

Black start research of the wind and storage system based on the dual master-slave control

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Abstract. Black start is the key to solving the problem of large-scale power failure, while the introduction of new renewable clean energy as a black start power supply was a new hotspot. Based on the dual master-slave control strategy, the wind and storage system was taken as the black start reliable power, energy storage and wind combined to ensure the stability of the microgrid systems, to realize the black start. In order to obtain the capacity ratio of the storage in the small system based on the dual master-slave control strategy, and the black start constraint condition of the wind and storage combined system, obtain the key points of black start of wind storage combined system, but also provide reference and guidance for the subsequent large-scale wind and storage combined system in black start projects.

1. Introduction

In recent years, there have been a large area of power failures all over the world, including America, Canada, Brazil, India, East China, China Southern Power Grid, which seriously harm the development of economy and society[1-2]. Because there were many factors may cause the power failures, as debris flow and rainstorm in Guangxi or Tianjin “8.12” and so on which cause the power failures requiring reconstruction of the whole power grid timely and reliable, ensure the power supply recovery [3]. At present, wind power generation is the cleanest energy and widely used in distributed energy generation, it has maintained a high annual growth rate. Although wind energy has intermittent, volatility and other issues, but the energy storage can stabilize the wave caused by wind turbine power generation, solving the stability problem of microgrid system. The possibility of wind energy storage system combined become true and can be used as a black start power, and can also solve the current large-scale “abandoned wind” problem[4-5], it effectively improve the utilization of wind energy. The introduction of various distributed new energy sources into black start has become a new development trend[6-8]. Different from usual, taken hydraulic turbine and gas turbine as black start power supply[9], more and more distributed energy also can be used as black start power, paper[10]: the electric vehicle charging and discharging storage integrated power plant is used as a black start power source, which participates in the black start of power grid.

In this paper, based on dual master-slave control strategy, large scale vanadium redox flow battery used as energy storage carrier, taken 1.5MW doubly-fed wind generator as the research object of wind power generation, the wind and storage units were considered as a joint small system, as the black start power supply, starting remote auxiliary generator, the wind power storage union system stability was analyzed, and the wind storage small system capacity ratio was found, which providing the basis and reference as the black start power supply for the future.



2. Dual master-slave control strategy

2.1. Dual master-slave control strategy

Different from the traditional master-slave control strategy, a dual master-slave control strategy was proposed in this paper. The core content was: under the full black condition of power grid, one or more of the energy storage inverter units were used as the main control power source in energy storage group, taking constant frequency and voltage control(V/f control) to establish the standard of voltage and frequency for other energy storage inverter unit, the remaining energy storage inverter unit was used as the control unit, taking constant power control(PQ control) to satisfy the power requirements of the system, and the dynamic self-adaptation on the charge/discharge balance cycle were obtained, which forming the first energy storage group of the master slave control mode; under the small system mode including the energy storage group and wind generator, energy storage group as the master control unit to provide voltage and frequency reference for joint operation, wind power generation system as the slave unit using PQ control tracking voltage and frequency provided by energy storage master unit, and effectively balance the power distribution among wind energy, energy storage and power grids. Coordination the second dual master-slave control mode of wind storage system, provide reliable voltage and power support for black start of the entire power grid. The schematic from of dual master-slave control is shown as Figure 1.

