Research on the Control Strategy of the Battery Energy Storage System in Wind-Solar-Battery Hybrid Generation Station

Maohua Shan*. Yening Lai*. Jian Geng*. Kaifeng Zhang **. Zonghe Gao *

*State Grid Electric Power Research Institute, Nanjing, China (e-mail: danmaohua@sgepri.sgcc.com.cn)

**School of Automation, Southeast University, Nanjing, China

Abstract: In recent years, wind-solar-battery hybrid generation systems (WSBHGS) with large-scale battery energy system (BESS) have been proposed to integrate into power grids. To smooth the output power and improve the schedulability of the WSBHGS, the BESS control strategy is researched and a distributed control architecture of a two-level hierarchy is proposed, which is consisted of the top-level centralized controller and the local controller. The control strategies of the top-level controller including power correction strategy, power distribution strategy and state of charge (SOC) control strategy for battery are proposed to establish the active power reference of each battery energy storage equipment (BESE) of the BESS. The local controller uses the control of grid-connected converter of BESE to trace the power reference signals rapidly. The fluctuations of the output power of the WSBHGS are tested, and the effectiveness of the proposed BESS control strategy is demonstrated under different power generation schedules from the dispatching center.

Keywords: Energy storage, Distribution control, Power distribution, Converters, Fluctuations.

1. INTRODUCTION

In recent years, with the progress of science and technology, the renewable energy represented by solar energy and wind energy has been developed rapidly, which may provide an effective way for us to solve the current energy crisis. However, for wind energy and solar energy are intermittent and random, the solar or wind power station is difficult to provide continuous and stable power output. When the solar or wind power is interconnected to power grid, how to make the solar or wind power supply and power grid in harmony has become the focus of attention (Hochheimer, 2006, Azmy, *et al*, 2005, Erlich, *et al*, 2006). The main research idea is from the viewpoint of power grid. The power resources in the whole grid such as thermal power, hydropower, etc. could be fully utilized by formulating a practical power dispatch and control scheme, to achieve the friendly integrating of wind power and solar power (Sun, *et al*, 2007, Gao, *et al*, 2010).

The other research idea is from the viewpoint of power supply. The energy storage technology is used to smooth the fluctuations of the wind or solar power (Boyles, *et al*, 2000, Kobayashi, *et al*, 2003). Meanwhile, the predictability of wind and solar generation should also be improved. Among these, wind-solar-battery hybrid generation systems (WSBHGS) with large-scale battery energy storage systems (BESS) have received considerable attention, because the technology of large capacity battery energy storage has made great progress currently (Barton, *et al*, 2004, Abbey, *et al*, 2007). At present, State Grid Corporation of China is building a wind-solar-battery power demonstration system in the city of Zhangjiakou. This system includes 100MW wind-power, 50MW PV-power and 20MW chemical storage device. Fig. 1 shows the structure of the wind-solar-battery

power demonstration system whose BESS is made up of an amount of battery energy storage equipments (BESEs) and directly connected to AC bus of the WSBHGS.

Fig. 1. The structure of the wind-solar-battery power demonstration system.

In addition to full use wind power and solar power complementary character in the time domain, the WSBHGS also uses the BESS to rapidly absorb the residual energy and add the insufficient power. Thus, the WSBHGS can achieve the smooth of power output, which is beneficial to the stability of grid system. Furthermore, to maintain grid system stability, we hope the WSBHGS can output the power in accordance with the curve of the power generation schedule from the dispatching center in the distance. Because the solar or wind power station is difficult to provide continuous and stable power output, the WSBHGS makes its actual power output close to the power generation schedule curve as much

as possible, primarily by controlling the BESS charge and discharge process.

In this paper, the research focuses primarily on the battery energy storage control system (BESCS) in WSBHGS, and a distributed control architecture with a two-level hierarchy is proposed. Through analysis and evaluation of the strategy, the results show that the strategy can improve the certainty of the WSBHGS power output, while reducing the risk of over-charging and over-discharging of the energy storage battery.

2. OVERALL CONTROL ARCHITECTURE OF BESS IN WSBHGS

In order to realize the goal that the output power of the WSBHGS can trace the curve of the power generation schedule, the BESCS needs to solve two basic problems: (1) Because the solar or wind power station is difficult to provide continuous and stable power output, the errors between the wind-solar hybrid generation system and the power generation schedule always exist. So, according to the energy depth of the BESS and the BESS power correction strategy, the BESCS can make the actual power output of WSBHGS close to the curve of the power generation schedule as much as possible; (2) For wind energy and solar energy are intermittent and random, it is difficult to regularly charge and discharge the energy storage battery. Thus, it is necessary to take appropriate charge and discharge control and protection strategy for the energy storage battery.

