

Research on Intelligent Energy Storage Control Method with Ethernet Communication

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Abstract: The increasingly severe global energy crisis has brought great challenges to the energy field, and renewable energy power generation system has been widely concerned because of its characteristics of green and inexhaustible. However, renewable energy also has some limitations in its specific application, and affects the grid-connected power generation of new energy. In this paper, based on the background of photovoltaic power station, the intelligent energy storage control method for single inverter is put forward to assist a single inverter, and the DC component of fluctuating power is extracted by using the moving average function; furthermore, the intelligent energy storage control method for the bidirectional DC/DC converters both the lead-acid battery side and the super capacitor side is put forward to ensure the stability of the voltage. Then, by using the Ethernet communication technology of the computer, the energy of the station-level intelligent energy storage is allocated reasonably to preserve the energy of the battery in a reasonable boundary. Finally, the system verification and experimental analysis illustrates that the intelligent energy storage control methods with Ethernet communication proposed in this paper can effectively achieve the intelligent control performance.

Keywords: Intelligent control method; energy storage; lead-acid battery; super capacitor; Ethernet technology

1 Introduction

With the problem of the global energy crisis becoming more and more serious, the renewable energy generation system represented by photovoltaic power generation has been widely concerned, and is becoming one of the global research hotspots [1–3]. However, due to the limitations of natural conditions, the application of renewable energy power generation also has some limitations [4,5], mainly for its own output power fluctuations, limited ability to resist grid faults, affecting new energy grid-connected power generation and other shortcomings. The intelligent energy storage system can achieve smooth power and other functions by charging and discharging different energy storage modules, thus it can increase the stability and reliability of the renewable energy generation system [6]. Also, through the



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computer network communication technology, the energy storage system between different power stations can be effectively allocated.

The energy storage components include two categories according to the power and energy characteristics, namely the power type and the energy type. The former has high power density, and represented by flywheel energy storage and super capacitor, it can release energy quickly; the latter has high energy density, and represented by battery and compressed air, it can conserve energy effectively. However, single energy storage component cannot take energy and power into account at the same time, so in practical application, intelligent energy storage control method has been concerned.

In the traditional photovoltaic power generation system, as the grid voltage is reduced to some certain threshold, the photovoltaic inverter will automatically disconnect from the grid to avoid the damage of the inverter caused by low-voltage fault [7,8]. However, in general, the fault duration of the power grid is relatively short. If the short-term fault leads to large-scale off grid of photovoltaic power station, it will not only reduce the power generation capacity of the station, but also make the grid unstable to some extent, which requires the photovoltaic power station to have a certain ability to resist the grid fault, such as the low-voltage fault [9]. Thus, as the grid fault or disturbance causes the voltage drop of the grid point of the inverter, the inverter not only can be designed to be connected into the grid uninterruptedly, but also can transmit reactive power until the grid returns to normal within a certain voltage drop range and time [10–12].

In the research of intelligent energy storage control method, Xu et al. [13] proposed an improved intelligent control method based on intelligent model predictive control, which can effectively improve the performance of the whole energy storage system. Guerrero et al. [14] took the hierarchical control technology as its study keystone, and it analyzes the intelligent control method for microgrid, and on this basis, it makes a deep analysis of discussion for the stability of its performance. In [15], it puts forward an artificial neural network-based intelligent energy storage control method, which can effectively realize the on-line optimization and adjustment of control parameters such as the steady-state voltage and frequency. In [16], an intelligent power quality controller is proposed, and it can mitigate the distortions of current and voltage through the control and regulation for the state of the series connection and parallel connection, so as to improve the overall quality of stored power. Wang [17] put forward an intelligent variable gain control method, which ensures the stability of the whole system through the intelligent control of the battery current. In [18], it proposes an intelligent control method based on dynamic evolution, and this method adjusts the current and voltage of the system through dynamic evolution, which can realize the intelligent control of the whole energy storage system.

