energy storage grid-connected inverter. Wind power p_{wind} is related to wind speed. By controlling the energy storage grid connected inverter to compensate the active power p_{wind} , a smoother grid connected power reference value p_{ref} can be obtained, so as to realize the reliable and smooth grid connection of wind power. Because the energy storage system has flexible “huff and puff” characteristics of electric power, it can cope with the different changes of load curve. According to the typical daily load curve, the optimal charging and discharging strategy of the battery energy storage system is formulated for 24 hours. The cost difference caused by overload standard deviation and time-sharing electricity price is used to evaluate the effect of peak load cutting and valley filling, so as to formulate the charging and discharging strategy of energy storage system, so as to achieve peak load cutting and valley filling.

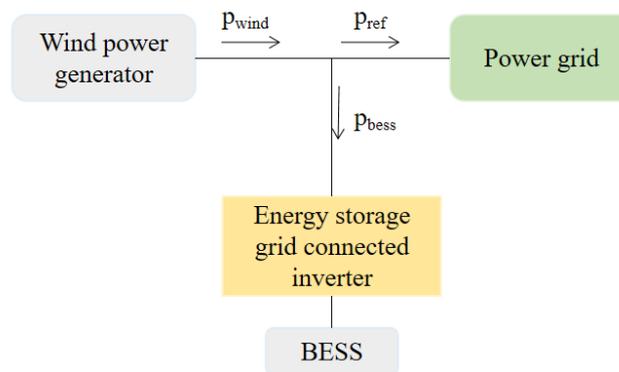


Figure 1 Typical wind power system based on BESS

2.2 BESS optimal control based on variable smoothing time constant and power limiting

The disadvantage of optimal control based on constant smoothing time constant is that SOC and power limitation of the energy storage system are not considered, which easily leads to overcharge, overdischarge or overload of the energy storage system and seriously reduces the service life of the energy storage system. The energy storage system can take the power required in the worst case of the wind farm as the rated power. At this time, it can ensure that the output power of the energy storage system can meet the requirements for stabilizing the power fluctuation of the wind farm under any circumstances [5]. Generally speaking, the electricity price is high in peak load period and low in low load period. The battery discharges when the electricity price is high and charges when the electricity price is low, which plays the role of cutting peaks and filling valleys [6]. The optimal scheduling algorithm needs to combine the real-time load information of users on that day, so it is considered to be carried out on the user side, which also requires the optimal scheduling algorithm to have the characteristics of fast calculation and response speed. If the owner of the energy storage system is the power user, under the market electricity price system, the goal of the user is to maximize the economic benefits brought by the energy storage system to the user; the control of variable smoothing time constant The system method is to adjust t according to the measured SOC in real time, section and level, which is essentially to adjust the charging and discharging power of the energy storage system indirectly and dynamically, so as to maintain the SOC working in the normal range. When working in the load transfer mode, the objective function is to minimize the variance of the load, because mathematically, the variance can reflect the

deviation of the random variable from its mean value.

3. Design of BESS Energy Storage Grid-connected Inverter

3.1 Topology design of energy storage grid-connected inverter

A three-phase voltage source PWM converter (VSC) is adopted as the topology of the energy storage grid-connected inverter, which facilitates bidirectional energy transfer between the energy storage system and the power grid and realizes power control at the same time. According to the load curve and battery usage. Considering that too many times of charging and discharging will affect the service life of the battery, the battery can be charged and discharged once a day. Mathematically, variance can reflect the degree to which random variables deviate from their mean. The variance of load can reflect the flatness of load curve [7]. In addition, in actual use, according to the peak cutting and valley filling effect required by different working conditions, peak cutting lines can be obtained by setting different peak cutting rates, so as to achieve the ideal peak cutting and valley filling effect under this working condition. On the day when optimization is needed, give instructions to the battery energy storage system according to the optimization results, control the charge and discharge of the battery energy storage system through the inverter, and adjust the previous optimization strategy according to the error of user load prediction to ensure the stability of the system [8]. Since the battery charging and discharging power is set as constant power charging and discharging, it can ensure that the “throughput” energy of the energy storage system is equal every day, and it is helpful to extend the service life of the battery energy storage system.

