Research on Grid-Connected/Islanded Control Strategy of PV and Battery Storage Systems as Emergency Power Supply of Pumping Storage Power Station

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***Abstract*—In order to solve the problem of the insufficient reliability of diesel engine as the emergency power supply of pumped storage power station, a grid-connected/islanded control strategy of PV and battery storage systems as the emergency power supply of pumped storage power station is proposed. To begin with, the control strategies of different operation modes of the optical storage system are introduced. In the grid-connected operation mode, PQ control strategy is used to coordinate the output of PV and battery storage to meet the station power load demand. When faults occur in the grid, the PV and battery storage systems switch to islanded operation mode. At this time, the battery storage system adopts V / F control to maintain the stability of system voltage and frequency. The PV system still uses PQ control, and the two coordinate to supply power for the load. The time domain simulation model of PV and battery storage systems is established and the control strategy of the converter is simulated. The simulation results verify the effectiveness of the proposed grid-connected/islanded control strategy.**

Keywords-pumped storage power station; emergency power suppl; PV and battery storage systems; grid-connected/islanded control

I. INTRODUCTION

At present, the domestic pumped storage power stations which have been put into operation basically use diesel engine sets as emergency power supply for station power load. However,as the diesel engine is used as emergency power supply has the risks of off-line power supply, unsuccessful start-up, environmental pollution and later maintenance costs are higher. Therefore, in order to ensure the reliability and stability of the station power load for pumped storage power station, it is necessary to supplement safe, reliable, and low maintenance cost emergency power supply to ensure the stable operation of station power system [1]-[4].

With flexible control and mature technology, PV and battery storage systems is an important application direction of new energy generation technology. Literature [5] studies and discusses the emergency power supply of storage power stations, and statistically analyzes the current emergency power supply configuration of pumping power stations and the main influencing factors. Literature [6] studied the configuration scheme and operation mode of the standby diesel generator set for the safe and reliable operation of the isolated network of the offshore wind farm. Literature [7]-[8] designed a coordinated operation control strategy for isolated micro-grid of Wind Power, PV System, Diesel Generator, and Battery Storage to ensure long-term stable operation of the isolated system.

This paper introduces a kind of PV and battery storage systems structure, and analyzes two control strategies of battery storage converter and their switching: constant power control, namely PQ control strategy; Constant voltage constant frequency control, that is V/f control strategy. In grid-connected mode, PV system and battery storage system adopt PQ control strategy to coordinate output and meet the station power load demand. In the islanded mode, the output power of the PV system is greatly affected by the environment and not controllable when generating power. PQ control is always adopted during the operation. In this case, the battery storage converter is controlled by V/f to provide stable voltage and frequency for the system, and can be switched according to the voltage and frequency of the grid.

II. SYSTEM STRUCTURE PRINCIPLE AND COORDINATED CONTROL STRATEGY

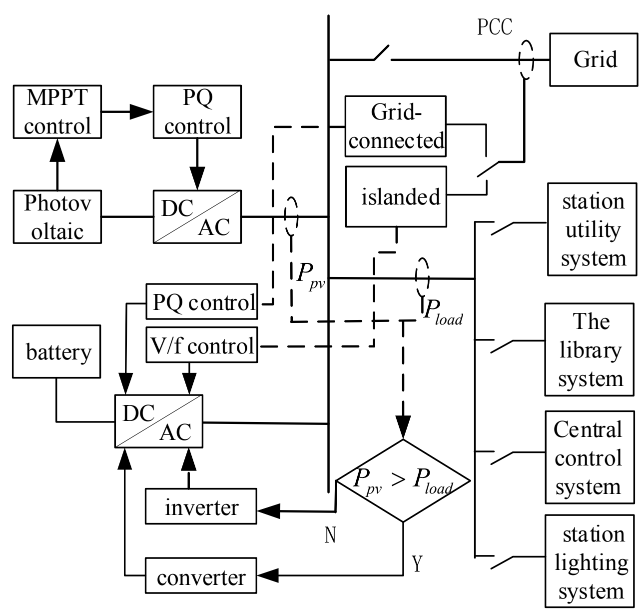

Figure 1. Overall structure of PV and battery storage systems.

The object of this paper is PV and battery storage systems, whose structure is shown in Fig. 1. The system consists of PV array, battery storage system, station power load, converter and grid. Among them, station power load includes station utility system, the library system, central control system, station lighting system,etc.

