The Control Strategy of VRB-ESS for Wind Power

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Abstract – Aiming at the application of Vanadium Redox-Flow Battery Energy Storage System (VRB-ESS) on wind power, this paper studied on the control strategy of BESS under the different time scale. Firstly, the paper introduced the operation mode of BESS under different working condition and the judgment principle for operation mode switch, which based on the comprehensive characteristics of wind power prediction, SOC of BESS and control objective of wind power- BESS. According to the technical requirements, the control strategy of BESS was presented, namely smooth control based on ultra-short-term wind power prediction. The smooth control works on smooth the rapid fluctuation of power output from wind farm with time scale 0-15min, it is very helpful to improve the power quality of wind power and reduce the influence from wind power on the frequency regulation capability of power system. Lastly, by means of simulation, the control strategy was applied to a study wind farm to verify the effectiveness.

Keywords: BESS, WP-BESS joint application, Smooth control, Simulation

1. Introduction

This According to research results in domestic and abroad, the major factor affects the acceptance capacity of Wind Power(WP) currently, is the influence of the ability of peak load regulation when large-scale WP connect to power grid[1~6]. In China, most developed wind farm are concentrated in northwest, north and northeast China. In these areas, most of the thermal power should take charge of heating missions in cold winter, which leads to limited capacity of peak load regulation. However, wind farm can produce more power in winter season, so there often appears wind abandoned conditions in some special operating mode. In order to improve the characteristics of WP grid connected and enhance the power supply reliability of WP, the Large-scale Energy Storage System (ESS) with the characteristics of bi-directional power flow should be considered. By the use of ESS, combined the WP prediction technology with the means of coordinated control of WP, the wind power output will be limited to a given range. At the same time, ESS can provide automatic rotating rotor blades power supply facilities to ensure the controllability of fan blade in strong winds, even when the external power supply break down, so as to avoid mechanical damage due to strong winds. In this paper, the combined application of battery energy storage technology and wind power technology, referred to as the WP-BESS joint application.

WP-BESS joint application belongs to research hotspots currently. For Vanadium Redox- Flow Battery (VRB) can response frequent charge and discharge switching rapidly and possess the advantages of long cycle life and lower cost, it has been considered as the most suitable battery type for smoothing the intermittent wind power output. At the beginning of study WP-BESS joint application, lots of basic research should be carried out. Now, there are many demonstration projects of WP-BESS joint application in abroad[7~12], which more focused on the view of WP or Photovoltaic (PV) systems, instead of BESS control and management. What’s more, it is difficult to directly access their advanced experience and core technical information because of the limitation of intellectual property issues currently. In view of this, the paper studied the application of VRB- ESS in smoothing the WP output, especially focus on the operation and control of battery side. And the paper proposed several operation modes and the mode switching conditions of WP-BESS joint application in detail; then by means of combining short-term prediction technology of WP, the paper proposed the smooth control strategy to restrain the fluctuations in wind power output, which can provide a theoretical basis and technical support for the follow-up demonstration and application.

2. Operating Mode and Switch Principle

Excluding the island operation, the application of WP-BESS joint system can be divided into several operating modes, as follows:
1. Combined operation mode (WP + BESS + Grid)
2. Stand-alone operation mode of BESS (BESS + Grid)
3. Hot reserve mode of BESS (WP + Grid)

In order to ensure the stability, reliability and efficiency of WP-BES joint system, the coordination control of WP and BES must be achieved. As this paper focuses on the application and control of BESS side, it is assumed that the wind energy control unit can achieve its control objectives well. To BESS, the energy management control is based mainly on the wind power output and current state of the battery. And through the energy conversion technology of bi-directional converter achieving battery charge and discharge, which can realize the harmonization between BESS and WP. For the three operation modes of WP-BES joint system, this section will specifically study the switch conditions among various modes.

In the control study of WP-BES joint system operation, use $P_{\text{max}}$ and $P_{\text{min}}$ to describe the control boundary of BESS start up or quit respectively, which can be considered as the envelope curve of the synthetic output of WP-BESS joint system; $U_s$ stands for terminal voltage of VRB system; $U_{b_{\text{min}}}$ indicates the discharge cut-off voltage; $U_{b_{\text{max}}}$ indicates the charge termination voltage. Suppose the battery discharge current direction of the system is positive.

$$P_{WG} > 0$$

**CASE I**: If the power output is higher than the upper boundary, that is $P_{WG} > P_{c_{\text{max}}}$, and for the battery system: $U_s \leq U_{b_{\text{max}}}$, then it satisfies the conditions for the startup of the battery charging-control. Then the PCS unit for WP will control the direction of the power output to charge the VRB system. The charging time depends on the current state of the battery and the output circumstance of the next sampling point. During this period, the DC-DC of the battery management system (BMS) is working at Buck mode, and the DC/AC is working at Rectifier mode.