3.2 Bottom control of grid connected inverter with energy storage

The commonly used power grid connected inverter control is generally double loop control, including constant power control, constant voltage constant frequency control and droop control. Based on the constant power dual loop control and the goal of maintaining the normal working voltage of the battery, an improved dual loop control strategy with switchable mode is proposed. That is, when the user's power load is relatively low, the battery energy storage system needs to be charged so that the battery energy storage system has enough power for subsequent peak regulation; If the optimization model contains only capacity constraints and power constraints, then the constraints are linear constraints and the objective function is quadratic. The optimization model meets the model requirements of quadratic programming and can be solved by effective set algorithm.

In order to evaluate the different control strategies of battery energy storage participating in peak and valley cutting in power grid, the following peak and valley cutting effect evaluation index is constructed based on the evaluation index of load peak and valley change degree before and after wind power integration in reference [8].

$$\Delta P = P_{\max} - P_{\min} \quad (1)$$

This index represents the maximum absolute deviation of load output in daily time scale. Peak-valley coefficient α :

$$\alpha = \frac{P_{\min}}{P_{\max}} \times 100\% \quad (2)$$

The index represents the flatness of load curve, and the flatter the curve is, the larger the coefficient is. Peak valley ratio β :

$$\beta = \frac{\Delta P}{P_{\max}} \times 100\% \quad (3)$$

The smaller the peak-valley difference rate is, the smaller the load fluctuation range is. Standard deviation of load change D:

$$D = \sqrt{\frac{1}{n} \sum_{i=1}^n (P_i - P_{ave})^2} \quad (4)$$

Where: n is the total number of sampling points; P_i is the load value at sampling time i ; P_{ave} is the average of the total sampling load. The smaller D is, the less discrete the data is, i.e. the smaller the load fluctuation is.

In order to keep the power balance of low load, the power output of thermal power units should be increased or decreased frequently, which will lead to an increase in coal consumption. The application of energy storage system to load side peak cutting and valley filling can effectively reduce peak load and has various benefits. After the battery voltage exceeds the upper voltage limit, switch to double loop control of DC voltage and reactive power, and the given DC voltage value is the upper voltage limit of the battery; When the voltage is lower than the lower limit, it is switched to DC voltage and reactive power double loop control. The given value of DC voltage is the lower limit of battery voltage. According to the principle of electricity balance of energy storage system, the operation time and depth of energy storage system can be obtained, which can realize the peak and valley cutting method of energy storage under the variable power charge and discharge control strategy, as shown in Figure 2.

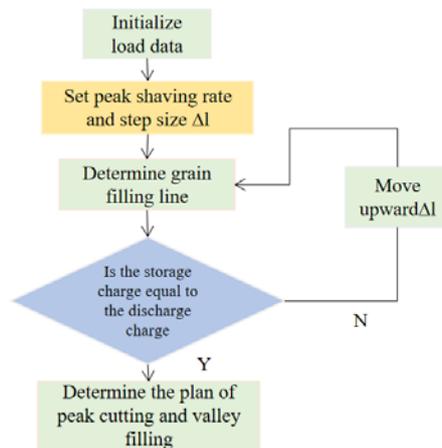


Figure 2 Control flow of peak load and valley load for energy storage battery

4. BESS Optimization Control Implementation Process

The application of battery energy storage system to load side for peak-valley cutting not only reduces the peak-valley difference of load and optimizes the load curve, but also effectively reduces the capacity of backup units during peak hours, improves the operation efficiency of generator units and reduces the power generation cost. The strategy takes one day as the time scale and the energy balance of the energy storage system as the criterion, and controls the charge and discharge power of the energy storage to dynamically change according to the actual load demand. The smaller the power change rate of electric field injected into the power system, the smoother the power output curve, and the better the effect of the energy storage system to stabilize wind power fluctuations, but the larger the energy storage power and capacity required to be installed, the higher the energy storage cost. During this period of time, there was no peak cutting and valley filling, and the load curve remained unchanged, but the battery capacity was reduced. With hardware topology and software control algorithm, BESS optimal control based on variable smoothing time constant and power limiting can be realized. The specific DSP program design can be compiled according to the flow chart of Figure 3. Through the charge / discharge function of the energy storage system, the initial load curve makes the load curve after peak shaving and valley filling within the range of peak shaving line and valley filling line, achieving the purpose of smooth load.