As can be seen from Fig. 1, in order to realize the coordinated operation of the PV and battery storage systems, the output power P_{pv} of the PV system and station power load P_{load} are detected. When $P_{pv} > P_{load}$ occurs, the station power load is all provided by the PV system, and the excess active power of the PV system is transferred to the battery storage system for charging. When $P_{pv} < P_{load}$, all the power of the PV system is transferred to the station power load, and the insufficient power demand is provided by the battery storage.

III. Grid-Connected/Islanded Control Strategy of System

A. *Grid-Connected Control Strategy*

The control structure of power outer loop and grid-connected current inner ring is adopted.

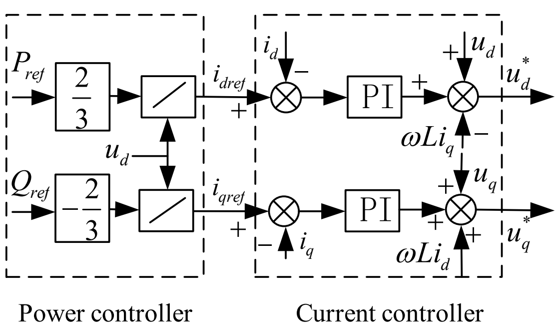

Figure 2. Grid-connected control strategy structure.

The power outer ring needs to collect the grid voltage U and grid current I in real time, and then get the instantaneous measured value of power through calculation. The difference between them and the given value P_{ref} and Q_{ref} is divided by u_{sd} to get the given value i_{dref} and i_{qref} of the current inner ring. Grid-connected power is obtained through dq coordinate transformation to obtain current id and i_q, which are different from i_{dref} and iqref. Through PI link and feedforward decoupling link, the inverter is controlled. The voltage reference values u_d^* and u_q^* are obtained. After the inverse transformation of coordinates and the SPWM modulation module, the driving signal of IGBT can be obtained, so as to ensure that the inverter delivers power to the grid at a given power value.

B. *Islanded Control Strategy*

When PV and battery storage systems is islanded, the voltage and frequency in the PV and battery storage systems must be stable. Therefore, the battery storage converter is controlled by V/f. The battery storage system is equivalent to a voltage source and outputs the given voltage and frequency through closed-loop control. V/f control adopts double closed loop structure of outer voltage loop and inner current loop.

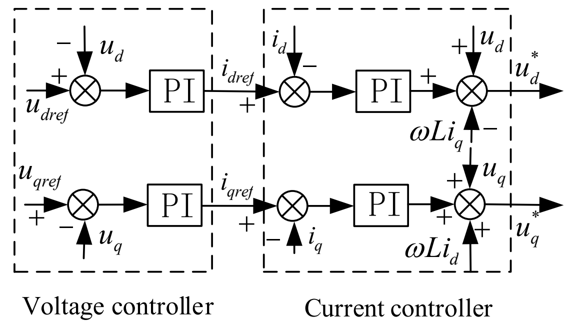

Figure 3. Control strategy structure.

Similar to PQ control, the reference voltage d-axis component u_{dref} is set as the base amplitude, and the q-axis component u_{dref} is set as 0.The differences between the u_d and u_q values obtained from the actual measured load side voltage through coordinate changes are adjusted by the PI controller to obtain the reference values i_{dref} and i_{qref} of the capacitance current axis d and q, respectively. Finally, the reference voltage components u_d^* and u_q^* in the internal axis coordinate system of the inverter are obtained through the PI controller and the feedforward decoupling link to realize the control of the inverter.

C. *Grid-Connected/Islanded Switch Control Strategy*

Since PV system always adopts PQ control in grid-connected operation and islanded, only the switch of battery storage system grid-connected/islanded control is considered.

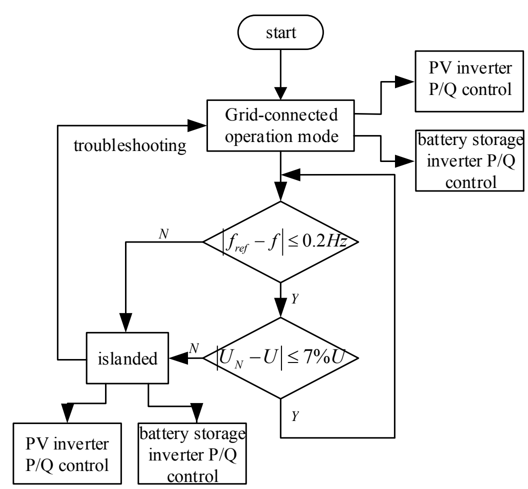

Figure 4. Grid-connected/islanded switching control flow.