Motivated by the above discussion, it can be seen that the intelligent energy storage control method has been widely used in power quality problems. However, the intelligent control is still in a research and development stage, and there are still unstable situations in the current power grid system. Thus, in order to further improve the power quality and the stable operation of the power grid, the intelligent control method needs to be further studied and discussed. Therefore, in this paper, based on the background of photovoltaic power station, it proposes an intelligent energy storage control method by using computer communication technology, which uses two-level intelligent control method to solve the problem of power quality when photovoltaic power station is connected to the grid. The main contributions of the paper are: (1) it puts forward intelligent energy storage control method for single inverter, which can meet the inverter-level intelligent control demand; (2) for the bidirectional DC/DC converter that is on the side of lead-acid battery, the intelligent control method is proposed, which can effectively improve the working efficiency of the battery; (3) for the bidirectional DC/DC converter that is on the side of super capacitor, the intelligent control method, which can ensure the stability of the voltage, is proposed; (4) it puts forward the station-level intelligent control method, which ensures the normal grid-connected working through the reasonable energy distribution between different power station.

The rest of the paper is organized as follows: in **Section 2**, it puts forward the inverter-level intelligent energy storage control method, which contains the intelligent control methods of bidirectional DC/DC

converters of both the lead-acid battery side and the super capacitor side, in Section 3, the station-level intelligent energy storage control method is described in detail, and Section 4 illustrates system verification and experimental analysis for the proposed intelligent energy storage control method, and finally, it discusses the conclusions and the next research work in Section 5.

2 The Inverter-Level Intelligent Energy Storage Control Method

The inverter-level intelligent energy storage control method proposed in this paper can be used for a single inverter. The composition diagram of the inverter-level intelligent energy storage control method is shown in Fig. 1.

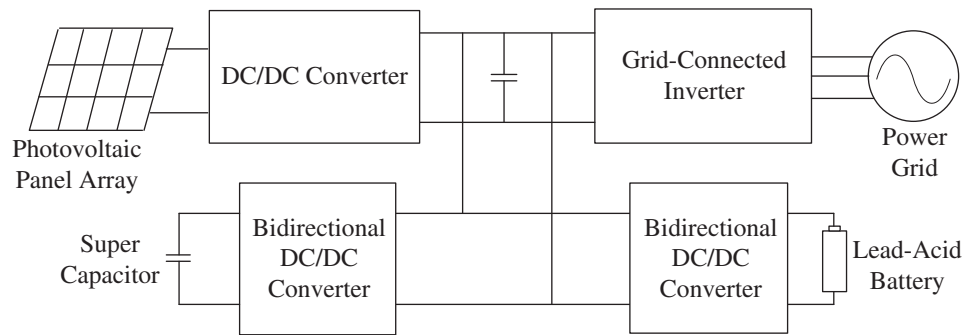


Figure 1: Composition diagram of the inverter-level intelligent energy storage control method

From Fig. 1, it can be seen that the inverter-level intelligent energy storage control method is designed by setting one super capacitor and on lead-acid battery on two bidirectional DC/DC converters respectively. Meanwhile, in this part, it will focus on the intelligent control method of the two bidirectional DC/DC converters.

In general, the DC/DC converter can achieve the maximum power tracking, and the grid-connected inverter is responsible for the energy transmission between the grid and ensuring the stability of the voltage [19]. During normal operation, the power transmission of the two converters should reach a balanced state. When low voltage ride-through, the phenomenon of power imbalance between the two converters may occurs, and it is mainly manifested that the output power of the converter remains unchanged, and the output power of the grid-connected inverter decreases, thus resulting in the voltage fluctuation and the damage of the switching devices [20]. Here, it uses the current source load to simulate the unbalanced power fluctuation, and the system is simplified as shown in Fig. 2.