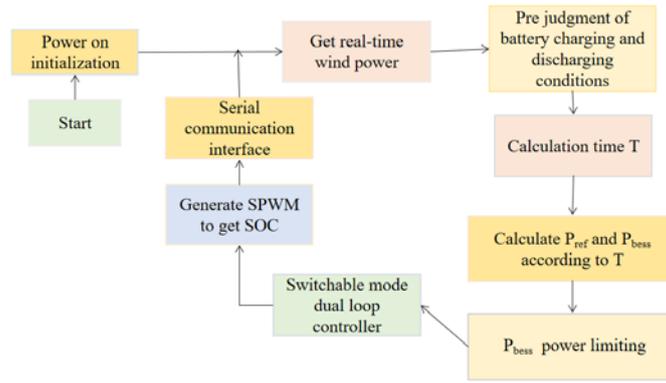


Figure 3 Implementation process of BESS optimal control

5. Experiments and Results

In order to verify the proposed BESS optimal control algorithm, a 3 kVA energy storage grid-connected inverter prototype is built according to the topology. With the demand of load peak cutting and valley filling, the state of charge and electric quantity of the energy storage system increase during the valley period and decrease during the peak period. The charge and discharge electric quantity are equal within one day, and the state of charge returns to its initial value by itself. In addition, the participation of the energy storage system delays the upgrading of power transmission and distribution equipment and has environmental benefits. However, the duration of the maximum power consumption load is usually short. In order to meet this short peak load, the cost of upgrading and transforming power transmission and distribution equipment is greatly increased, resulting in a decrease in equipment utilization rate and a waste of resources. In order to make the capacity configuration of the energy storage battery exactly the same as that of the constant power, and to compare the effect of the two strategies, the peak clipping rate is set to 0.452. For the convenience of experiment, the universal battery simulator is used instead of the battery prototype, which can simulate the external characteristics of different kinds and parameters and various extreme conditions conveniently. The battery simulator sends SOC value through RS-232, which is convenient for the inverter to obtain SOC of energy storage system in real time.

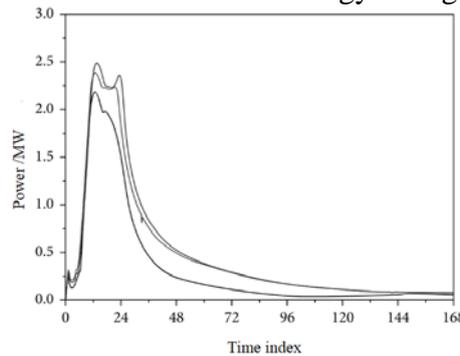


Figure 4 Effect diagram of peak cutting and valley filling under constant power mode

It can be seen from Figure 4 above that when the load curve is higher than the peak shaving line, the energy storage system will release electric energy as a “power source” to meet the power demand of the redundant load; when the load curve is lower than the valley filling line, the energy storage system will absorb electric energy as a “load” to store the redundant power of the grid. The energy storage system can effectively cut peak and fill valley with one charge and two discharge per day under the optimal capacity configuration. According to this control strategy, the life of lithium-ion battery energy storage system can reach 30 years. When the SOC is in the normal interval, it is 90 s, after exceeding the normal operating interval, the SOC starts to change, and at the same time t suddenly increases in the process of continuous decrease at 10 min. under the variable power control strategy, the battery energy storage output changes dynamically with the

need of load peak cutting and valley filling. the peak stage and the valley stage are accurately identified and effectively reduced, which effectively plays the role of peak cutting and valley filling. the control based on variable t can adjust and distribute the charging and discharging power of the energy storage system in real time, and has advantages over the fixed t control.

6. Conclusion

In this paper, an upper and lower control algorithm for BESS optimal control of grid-connected energy storage inverter is studied. The upper layer adopts optimal control based on variable smoothing time constant and power limiting, and adjusts the smoothing time constant in real time according to the state of charge of the energy storage system so as to dynamically adjust the charging and discharging power. The constant power charging and discharging model is favorable for controlling the battery energy storage system in the real-time control stage. By changing the model parameters, the charge and discharge times of the battery can be flexibly controlled, and the service life of the battery can be prolonged. BESS can realize multi-function coordinated control. While performing the function of peak clipping and valley filling, the energy storage system can also respond to the command of frequency modulation and voltage regulation. The control strategy developed in this paper has the equivalent charge and discharge times of one charge and two discharge per day, and there is no overcharge and over discharge phenomenon, which is conducive to the long-term use of the battery, making the actual investment project recover the cost faster than other charge and discharge modes. On the basis of smoothing the power fluctuation of wind power, the optimal control algorithm can effectively avoid the overcharge, overdischarge and overload operation of the energy storage system, and extend the working life, which has great engineering practical value.

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