According to the documents of GB/T12325-2008"allows the power quality of power supply voltage deviation" regulation, which is 10 kV and below power grid to allow the three-phase voltage deviation value is 7% of the rated voltage, frequency deviation should be allowed to meet GB/T15945-2008"power quality of power system frequency deviation" regulation, allowing frequency deviation is 0.2 Hz, as the frequency of the detected lines or voltage exceeds the allowed range, system switch to islanded; When the fault is eliminated and the voltage frequency returns to the normal range, the PV and battery storage systems is reconnected to the grid.

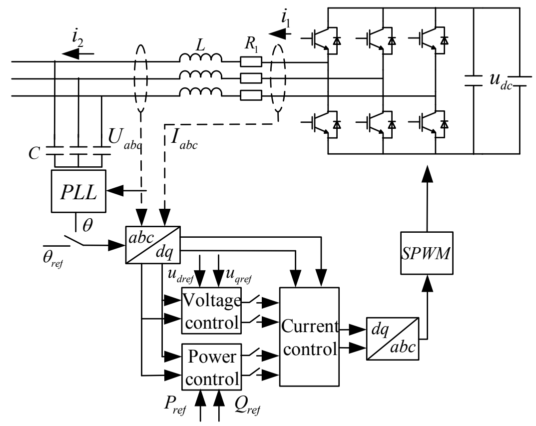

Figure 5. Grid-connected/islanded switching control strategy of the battery storage system.

As shown in the Fig. 5 above, during grid-connected operation, phase information required for coordinate transformation is provided by the PLL. Meanwhile, PQ control strategy of power control of the outer loop and current control of the inner loop is adopted. When a fault is detected in the grid, the frequency is switched to the given 50Hz to ensure the stable frequency of the system, and the corresponding power control of the outer loop is switched to the V/f control strategy of voltage control. The inner current loop does not need to be changed during the switching of the shunt.

IV. The Simulation Analysis

On the basis of theoretical analysis, the PV and battery storage systems is modeled, and Simulink simulation software is used to simulate the PV and battery storage systems as shown in Fig. 1.

A. Grid-Connected Control Strategy Simulation

The irradiance change of the PV array is set as shown in Fig. 6, the station power load is set to 50kW, and the output power of the PV system and battery storage system is changed as shown in the figure below.

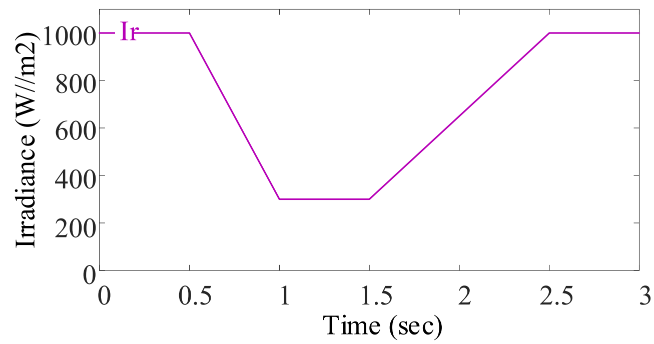

Figure 6. Irradiance changes of PV array.

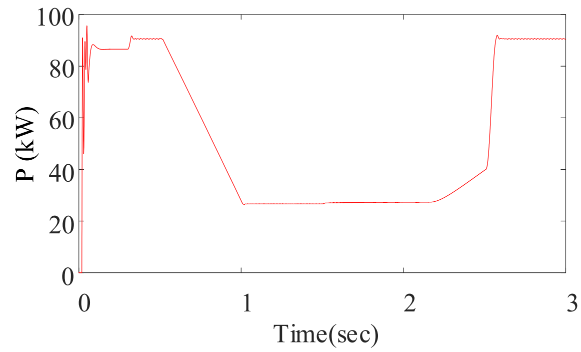

Figure 7. Active power change of PV system output.