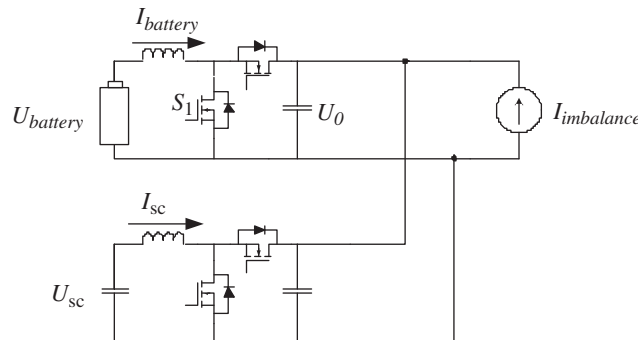


Figure 2: Simplified composition diagram of intelligent control method

During the occurrence of low voltage ride-through, unbalanced power fluctuation occurs between the input and output, which can be divided into the components AC and DC according to the frequency characteristics. The AC component represents the power demand, and the DC component represents the energy demand. According to the power and energy characteristics, and considering the cost, efficiency and battery life of the system, it can

use the components of energy type such as lead-acid battery to deal with the DC component of fluctuating power, and the components of power type such as super capacitor to deal with the AC component of fluctuating power. Therefore, the proposed inverter-level intelligent energy storage control method is that, using the moving average function to calculate the DC component of the output power in the unbalanced part between the photovoltaic panels and inverter when the low voltage ride-through occurs, and the calculated DC component will be used as the battery charging current command to deal with the slowly varying fluctuating power; the bidirectional DC/DC converter connected on the side of the super capacitor is used for ensuring the stability of the voltage, and because the battery absorbs the DC fluctuation power, the remaining AC fluctuation power can be processed by the capacitor. This intelligent control method can not only ensure the performance of the battery, but also can use the super capacitor for its characteristics of fast charging and discharging to ensure the overall working performance of the system. The proposed inverter-level intelligent energy storage control method mainly includes the following three aspects.

(1) Fast and accurate detection

After the inverter-level intelligent energy storage control method is used, the voltage on the side of DC should be stable even if low voltage ride through occurs, and because of good dynamic characteristics of the super capacitor, the detection of unbalanced power can be changed into the detection of unbalanced current. In the specific implementation, two current sensors need to be added to the output of the converter and the input of the inverter respectively to detect the unbalanced current, and then the unbalanced power can be detected simply, quickly and accurately through the unbalanced current. When extracting the DC component from the fluctuating power, it uses the moving average function. Compared with the previous low-pass filter method, which uses more complex parameter design and long parameter adjustment time, the moving average function has the advantages of fast and accurate. In the specific implementation, the moving average function is to average multiple values sampled in the sliding windows, and then get the filtering results. Its basic principle is shown in Fig. 3.

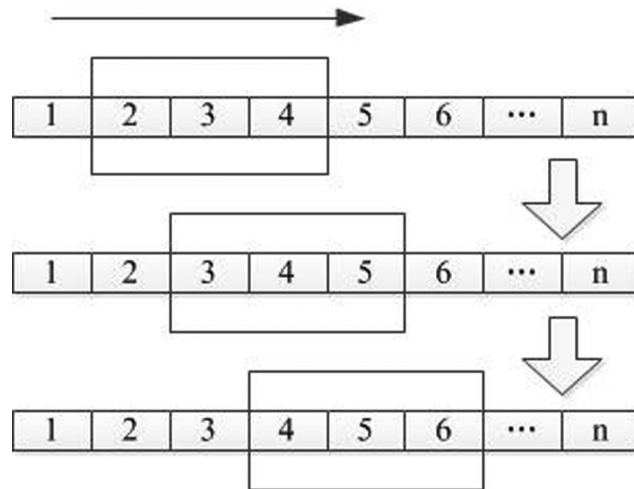


Figure 3: Schematic diagram of moving average function

The width interval of the sliding window can be defined as:

$$t \in [t_{min}, t_{max}]$$

(2) where t is the width of the sliding window, t_{min} is the lower limit of the width, and t_{max} is the upper limit of the width. In the experimental part of this paper, t_{min} is 0.2 s, t_{max} is 1 s, and the width of sliding window t takes a fixed value of 0.5 s. Intelligent control method for the bidirectional DC/DC converter on battery side