The distributed control architecture of the two-level hierarchy is proposed in this paper (as shown in Fig. 2), which is consisted of the top-level centralized controller and local controller. The top-level centralized controller accepts power instructions from the dispatching center and uses power control strategies for BESS to establish the active power target value of each BESE of BESS, including system power correction strategy, power distribution strategy, state of charge (SOC) control strategy for batteries, etc. According to the power reference value of each BESE from the top-level controller and an appropriate closed-loop control strategy, the local controller produces the driver pulses for every bridge arm of the grid-connected converter to control its current amplitude and phase between BESEs and the grid, and implements rapid tracking the power reference signal.

3. THE CONTROL STRATEGY OF THE TOP-LEVEL CENTRALIZED CONTROLLER

3.1 Power Correction Strategy

In order to make the WSBHGS output power trace the curve of the power generation schedule, the WSBHGS power correction controller produces the power adjusting signals of BESS, trying to estimate the errors between the WSBHGS output power and the control reference of the power values from the dispatching center. The control block diagram is as shown in Fig. 3.

Fig. 2. A distributed control architecture of a two-level hierarchy.

Fig. 3. The block diagram of the power correction controller.

In Fig. 3, P_{ref} is the control reference of the power from the dispatching center; P_{W-PV-B} is the actual output power of WSBHGS; P_{W-PV} is the actual output power of the wind and solar power farms; ΔP_{W-PV-B} is the adjusting output power of the power correction controller.

As shown in Fig. 3, the power adjusting signal of the controller consists of two parts: one is the precise adjusting signal (a closed-loop controller), and the other is the rough adjusting signal (a feed-forward controller). The precise adjustment is a closed-loop adjusting process, and it uses proportional-integral control rules to achieve negative feedback control, according to deviation between P_{ref} and P_{W-PV-B} . The rough adjustment uses proportional control rules to achieve feed-forward control, according to deviation between P_{ref} and P_{W-PV} .

Generally, the closed-loop controller with proportional-integral control rules can reduce or even eliminate the errors between P_{W-PV-B} and P_{ref} , and then the output power of WSBHGS can track the control reference closely. But this control method always lags the occurrence of output power fluctuations from the wind or the solar power farms. Or, the controller doesn't produce regulatory action until the errors between P_{W-PV-B} and P_{ref} occur. So, a feed-forward control is

added to the controller which will output immediately a rough power adjusting signal in the event of power output fluctuations from the wind or the solar power farms. Therefore, the complex correction strategy can more effectively and quickly reduce the impact of power output fluctuations.

3.2 Power Distribution Strategy

Currently, a large capacity BESS is composed of a number of BESEs, and each BESE is connected to the AC bus via an AC/DC converter in WSBHGS. So, it is necessary to research how to get power reference signals of every AC/DC converter from ΔP_{W-PV-B} . Therefore, the top-level controller sets the power dispatcher of BESS to assign a power adjusting signal for every AC/DC converter according to the energy depth of each BESE.

To avoid the charge/discharge capacity exceeding the limit value, ΔP_{W-PV-B} is allocated to every AC/DC converter by the power dispatcher of BESS according to the margin of the charge and discharge capacity of each battery. The implementing method is discussed under the two conditions:

(1) In each control cycle, if $\Delta P_{W-PV-B} > 0$, the BESS should be discharged, and the discharged power of each BESE is obtained from expression (1).

$$\Delta P_i^B = P_{Ri}^+ \cdot \Delta P_{W-PV-B} \quad (1)$$

In (1) ΔP_i^B is the adjusting power of the i th BESE; P_{Ri}^+ is the participation factor of the i th BESE, and it is obtained from expression (2).

$$P_{Ri}^+ = \frac{W_g^i - W_{g \min}^i}{\sum_{j=1}^n (W_g^j - W_{g \min}^j)} \quad (2)$$

In (2) W_g^i is the current reserve electric quantity of the i th BESE; $W_{g \min}^i$ is the lower limit of the reserve electric quantity.

From (2), if the current reserve electric quantity of the i th BESE is insufficient, P_{Ri}^+ will be less than or equal to 0. This indicates that the BESE does not participate in power discharging regulation, and then the BESE will avoid being over-discharged.

(2) In each control cycle, if $\Delta P_{W-PV-B} < 0$, the BESS should be charged, and the charged power of each BESE is also obtained from (1), but the participation factor P_{Ri} is obtained from expression (3).

$$P_{Ri}^- = \frac{W_{g \max}^i - W_g^i}{\sum_{j=1}^n (W_{g \max}^j - W_g^j)} \quad (3)$$

In (3) $W_{g \max}^i$ is the upper limit of the reserve electric quantity.