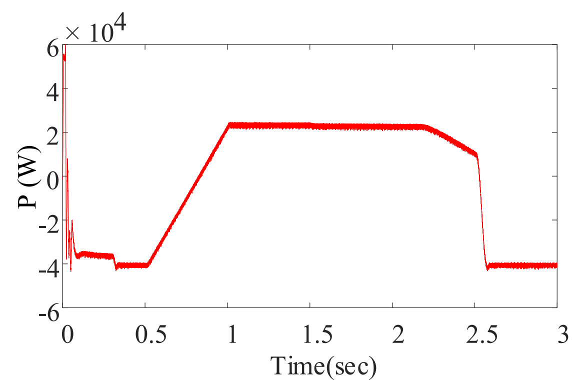

Figure 8. Active power change of battery storage system output.

The grid-connected current of PV inverter and battery storage converter is shown blow.

It can be seen from Fig. 9-11 that the output current of PV inverter and battery storage converter changes with the change of irradiance, and both of them jointly maintain the stability of current at the grid point. Before 0.8s, the PV output power is greater than the station power load, the battery storage is charged. At 0.8s, the PV output power is less than the station power load, and the phase of the output current of the battery storage inverter is changed. The battery storage changing from charging state to discharge state to supply power to the load. It changed again around 2.5s.

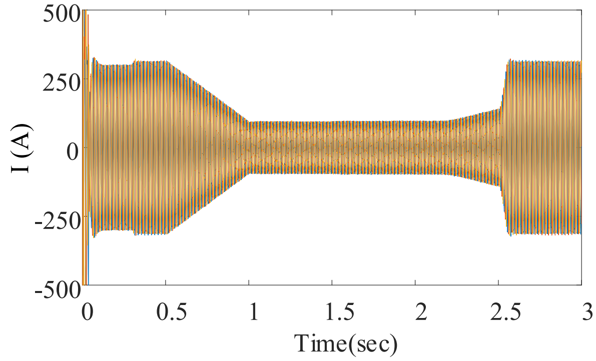

Figure 9. Output current of PV inverter.

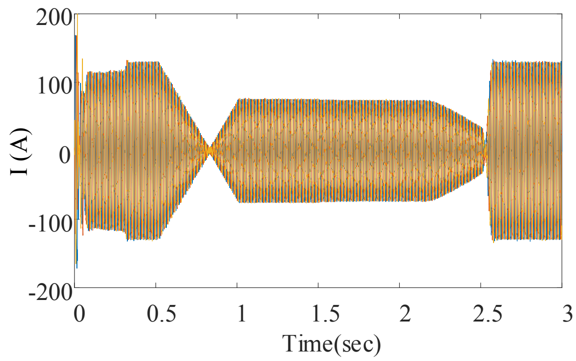

Figure 10. Output current of battery storage inverter.

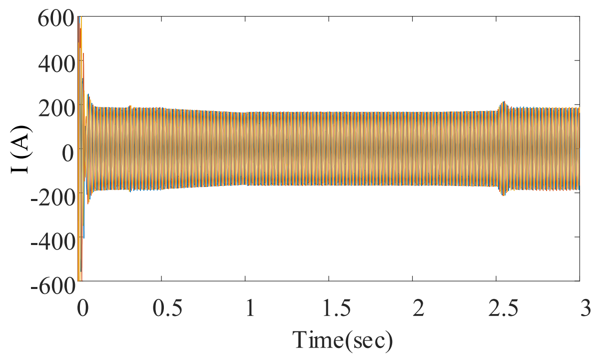

Figure 11. Junction current.

B. Islanded Control Strategy Simulation

Under the operation condition of the islanded, let the initial station power load be 120kw, cut out 60kW at 0.5s, cut-in 50kW at 1.5s, and the PV output is 100kW.At this point, the battery storage converter is controlled by V/f.

As can be seen from the Figs. 12-13, before 0.5s, the PV output was always lower than the station power load, so it was necessary to combine battery storage to supply power to the station power load. When the 60kW load is removed at 0.5s, the excess power will charge the battery storage when the PV output is greater than the station power load, corresponding to the part of the battery storage output curve in the Fig. below zero. At 1.5s, the load is cut-in 50kW, at which point the station power load is greater than the PV output, and the battery storage changes from charging to discharging, which together with the PV power supplies the station power load.

