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Operation Performances Enhancement of Micro-grid by Battery Energy Storage System

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Abstract: The intermittent and unpredictable of renewable energy generations such as PV and wind turbine may affect the operation performance of micro-grid including frequency, voltage and diesel generator operation state. And battery energy storage system (BESS) is usually equipped in micro-grid to mitigate the fluctuations of distributed generator output. This paper presents a P/V control strategies in a typical micro-grid composed of diesel generator, asynchronous wind turbine, PV generator, and BESS. Simulation proves that the operation performances of micro-grid could be greatly enhanced by BESS under the control strategies presented in this paper.

Key words: micro-grid; operation performance; bess; P/V control
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电池储能系统对微电网运行特性的改善作用研究

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摘要：光伏发电、风力发电等可再生能源发电系统的波动性、间歇性和不可预测性会对微电网的运行特性产生一定的影响，包括电压波动、闪变、谐波，频率波动以及柴油发电机输出功率大幅波动、定子电流三相不平衡等。电池储能系统(BESS)由于其快速的有功/无功响应特性，可用于微电网中平滑分布式电源的输出功率，从而改善微电网的运行状况。首先研究了可再生能源发电系统的随机波动对微电网运行状况的影响，提出了采用 P/V 控制调节可再生能源发电系统的输出功率，同时稳定微电网母线电压的控制策略。并针对一种典型的微电网结构，仿真验证了 BESS 对微电网运行状况的改善作用。

关键词：微电网；运行特性；电池储能系统；P/V 控制

As a promising distributed generation (DG) network structure, micro-grid plays a very important role in enhancing system reliability, increasing utilization of renewable energy, and saving investment [1-4]. Normally, micro-grid consists of distributed generations such as PV and wind turbine, energy storages and loads[5-8]. As a power grid, micro-grid should satisfy the requirements of load for power quality to ensure the power frequency, voltage and harmonic wave within a specified range. However, renewable energy generations are easily affected by the natural environment and the output power is intermittent and unpredictable. Unfortunately, micro-grid has little system inertia, so the change of wind velocity, sunlight or load power may increase the fluctuation of power frequency and voltage, and even lead to unstable, especially in island operation mode. So with more and more DG connecting in micro-grid, the operation performance of islanding micro-grid may be affected and the penetration of DG may be restrained unless some measures are adopted [9-10].

The influence of renewable energy on micro-grid

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can be mitigated with battery energy storage system (BESS). Through the control of power converter, battery energy storage system can operate in four quadrants flexibly and can absorb or output energy quickly, to maintain the instantaneous energy balance, smooth the fluctuation of frequency and voltage, and enhance the operation performances of micro-grid.

In this paper, a simulation model of typical island micro-grid composed of diesel generator, asynchronous wind turbine, PV generator, and BESS is established in Matlab/Simulink. The control strategy of BESS is designed combining with the influence of renewable energy to micro-grid. And the operation performances of micro-grid including frequency, voltage and diesel generator operation state are analyzed with/without BESS respectively.

1 Operation Performance Influenced by DG

With the deepening research and enlargement application of micro-grid, more and more types and quantities of DG are connected in micro-grid. The power quality problem is more and more terrible caused by the special characteristics of DG. It badly affects to the operation performance of micro-grid, mainly as follows[11-12]:

1) The start-stop and switching of DG is influenced by the environmental and climatic conditions, user needs, policies and regulations and other factors. Its uncertainty could easily lead to the micro-grid voltage fluctuation and flicker. At the same time, the interactions between control and feedback links of DG will directly or indirectly lead to voltage flicker.

2) Many of distributed generations are connected in micro-grid based on power electronic technology. Frequent switching of the switching devices will bring harmonic component and pollute grid.

3) DG is generally closer to load. Its reactive power output can increase the voltage of load node and even beyond the offset standard. When DG out of operation, the nodes which are affected seriously by DG will lack voltage support and suffer serious power quality problems such as low voltage. And the extent of effect is related to the type, location and capacity of DG.

4) Various forms of DG access to micro-grid causes the operation performance easily influenced by outside conditions because of the scale of micro-grid is generally small. During island operation mode, the randomness and volatility of DG output could easily lead to the fluctuations of micro-grid voltage and frequency, and affect the normal power supply.