Through the moving average function mentioned above, it can get the DC component of the unbalanced current. Because the charging and discharging current changes slowly, the DC component of the unbalanced current is taken as the reference. Based on the principle of power balance and the voltage ratio between the DC bus and the battery, the charging and discharging current value of the battery is calculated. PI regulator is used as the controller.

(3) Intelligent control method for bidirectional DC/DC converter on super capacitor side

The DC component in the unbalanced current cannot be absorbed by the battery, and if calculating the AC component, it will increase the complexity of the system, and the control process is complex [21]. Therefore, the bidirectional DC/DC converter on the side of the super capacitor will be used to stabilize the voltage. As the converter stabilizes the DC bus voltage, it will absorb the remaining AC component in the unbalanced power to ensure the voltage stability. Thus, in the specific design and implementation, it takes the voltage on the DC bus as the control target, and then adopts the intelligent double loop control method for the converter.

3 The Station-Level Intelligent Energy Storage Control Method

The proposed station-level intelligent energy storage control method can be used to deal with the energy distribution. The state of charge (SOC) of lead-acid battery is a very important indicator in the energy storage system, which represents how much energy can be absorbed or released by the battery [22]. High SOC value means that the battery can release more energy and absorb less energy, and vice versa. Therefore, the SOC of the battery should be kept at a reasonable level to keep the battery working normally. The station-level intelligent energy storage control method focuses on the intelligent control of SOC of different inverters, mainly to ensure that the energy distribution between different systems can be maintained at a reasonable level, and then to ensure that the system can be charged or discharged in time. The block diagram of the station-level intelligent energy storage control method is shown in Fig. 4.