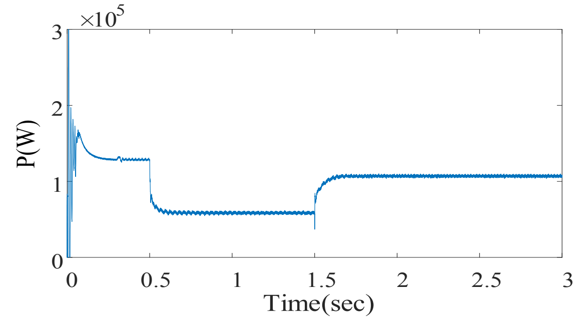

Figure 12. Active power change of the station power load.

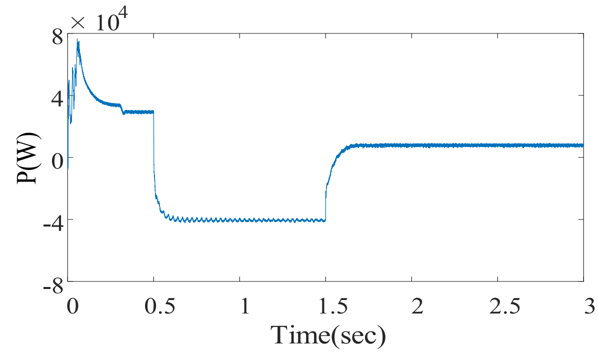

Figure 13. Active power change of battery storage system output.

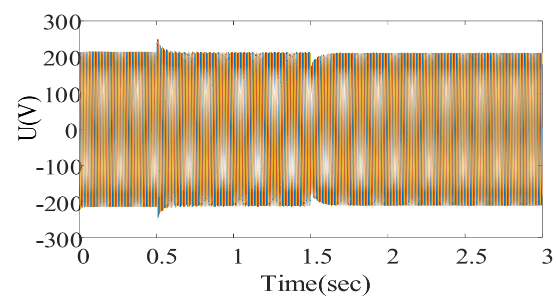

Figure 14. Three-phase voltage variation.

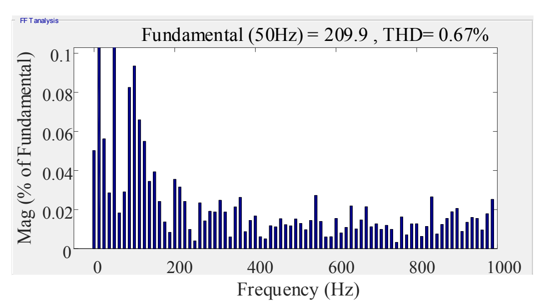

Figure 15. Voltage spectrum diagram.

Figs. 14-17 show the load voltage, current and spectrum diagram. It can be seen that the load voltage fluctuates when the load is cut-in and cut out, and then quickly returns to stability. The load current decreases when the load is cut out, and increases when the load is cut in. The total harmonic distortion rate of voltage and current is 0.67%.

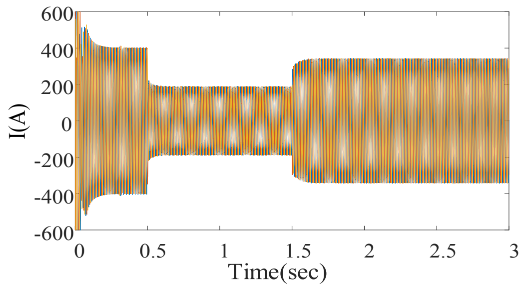

Figure 16. Change of three-phase current.

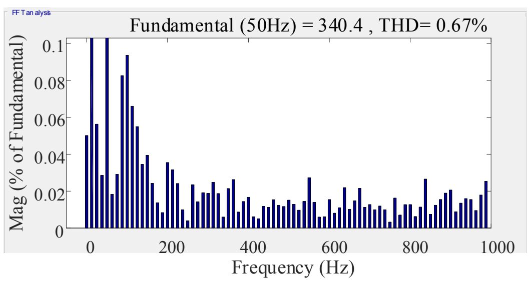

Figure 17. Current spectrum diagram.