In addition, the output power of DG such as PV and wind turbine is affected by the real time environmental and climatic conditions. To achieve the power balance, the output of diesel generator is changes real time following with DG and loads. This makes the diesel generator difficult to run under the economic and safe operation state unless some measures are adopted.

2 Control Strategy of Battery Energy Storage System

For a typical island micro-grid composed of diesel generator, asynchronous wind turbine, PV generator, and BESS, when the output active power of asynchronous wind turbine changes, reactive absorption also changes. And the connection node voltage will change follow it. To both restrain the output active power and voltage fluctuation of DG, an active power and voltage control strategy (P/V control) is used in this paper. Set value of active power and voltage as reference value of P_{ref} and V_{ref} at the point of common connection. Then the output active and reactive power of BESS can be controlled respectively. The converter control block diagram of BESS is shown in Fig. 1[13]. Through a coordinate transformation to the rotating frame which its d-axis coincides with the initial phase angle of grid electromotive force, the d-axis and q-axis could represent active component and reactive component respectively after the introduction of current state feedback and voltage feed forward. So, the active power could be controlled through d-axis, and the reactive power could be controlled through q-axis.

In Fig. 1, the active power partial ΔP as a control signal of outer loop d-axis acts with an active power controller to generate the reference value of d-axis current control signal I_{dref}. And the AC voltage partial ΔV as a control signal of outer loop q-axis acts with a voltage controller to generate the reference value of q-axis current control signal I_{qref}. The inner loop is an AC current loop. The d-axis component I_d and q-axis component I_q are obtained by the three phase input current through coordinate transformation. And they are subtracted by the reference value of current respectively to obtain the current partial. Though the controlling of inner loop, the PWM control signal can be obtained.

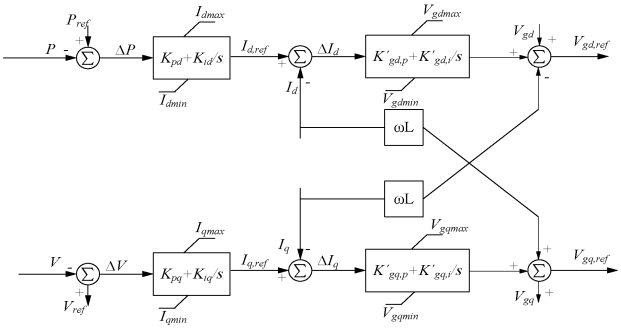


Fig. 1　Control Block Diagram of BESS

3　Simulation analysis

Figure 2 shows the micro-grid structure of Wanshan island in Zhuhai, China. It is composed of diesel generator (500 kW), asynchronous wind turbine (260 kW), PV generator (two sets and each group 100 kW), and load (410 kW). The simulation model of this micro-grid is established in Matlab/Simulink. The simulation parameters of diesel generator, asynchronous wind turbine and PV generator are shown in table 1 to table 3 respectively. And the sunlight and wind speed curve are shown in figure 3 and figure 4 respectively. Simulation assumes that a group of PV generator out of operation at the 5th seconds, and another group out of operation at the 10th seconds. According the above parameters, the operation status is simulated in Matlab. And the operation performances of micro-grid including frequency, voltage and diesel generator operation status will analyzed with/without BESS detailed in later sections.

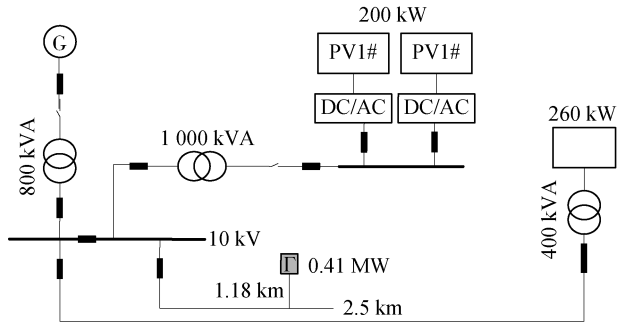


Fig. 2　Micro-Grid Structure of Wanshan Island

Table 1　Simulation Parameters of Diesel Generator

Parameters	Description	Value
P	Rated power	500 kW
f	Rated frequency	50 Hz
U_N	Rated output voltage	520 V