**CASE II**: If the power output is higher than the upper boundary, that is $P_{WG} > P_{c_{\text{max}}}$, and for the battery system: $U_s \geq U_{b_{\text{max}}}$, that means the battery is under saturated state. Then the BEMS will abandon control and switch to spinning reserve state because the battery can not absorb redundant energy, until a proper instructions startup. At this time, it should be combined the control with the propeller elongation, and avoid power jumping of the joint system output as possible.

**CASE III**: If the power output is lower than the lower boundary, that is $0 < P_{WG} < P_{c_{\text{min}}}$, and for the battery system: $U_{c_{\text{min}}} \leq U_s \leq U_{b_{\text{max}}}$, that means there has energy remained in BESS can be used. Then the system can be switched to discharging mode. The discharging time depends on the State of Charge (SOC) of the battery. During this period, the DC-DC of the BMS is working at Boost mode, and the DC/AC is working at Inverter mode.

**CASE IV**: If the power output is lower than the lower boundary, namely $0 < P_{WG} < P_{c_{\text{min}}}$, and for the battery system, there is $U_s \leq U_{b_{\text{min}}}$, that means current SOC of the battery is lower than normal working level. Then the BMS will abandon control and switch to spinning reserve state because there’s no adequate capacity for the battery to support the lack power of WP, until a proper startup instructions to startup BESS. At this time, the synthetic output of the joint system will jumping downward.

$$P_{WG} \leq 0$$

**CASE V**: The wind turbine has no power output, and for the battery system, $U_{b_{\text{min}}} \leq U_s \leq U_{b_{\text{max}}}$, this situation can be regarded as a special example of CASE III. At this time, the battery system will be switched to discharging mode and supply the electricity alone. Similarly, the discharging time of the battery system depends on the SOC of the battery. During this period, the DC-DC of the battery management system (BMS) is working at Boost mode, the DC/AC is working at Inverter mode.

**CASE VI**: The wind turbine has no power output, and for the battery system, $U_s \leq U_{b_{\text{min}}}$, at this situation, the system will be rested and switched to spinning reserve mode.

**Fig. 1.** Ultra-short-term forecast output and real power comparison of wind power.
For the whole wind farm, CASE V and CASE VI of the rare. If they do occur in extreme cases, it will be controlled and protected by BMS. Because of the randomness and intermittence of WP, sometimes leading to charge the battery with high power, which resulting in the current over the limitation of battery system. Therefore, besides constant power charge mode, constant voltage with current limiting also be used in charging method. Taking into account the protection of the BESS, another mode switch condition is when the charge current over the limitation.

Fig. 2. The fluctuate rate probability distribution histogram of wind power interval 15 minutes.

3. Smooth Control Strategy

In last section, the operational mode and the switch conditions of WP-BES joint System is described. Based on the ultra-short-term wind power forecasting technology, this section studies the charging and discharging control of BESS when the WP-BES joint system is applied to the grid-connected operation, a control strategy to smooth the wind power fluctuation is presented. The time scale and time resolution of the ultra-short-term wind power forecasting is 0~4h and 15min respectively, the forecasting accuracy is quite good, specially to the 0~15mins, whose RMES is close to 2%. Fig. 1 shows the comparison between actual and forecasting power of a wind farm. According to the Fig. 1, the ultra-short-term wind power forecasting predicts the change trend of the power output from a wind farm well, could be the reference of the charging and discharging control of a BESS.

Smooth control strategy of WP-BES joint application focuses on the regulation of WP fluctuation in 0~15mins, therefore, it is required to collect the WP output within 15 minutes, so as to determine the need of smoothing the output power and preset operation instruction of the battery charge and discharge. As the time scale of the control method’s theoretical basis is shorter, the results of macro point of view, the performance of the control strategy of BESS shows that the jumping slop of WP output has been reduced apparently, and lower the fluctuations in the amplitude and probability. So, this control method can be used in large-scale wind power grid connected to solve the access problem of power system frequency.

The smooth control strategy of WP-BES joint system is as follows:

1. Determining the wind power fluctuation during 15mins, according to the ultra-short-term wind power forecasting;
2. Determining the smoothing range, according to the regulation speed and climbing speed of Thermal Power Unit;
3. Regarding the predicted wind power as the actual wind power, and subtracting the power output from the WP-BES joint system by this predicted wind power;
4. If the difference from step 3 is within the smoothing range, then the BES starts charging and discharging control to limit the wind power fluctuation;
5. For the next sampling time, the step 3 will be carried out repeatedly to determine the operation instruction.