C. Grid-Connected/Islanded Control Strategy Simulation

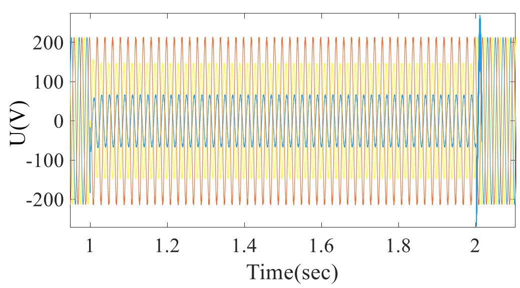

Figure 18. Voltage changes on the grid side.

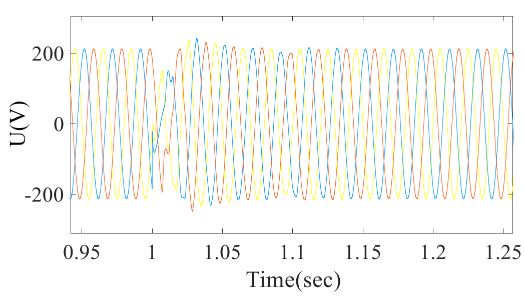

Figure 19. Load voltage variation.

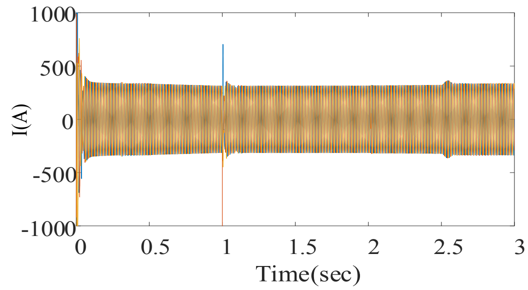

Figure 20. Load current variation.

Let the two-phase grounding short-circuit fault occur at the grid side at 1s, and the fault disappears at 2s, as shown in Fig. 18. The output power of the PV system is shown in Fig. 6, and the station power load is set to 100kW.

As can be seen from the Figs. 19-20, when the power grid fails, the optical storage system quickly switches to islanded. After 0.1s, the system runs stably in islanded. After the fault disappeared, the system switched to the grid-connected operation mode without obvious fluctuation.

V. Conclusion

In this paper, PV and battery storage systems is proposed as the emergency power supply of the pumping storage power station and grid-connected/islanded control strategy. Through simulation and analysis of the system voltage and power waveform under different operating modes, the following conclusions are drawn:

Under the grid-connected condition, the battery storage system can coordinate with the PV system to supply power to the station power load. Under the condition of islanded, the V/f control of the battery storage converter can provide stable voltage and frequency for the station power load.

When faults occur in the grid, the control strategy should be switched quickly to ensure the stable voltage of the pumping storage power station and the reliable operation of the station power load.

Acknowledgment

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References

[1] Q. Lu, W. Zhao, X. Huang. Preliminary discussion on comprehensive utilization of pumped storage power station [J]. *Hydropower and pumped storage*, 2017, 3(06): 58-62.

[2] Z. Huang. Function research of pumped storage power station [J]. *Modern industrial economy and informatization*, 2018, 8(13): 96-98.

[3] K. Wang, Z. Li, C. Bai, H. Zhou, et al. Study on price mechanism and market bidding model of pumped storage power station [J]. Smart power, 2019, 47(06): 47-55.

[4] Y. Huang, X. Yuan, J. Hu, P. Zhou. Modeling of VSC connected to weak grid for stability analysis of DC-link voltage control[J]. *IEEE Journal of Emerging and Selected Topics in Power Electronics*, 2015, 3（4） : 1193-1204.

[5] J. Li. The Design and Analysis on the Emergency Power Supply Configuration of Pumped Storage Power Plant [J]. *Hydropower and pumped storage*,2016,2(01):97-102.

[6] M. Zheng, Y. Yang, Y. Shen, X. Xu, Y. Tao. Research on the Standby Diesel Generator Set Scheme of Offshore Wind Farm in the State of Island Operation Mode [J]. *Southern energy construction*,2019,6(01):24-30.

[7] M. Liu, L. Guo, C. Wang, et al. A Coordinated Operating Control Strategy for Hybrid Isolated Microgrid Including Wind Power, Photovoltaic System, Diesel Generator, and Battery Storage [J].*Power system automation*, 2012, 36(15): 19-24

[8] Q. Wang, J. Sun, Y. Tang. Research on intelligent control strategy of wind-wind-firewood storage combined power generation system [J]. *Journal of electrical applications*, 2012, 31(24): 96-100.