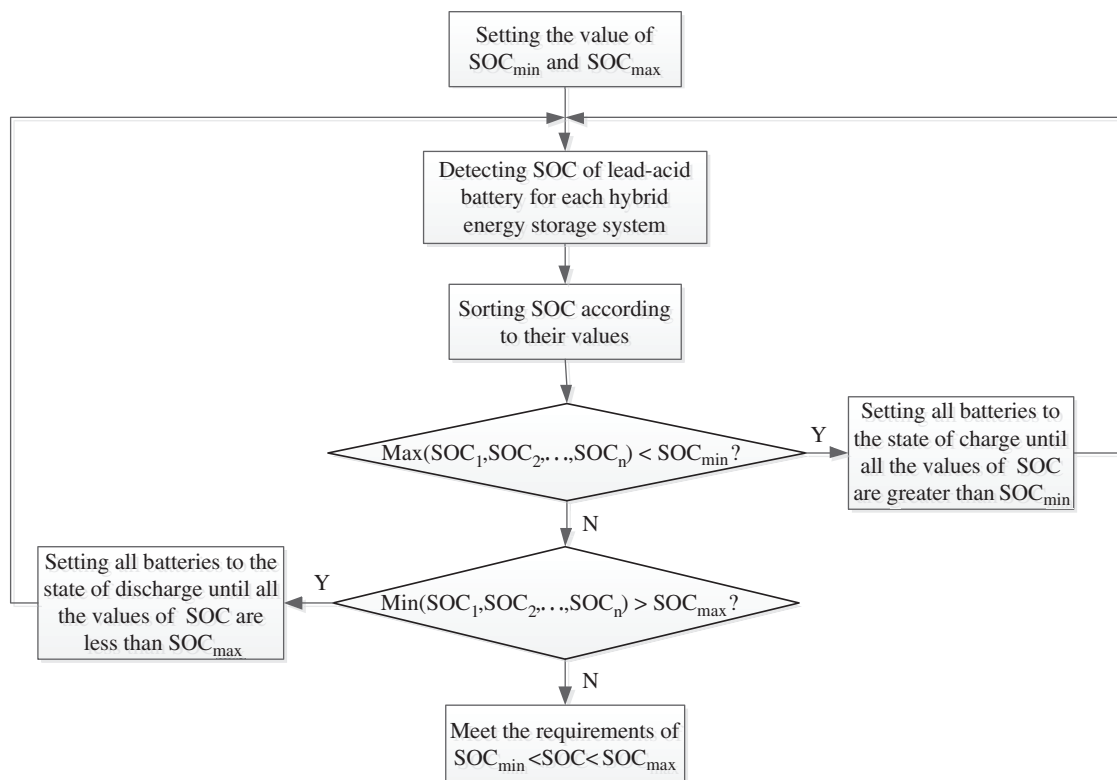


Figure 4: Control block diagram of the station-level intelligent energy storage control method

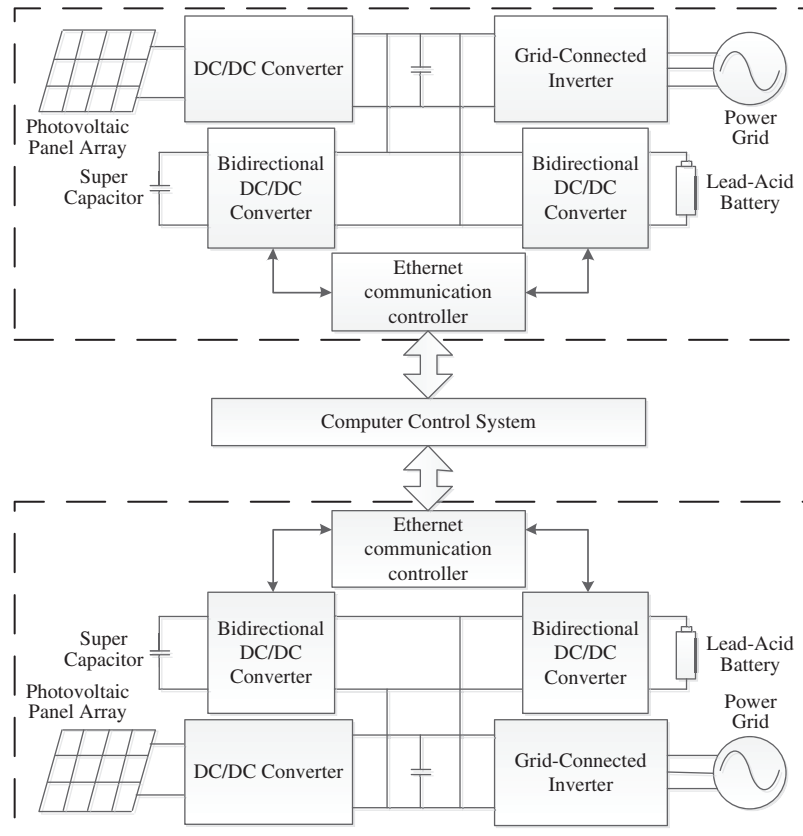


Figure 5: Control diagram of the station-level intelligent energy storage control method

When the SOC state of lead-acid battery in each energy storage system is detected, if the SOC exceeds the upper limit, it will be set to the discharge state; and when the SOC is lower than the lower limit, it will be set to the charge state. Through such modulation, the SOC of the battery can be maintained in a reasonable range.

In addition, considering that the photovoltaic inverter is not centralized, but scattered in different locations of the photovoltaic power station, therefore, by using the Ethernet communication technology LAN, when the grid-connected inverter works normally, the energy can be balanced among different battery groups by adjusting the grid-connected current instructions. Through Ethernet communication, different inverters upload the state of their own energy storage systems to the computer, which adopts intelligent control method to adjust the state of them according to the user settings. On the basis of the above scheme, and take two energy storage systems with Ethernet communication controllers for example, the control diagram of the designed station-level intelligent energy storage control method is shown in Fig. 5.