The characteristics of this presented control strategy are as follows: regarding the predicted wind power as the actual wind power, taking the difference between the predicted wind power and synthetic output as the operation instruction to determine the charging and discharging control. By this control strategy, the capacity of the BES could be smaller which should bring more benefit.

4. Simulations

This section is based on Matlab simulation platform for example wind farm to test the effectiveness of the WP-BES joint system control strategy. The wind farm installed capacity is 100MW, including 50* 2MW Vestas wind turbines. For output data collected, it selected March as a test period.

First, Fig. 2 shows the statistical sampling interval of 15 minutes of power fluctuation ratio of the probability distribution of example wind farm in March. Known by the analysis of Fig. 2, during 15 minutes of example wind farm, the probabilities of the ratio as |10%|, |5%| and |2%| between the fluctuations of wind power and the installed capacity, were 98%, 90% and 80%. To verify the BESS smoothing effect of fluctuations in wind power, this section will choose the fluctuation ratio as |5%| and |2%| within 15 minutes as the smooth control objectives scope, and analyse the effectiveness of control strategy in detail.
Battery power settings used to numerical verification need to be combined with statistical actual historical power data of the wind farm. The maximum value for the difference between fluctuation power amplitude and limited range was taken based on the output power over the same period of history in the 0~15mins. In the example wind farm, according to statistical analysis of the same period’s historical output power, the extreme value of the wind power fluctuation within 15 minutes is 30MW. When the acceptable fluctuation rate range was set as 5% and 2% of installed capacity, respectively, within 15 minutes, the corresponding power ratings of the BESS should be 25MW and 28MW, respectively. Moreover, the 50% or higher SOC should be a normal working status for the BESS, the ultimate rated capacity of the BESS should be at least 50MW and 56MW. And the discharge time of the battery system was set to typical value of 10 hours.

We will analyze smooth control effect when the different fluctuation ranges were used as control scope.

\[\text{(I) Fluctuate rate} < |5\%|\]

Fig. 3 describes the output of WP-BES joint system with the sample interval 15mins. In this case, the acceptant fluctuate rate is 5%. Known by the chart analysis, the performance of the BESS smooth control shows that the fluctuation slope of wind power is decreased, which relieve the instantaneous mutation of WP effectively. And the control strategy was useful to reduce the impact of power system frequency.

Fig. 4 shows the fluctuate rate probability distribution histogram of WP-BES joint system interval 15mins. By comparing to Fig. 2, it can be seen that the fluctuate rate of WP-BESS joint application was restricted in the ratio of 5% less, which is achieve the basic control objectives.

\[\text{(II) Fluctuate rate} < |2\%|\]

Fig. 5 describes the output of WP-BES joint system with the sample interval 15mins. In this case, the acceptant fluctuate rate is 2%. With respect to Fig. 3, taken to limit fluctuations as 2% of the installed capacity, the BESS control to power fluctuation is more obvious changes in jumping slope, and significantly reduced the probability of wind power fluctuations in short-term, which not only play the role of frequency regulation, also to some extent reduce the wind power impact on system stability.

Fig. 6 shows the fluctuate rate probability distribution histogram of WP-BES joint system. With the application of BESS, the wind power fluctuate rate in the range of 15 minutes, can be limited to 2% less, which can achieve the basic control objectives.

In summary, it can deduce negative impacts of large-scale WP grid connected in the problem of frequency of the power system, and to a certain extent, reduce wind disturbance on the power system stability by the use of the high degree of confidence over the Ultra-short-term wind power prediction as a reference value, so as to limit the fluctuate rate of wind power with 15mins time scale to control the target rate of the BESS control strategy of smoothing fluctuations in wind power.
5. Conclusion

As a typical application of VRB-ESS, WP-BESS joint application is the research hotspot currently. This paper analyzed various operating modes and mode switching conditions of WP-BESS joint application; proposed fluctuations in wind power smoothing control strategy in the theoretical base of ultra-short-term wind power prediction, which can reduce the slope of output jumping rate, reduce negative effect of the wind power fluctuations on power system frequency, and to a certain extent, reduce wind power on the adverse effects of power system stability. At the circumstance of poor accuracy of wind power Short-term prediction, and the scale of the battery capacity constraint by cost and material technology which leads to difficult to meet the requirements of peak shaving, set smooth fluctuations in wind power applications as the control objective, should be more reality with high practical engineering value.

References


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