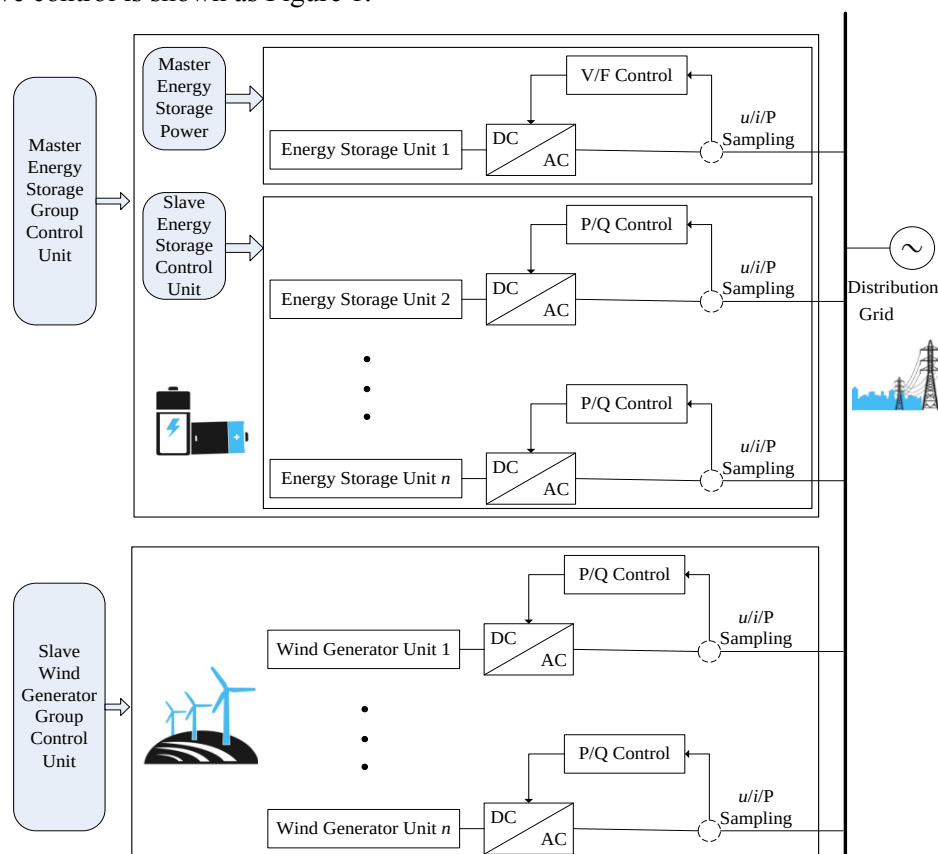


Figure 1. The schematic from of dual master-slave control.

Simulation calculation were based on PSCAD software, simulation model of wind storage system shown as Figure 2, taking 1MW energy storage as the master unit, 1MW energy storage as the slave unit, the output of wind generator was 1MW. According to the change of the load, the dual master-slave control mode can adjust the capacity of the unit, while the traditional master-slave control cannot dynamically adjust the slave the unit. In order to show dual master-slave control was superior to the traditional master-slave control strategy, the simulation results of active power and bus voltage under

different control strategies were compared. As Figure 3(Description of symbols in the Figure 3: P_{esc} was energy storage charging unit, P_{esd} was energy storage discharge unit, PL was the load, $PG1$ was output of wind generator), at the initial moment, input 1MW energy storage master unit and 1MW energy storage accessory unit charging, at 0.5s time wind generator output was 1MW, 2s time input the load (The traditional master-slave control load was 1MW, the dual master-slave control load was 2MW).

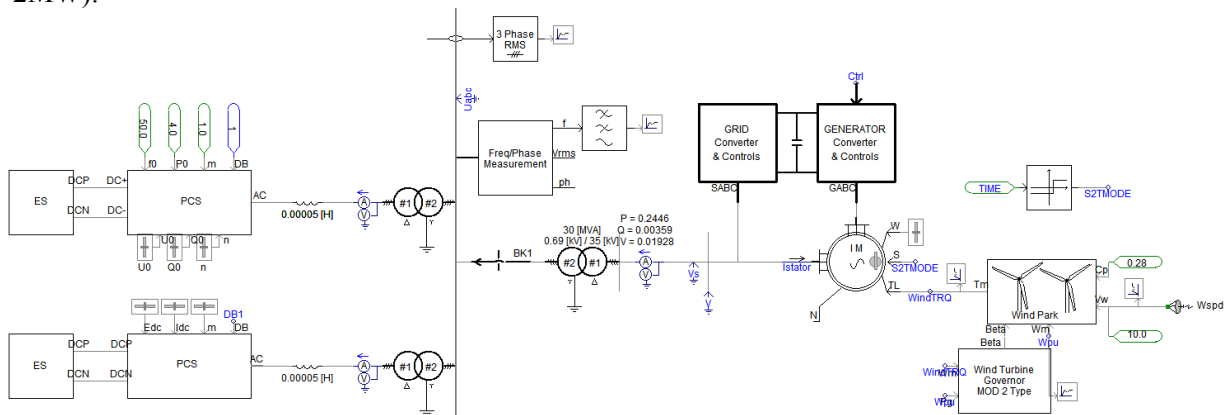


Figure 2. Wind and storage system simulation schematic.