Table 2　Simulation Parameters of Wind Turbine

Parameters	Description	Value
P_{nom}	Rated power of wind turbine	260 kW
$P_{mec\_\ nominal}$	Generator rated power	260/0.9 kVA
f	Generator rated frequency	50 Hz
U_N	Generator rated output voltage	520 V
S_{wind}	Rated wind speed	12 m/s

Table 3　Control Parameters of PV

Parameters	Description	Value
K_{pd}	Voltage outer loop K_p	50
K_{id}	Voltage outer loop K_i	0.1
K_{pq}	Reactive power outer loop K_p	0.01
K_{iq}	Reactive power outer loop K_i	1
$K'_{gd,p}(K'_{gq,p})$	Inner loop K_p	40
$K'_{gd,i}(K'_{gq,i})$	Inner loop K_i	0.1

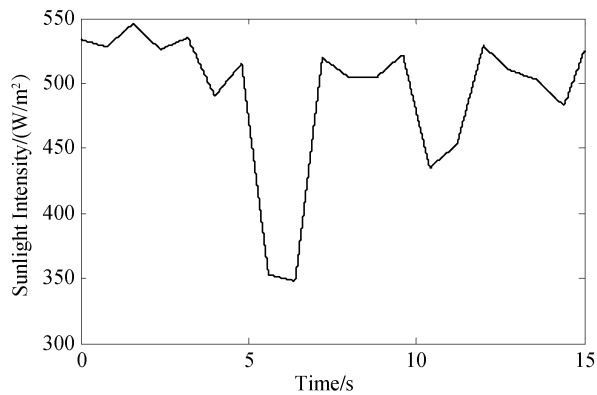


Fig. 3　Sunlight Curve in Simulation

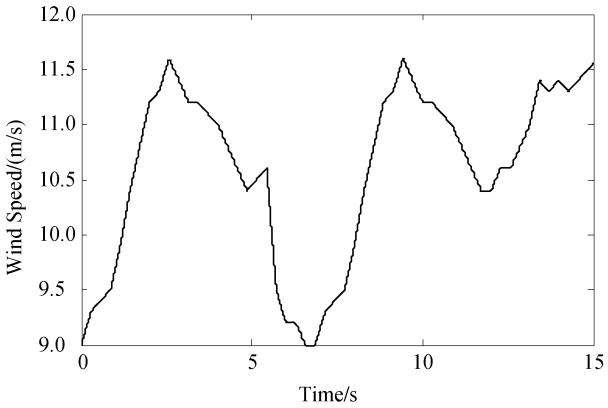


Fig. 4 Wind Speed Curve in Simulation

3.1 Operation status of diesel generator

Figure 5 to figure 9 show the simulation results of diesel generator. From this we can see that the rotational speed and electromagnetic torque of diesel generator could be fast reach a relatively stable output when the BESS adjusting in the micro-grid. Accordingly, the active power output is also relatively stable, and the reactive power output is lower. A smooth output makes to set the diesel generator operation at economic state easily. And low reactive output can increase the power factor of diesel generator, and improve the economy. Especially, the three-phase unbalance of the stator current of diesel generator is reduced significantly through the use of BESS (see fig. 7). It is very useful to the safe operation of diesel generator. From this, we can see that the use of BESS can enhance the operation performances and improve the economy operation level of diesel generator.