4 System Verification and Experimental Analysis

(1) Verification of the inverter-level intelligent energy storage control method

Firstly, the proposed inverter-level intelligent energy storage control method is verified. The relevant parameters are set as: the sliding average window $t = 0.5$ s, the number of sampling points $N = 1000$, and the voltage of DC bus $U = 50$ V. The three subfigures of Fig. 6 show the experimental results.

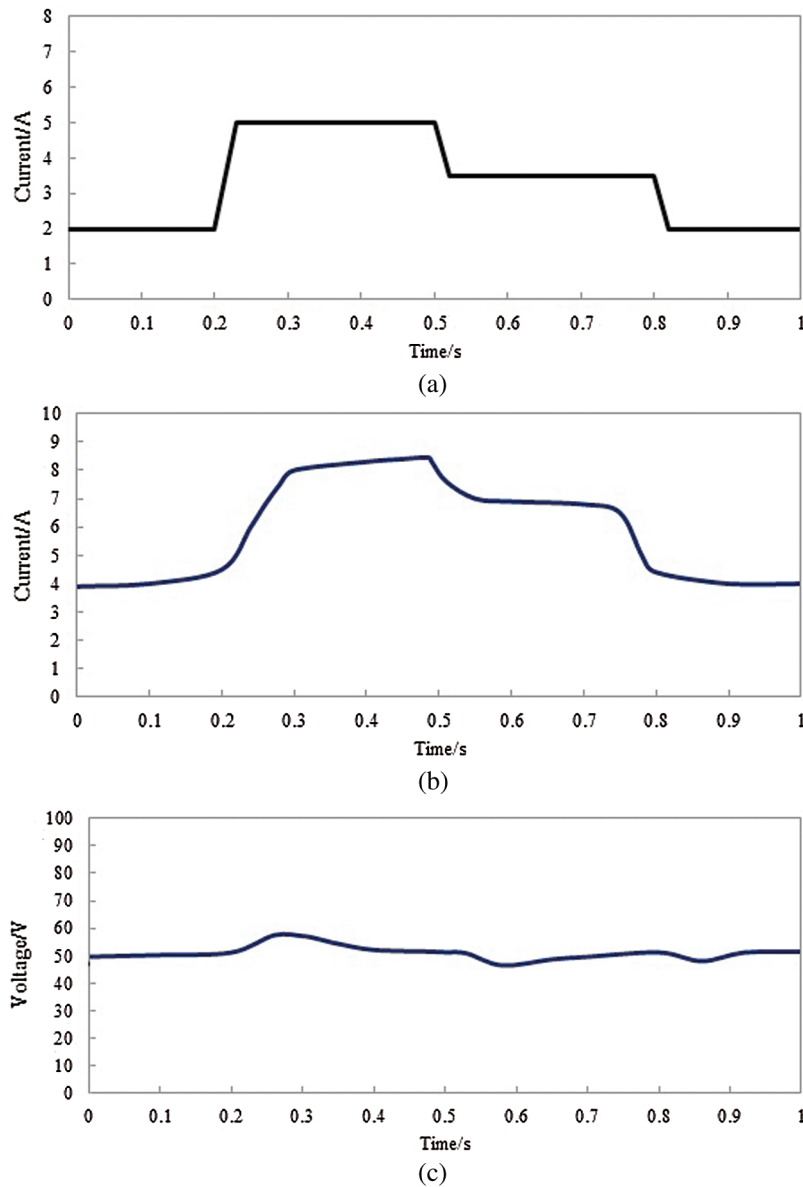


Figure 6: Experiment results of the inverter-level intelligent energy storage control method. (a) The curve of the current for the load; (b) The curve of the current for the battery and (c) The curve of the voltage for the DC bus