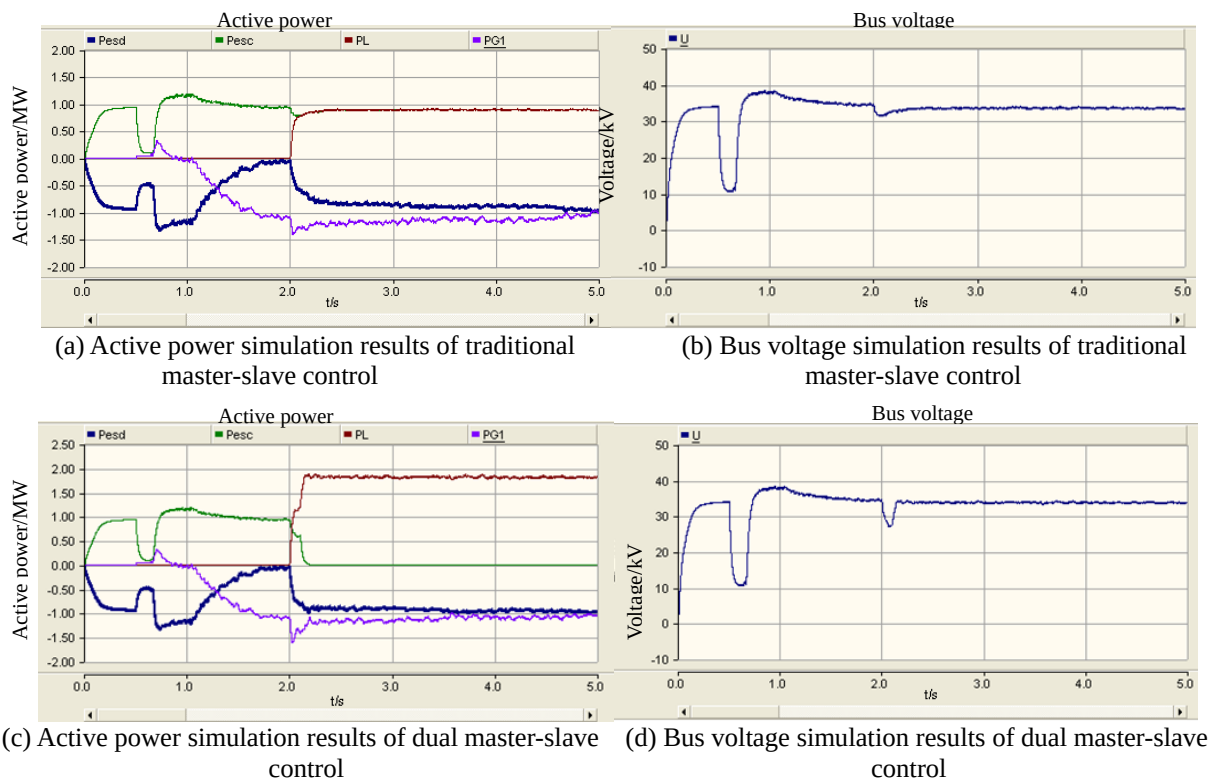


Figure 3. Simulation results.

Figure 3 shows: the dual master-slave control strategy can dynamically adjust the capacity of slave unit, but the same condition, the limit capacity was significantly higher than that of the traditional master-slave control, while ensuring that the bus voltage and frequency were up to the grid standard.

1.1. Constraint conditions of slave unit adjustment capacity

Although the dual master-slave control strategy can effectively improve the ultimate load capacity of the wind energy storage system, which starting of the remote load under the maximum capacity. In order to obtain the constraint conditions of the combined storage system for black start, the simulation analysis was carried out in this paper. The slave unit capacity was changed step by step, and the simulation under the different load results were compared and analyzed.

Simulation conditions: at the initial moment, input 1MW energy storage master unit and 1MW energy storage slave unit, at 0.5s time the wind generator is 1MW, at 2s time input the load (divided into 1MW, 0.8MW and 0.5MW three cases), at 2.1s time adjust the charge capacity slave unit (different step conditions: 30%, 50%, 100%), 10 calculation examples are shown in Table 1, the active power, reactive power, bus voltage and frequency of each kind of load were simulated, and the optimal adjustment value of the unit capacity was compared and analyzed.