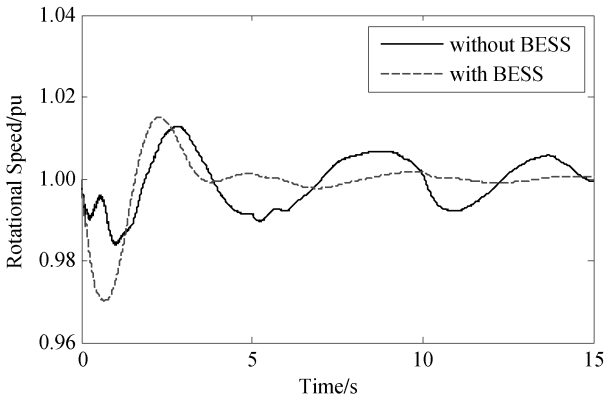


Fig. 5 Rotational Speed of Diesel Generator

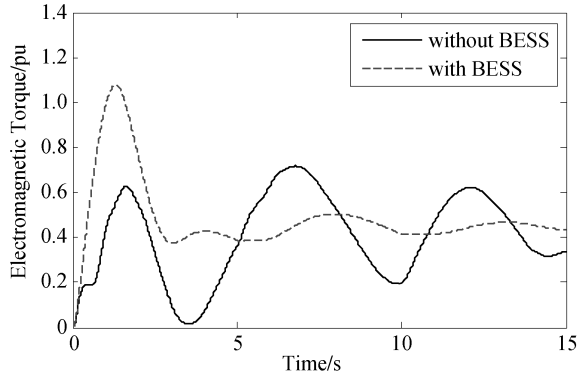
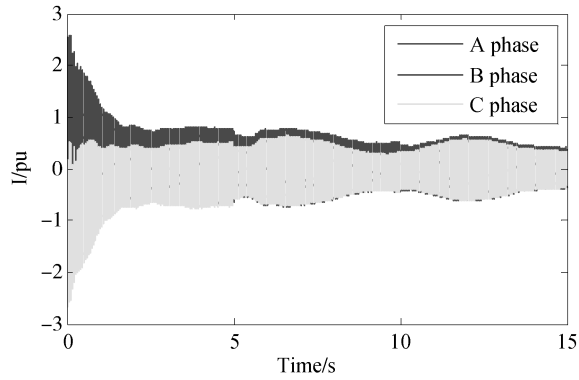
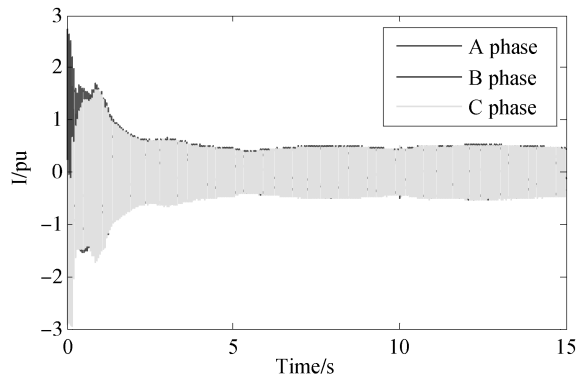


Fig. 6 Electromagnetic Torque of Diesel Generator



(a) Without BESS



(b) With BESS

Fig. 7 Stator Current of Diesel Generator

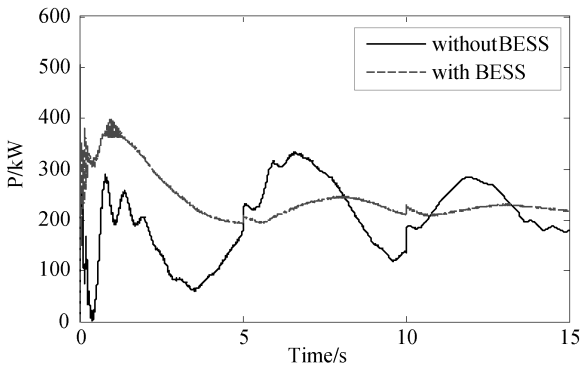


Fig. 8 Output Active Power of Diesel Generator

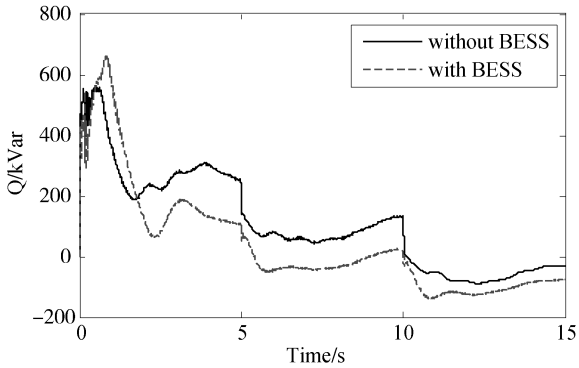


Fig. 9　Output Reactive Power of Diesel Generator

3.2　Voltage

Figure 10 shows the voltage deviation of 10 kV bus bar in the above simulation. If the BESS is not used in the micro-grid, the biggest voltage deviations of 10 kV bus bar are 8.5%, 4.4% and 4.85% respectively at the time of starting diesel generator, cutting of group 1#PV generator and cutting of group 2#PV generator. And the durations of voltage fluctuation are respectively about 5 seconds, 4 seconds and 5 seconds. But after the use of BESS, the biggest voltage deviations are respectively reduced to 5.5%, 1.95% and 2.2%, and the durations of voltage fluctuation are respectively reduced to 3.5 seconds, 0.5 seconds and 0.7seconds. And when the PV generator cut of, the voltage deviation can be reduced to less than 2% in 10 ms or less. So, under the P/V control strategy, the system voltage has significant control effect by using BESS.