From the above figures, it can be seen that, at the time of 0.2 s, the unbalanced load current changes rapidly, but the change of the battery current is smooth, thus the procedure of charge and discharge current for the battery is also smooth, and the life of the battery is extended. And meanwhile, the voltage of the DC side is stable. At the same time, the DC bus voltage also maintains a relatively stable state clearly. And at the time of 0.5 s, the unbalanced load current decreases quickly, however, in the face of this rapid change, the battery current and DC bus voltage can maintain a relatively stable and gentle state of change; then at the time of 0.8 s, the unbalanced current decreased rapidly again, while the battery current and DC bus voltage can still maintain a stable state of change, which effectively shows that the proposed inverter-level intelligent energy storage control method performs well on the control performance.

(2) Verification of the station-level intelligent energy distribution control method

Based on the above analysis, the station-level intelligent energy distribution control method is further verified. To simplify the experiment, the experimental simulation model is designed with two grid-connected inverters is used in the experiment. In this experiment model, the SOC values of the different batteries are set to 0.7 and 0.3 respectively, and Fig. 7 shows the simulation results.

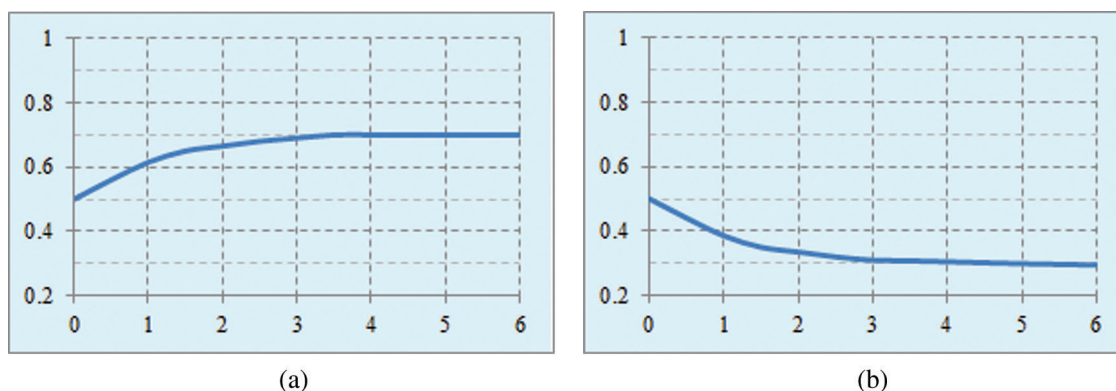


Figure 7: The curve of SOC for different experimental conditions

As can be seen from the figures, Through the operation of the experiment, it can be seen clearly that, the SOC values of the two different energy storage systems will approach to the preset SOC values, and finally converge to the set SOC values of 0.7 and 0.3 respectively, which effectively shows that the proposed inverter-level intelligent energy storage control method effectively achieves the expected control effect.

5 Conclusion

With the technology development for the new energy distributed generation, the intelligent energy storage control method is playing an increasingly important role. In this paper, based on the background of photovoltaic power station, it puts forward two-level intelligent energy storage control method by using computer communication technology, such as the inverter-level intelligent energy storage control method and the station-level intelligent energy storage control method. Among them, the inverter-level intelligent energy storage control method can be used for a single inverter, while the station-level intelligent energy storage control method can be used to deal with the energy distribution. Through such a two-level intelligent energy storage control method, it can effectively improve working ability of the single inverter, optimize the operation condition and the battery service performance, and then effectively solve the power quality problems. However, for the design of two-level intelligent energy storage control method, especially for the station-level intelligent energy storage control method, the design idea is relatively simple, and there are many complex factors in the actual engineering application that have not been involved, therefore, this will be the next research focus, and the research team will further optimize and improve the intelligent energy storage control method in combination with more complex factors in practical engineering application.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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