Table 1. Simulation initial conditions of different models

Example	Main Unit	Slave Unit	Wind Generator Output	Load	Slave Unit Adjusted Capacity
②-1	1MW	1MW	1MW	1MW	0.7MW
②-2	1MW	1MW	1MW	1MW	0.5MW
②-3	1MW	1MW	1MW	1MW	0.0MW
②-4	1MW	1MW	1MW	0.8MW	0.7MW
②-5	1MW	1MW	1MW	0.8MW	0.5MW
②-6	1MW	1MW	1MW	0.8MW	0.2MW
②-7	1MW	1MW	1MW	0.8MW	0.0MW
②-8	1MW	1MW	1MW	0.5MW	0.7MW
②-9	1MW	1MW	1MW	0.5MW	0.5MW
②-10	1MW	1MW	1MW	0.5MW	0.0MW

Following conclusions are obtained through the 10examples: When load was 1.0MW, under the same conditions, the slave unit step 100% (cut all slave units); when load was 0.8MW, the slave unit step 80% (slave unit from 1MW to 2MW); when load was 0.5MW, the slave unit step 50% (slave unit from 1MW to 0.5MW). In these three cases, the steady-state of system was the best.

When

$$PL + P_{esc2} = PG1 \quad (1)$$

and

$$P_{esc2} = P_{esc} - P_{escs} \quad (2)$$

The master unit was only responsible for providing the voltage and frequency standard, without charging, thus the adjustment effect and stability were the best. Due to the master energy storage unit capacity was limited, not only providing voltage and frequency standards, but also dynamically adjusting the slave unit capacity. When the system power was surplus, the master unit was required to charging. So the performance and the adjustment ability of master unit were decreased, and other requirements cannot reach. Therefore, under the system control of voltage and frequency, master unit did not charge, the wind storage system was stable and reliable. The constraint condition formula of the dual master-slave control strategy considering the capacity and stability of the slave unit can be obtained:

$$P_{escs} = PL + P_{esc} - PG1 \quad (3)$$

This providing the theoretical basis for the wind power storage combined system as a black start power supply. And the wind and storage system can be used as the research of black start scheme for starting the remote auxiliary generator.

3. Stability analysis of black start in wind and storage system

3.1. Stability analysis of the system under constant wind speed

Taking the total energy storage capacity of 5MW, the wind generator rated capacity 1.5MW (wind speed 10m/s, output 1MW) as an example, the simulation calculation is carried out for the typical model while the energy storage unit as charge load, to research master-slave capacity ratio of wind storage system; the stability and power quality of microgrid system when the energy storage charging.

The discharge capacity of the energy storage V/f control strategy was 1MW, 2MW, 3MW and 4MW in four cases, wind generator rated capacity 1.5MW (wind speed 10m/s, output 1MW), the storage capacity of PQ control strategy is 1MW, wind storage system was modeled, analysis of different models of active power, reactive power, bus voltage and frequency, bus voltage simulation results as an example shown in Figure 4.