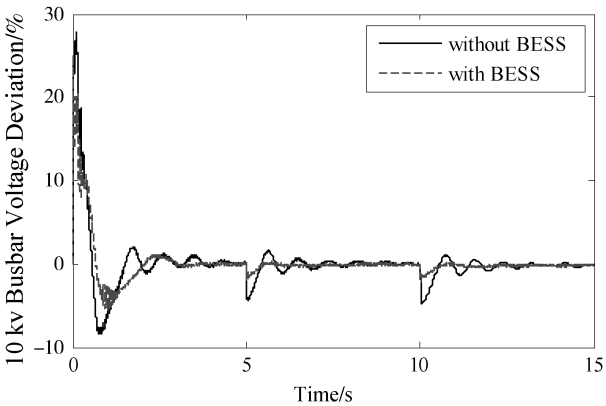


Fig. 10　10 kV Bus Bar Voltage Deviation

3.3　Frequency

The output power of DG like as PV is affected by the environmental and climatic conditions. And it changes in real time. To achieve the power balance, the diesel generator should regulate its output real time and follow the changes of DG. But the response time and regulation ability of diesel generator is limited. So the frequency of islanding micro-grid is hard to stable unless some measures are adopted especially when the penetration of renewable energy generator is high.

Figure 11 shows the frequency of the micro-grid system in the above simulation. The deviation of frequency is about −0.6 Hz to 0.4 Hz after the diesel generator completely started without BESS. It is greatly exceeds the safe operation requirements of loads. So the BESS must be used in this situation. The simulation result shows that the deviation of frequency can be reduced to less than ±0.1 HZ by BESS.

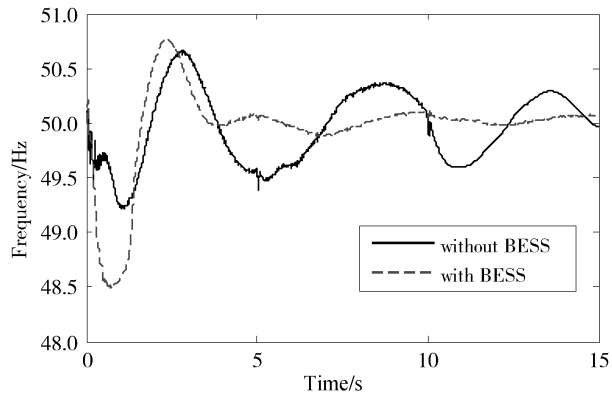


Fig. 11　System Frequency

4　Conclusion

The randomness and volatility of DG output power could easily influence the operation performance of micro-grid including frequency, voltage and diesel generator operation state. Aiming at the characteristics and causes of these influences, a control strategy of BESS is analyzed to mitigate the influences and enhance the operation performance of micro-grid. Taking Wanshan island micro-grid structure as an example, the operation performances of an islanding micro-grid are analyzed through simulation. From the simulation, the following main conclusions can be derived.

1) In islanding micro-grid, the output of diesel generator is fluctuant greatly with the changes of envi-

ronmental and climatic conditions. And the three-phase unbalance of the stator current is serious. Equipped with BESS, the operation performances can be good enhanced.

2) Cutting of DG can cause system voltage decrease in several seconds. Equipped with BESS can reduce the amplitude and duration time of voltage sags.

3) Wind velocity and sunlight change may cause system voltage and frequency fluctuant, especially when the penetration of renewable energy generator is high. Equipped with BESS can control the fluctuation of voltage and frequency within a specified range.

To sum up, BESS can greatly enhance the operation performance of micro-grid especially at islanding operation status. The research results provide a feasible way to solve the basic problem of power supply and economic operation in islanding micro-grid.

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