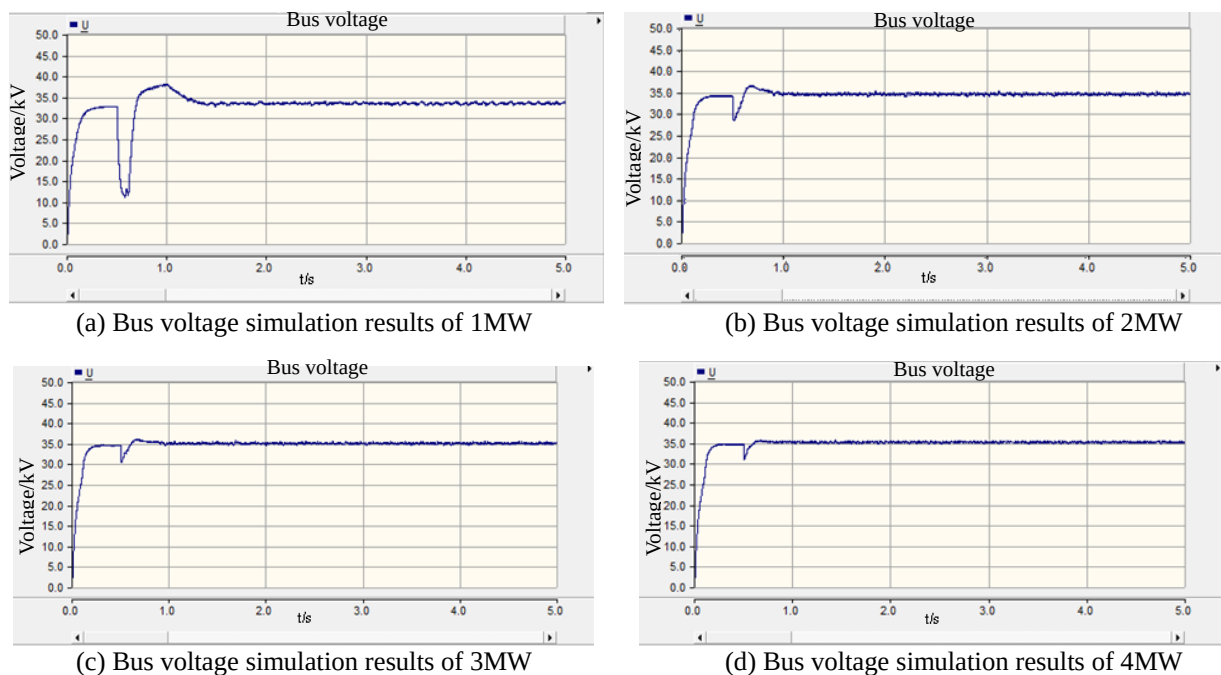


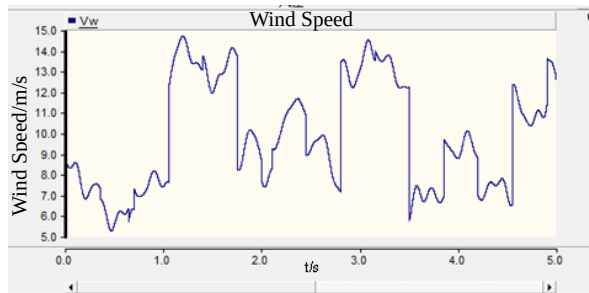
Figure 4. Simulation results.

From Figure 4: During self starting of the storage system, the V/f control strategy was used as the master power supply, and the PQ control strategy is adopted in the wind power generation system. The microgrid system can provide voltage and frequency standard, and power support for black start. The typical configuration rules for the operation are obtained: wind power generation system capacity cannot exceed the capacity of storage, the system more stable and smaller fluctuant voltage rate when the master power supplies capacity greater.

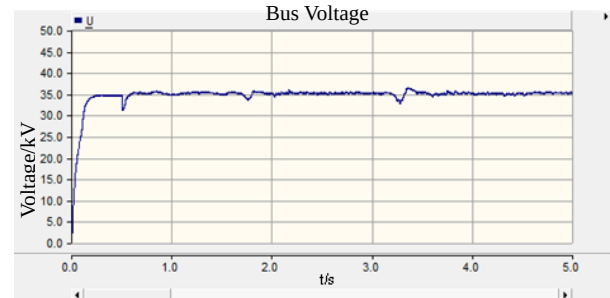
3.2. Analysis of system stability under wind speed variation

The actual wind speed was not always the same value, in order to simulate the actual wind speed fluctuation on the stability of wind energy storage system; wind speed was set by time variation with wind speed fluctuations. The discharge capacity of energy storage V/f control strategy was 4MW, the rated capacity of wind generator was 1.5MW, and the charge capacity of the storage PQ control

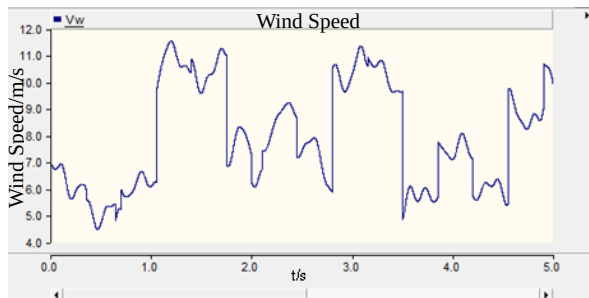
strategy was 1MW, also considering wind speed fluctuation. Three conditions were considered on stability simulation and analysis of the whole storage system, when the average wind speed was 10m/s, 8m/s and 5m/s. The fluctuation of different wind speed changes with time was shown in Figure 5. The results of active power, reactive power, bus voltage and frequency were obtained under different average wind speed. Taken bus voltage simulation results, as an example, were shown in Figure 6.



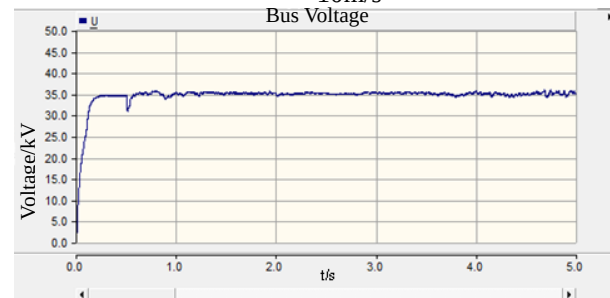
(a) Wind speed when the average wind speed was 10m/s



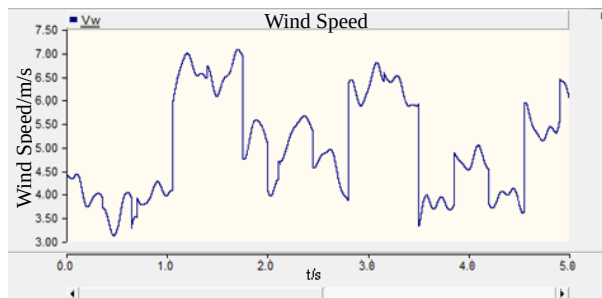
(a) Bus voltage result when the average wind speed was 10m/s



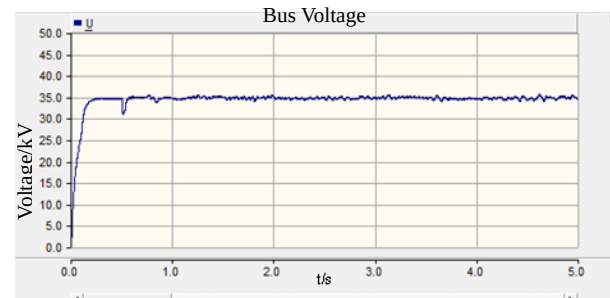
(b) Wind speed when the average wind speed was 8m/s



(b) Bus voltage result when the average wind speed was 8m/s



(c) Wind speed when the average wind speed was 5m/s



(c) Bus voltage result when the average wind speed was 5m/s

Figure 5. Wind speed under different average speed.

Figure 6. The results of bus voltage under different average wind speed.

From Figure 6 (a) the active power, reactive power and bus voltage of the wind energy storage system were always in the process of micro oscillation due to the large fluctuation of wind speed, while the wind speed was large, can cause small amplitude fluctuations of the bus voltage. The maximum speed can reach 15m/s, thus the wind generator reach full state. The fluctuation range of the wind speed was between the two states: full state and critical generation, which directly leading to the fluctuation range increase of the active power and reactive power. Because the energy storage capacity was limited, a small fluctuation when the wind generator under full state occurred.

In Figure 6 (b), when the average wind speed was 8m/s, the fluctuation of 10m/s was slightly smaller than 10m/s condition, but the maximum wind speed was 11m/s, which close to the full state.

As the average wind speed decreases, the fluctuation range of the wind speed was smaller, and the fluctuation range of the active power and reactive power was reduced. The system was more stable compared to the average wind speed of 10m/s.

In Figure 6 (c), when the average wind speed was 5m/s, the fluctuation range of the wind speed was 3m/s-7m/s. From the active power and reactive power point of view, the critical state of the power generation and power generation is relatively clear, continuous wave impact didn't existed. The active power and reactive power waveform were relatively stable, bus voltage and frequency also maintained standard value.

4. Conclusions

Through the relevant simulation calculation of the wind and storage combined system, different models were compared and analyzed, the following conclusions were obtained:

(1)The dual master-slave control strategy was better than traditional master-slave control strategy, and the capacity adjustment was stronger.

(2)Wind generator system capacity cannot exceed the capacity of the storage, the greater master power supply capacity of the wind and storage system, the smaller voltage fluctuation rate was, and more stable.

(3)As the wind speed changing, the active and reactive power of the wind turbine was in a state of fluctuations. The smaller wind speed fluctuates, the more wind storage system relatively stable was. But from the range of wind speed, when the wind generator between full and critical power generation, can cause fluctuations in the wind and energy storage system, but the energy storage had the ability to adjust the volatility, just following the change of wind speed, not reaching the limit.

Acknowledgment

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