From (3), if the current reserve electric quantity of the i th BESE is adequate, P_{Ri}^- will be less than or equal to 0. This indicates that the BESE does not participate in power charging regulation, and then the BESE will avoid being over-charged.

3.3 The Control Strategy of SOC for Battery

Currently, as the prediction accuracy of wind power is relatively low, and solar-power forecasting system is not yet mature, the power generation schemes according to the prediction are often beyond the power regulating ability of BESS, and may make the BESS over-charge or over-discharge. This will not only cause the BESS to lose the function of smoothing the power of wind-solar, but also shorten the working life of the BESS. Therefore, it is necessary to control the SOC of the battery in the period of the dispatch. Fig. 4 shows its control strategy.

Fig. 4. The block diagram of the control strategy of the SOC of the battery.

In Fig. 4, W_B^{ideal} is the reserve electric quantity corresponding to the best SOC work area of the BESS; W_B is the actual reserve electric quantity of the BESS; T is the control cycle; P'_{ref} is the amended generation scheme. P'_{ref} is got by comparing W_B^{ideal} and W_B , and then adding to P_{ref} through proportional controller.

The SOC control changes the generation schemes from the dispatching center. When W_B is higher than W_B^{ideal} , P'_{ref} is upward, and the control reference of the power is increased, which promotes the BESS to release energy to compensate the power shortfall of the wind-solar hybrid power station and makes the work area of BESS be back to the best SOC.

When W_B is less than W_B^{ideal} , P'_{ref} is downward, and the control reference of the power is reduced, which promotes the BESS to absorb the surplus energy of the wind-solar hybrid power station and makes the work area of BESS be back to the best SOC.

4. THE LOCAL CONTROL STRATEGY OF THE BESS

The BESS is interconnected to the grid via the voltage AC/DC converter. Because the grid capacity can be considered infinitely, the output voltage of the converter is clamped to the grid voltage. Therefore, it is not necessary to control the grid voltage and frequency for the converter, but the grid current and its phase should be controlled. If the grid voltage is set to be the reference voltage, the output current

phase of the converter can accurately track the phase of grid voltage via an appropriate control strategy.

If output current of the converter flows from the BESE to the grid, the converter adopts the discharge control mode of the constant current. Using the decoupling and feed-back control principle, the output active current and the output reactive current can be controlled through a close-loop controller independently. When the battery voltage is less than the minimum of monomers, the control system immediately turns into the locked discharge power control. Thus, we can avoid the over-discharge and can effectively ensure the discharge safety. The active current and reactive current control is as shown in Fig. 5.

Fig. 5. The block diagram of the active current and reactive current controller.

In Fig.5, P_i^B is the active power of the i th BESE; P_i^{Bref} is the control reference of the active power; i_i^{Df} and i_i^{Qf} are the D and Q axis currents of AC side of the i th AC/DC converter; u_i^D and u_i^Q are the D and Q axis voltages of AC side of the i th AC/DC converter.

If output current of the converter flows from the grid to the BESE, the converter adopts the charge control mode of the constant current and the constant DC side voltage of the converter, namely double closed-loop control. The constant current control is the same as the discharge control (see Fig. 5). But, when the BESE is charged, the battery terminal voltages rise gradually, and once they rise to upper limit, the charge control of constant DC side voltage of the converter should be adopted. Using the decoupling and feed-back control principle, the DC side voltage and the output reactive current can be controlled independently. The DC side voltage and the reactive current control is as shown in Fig. 6.

Fig. 6. The block diagram of the DC side voltage and the reactive current controller.

In Fig.6, $V_i^{DC-Bref}$ is the control reference of the terminal voltage; V_i^{DC} is the terminal voltage; i_i^{Df} and i_i^{Qf} are the D and Q axis currents of AC terminal of the i th AC/DC converter; u_i^D and u_i^Q are the D and Q axis voltages of AC terminal of the i th AC/DC converter.

5. CONTROL CAPABILITY EVALUATION

To evaluate the effectiveness of the proposed control strategy, the WSBHGS whose rated power is 15MW is interconnected to a single machine infinite bus (SMIB) system. In the WSBHGS, the BESS whose rated power is 5MW is made up of two BESEs, and the rated charge capacity of each BESE is 1000kWh. The best SOC of each BESE is 20-80%. The configuration of the WSBHGS is shown in Fig. 1.

Firstly, simulations are carried out to simulate the dynamics of the WSBHGS when its power generation schedule is 10MW. The dynamics of the active power of the WSBHGS is shown in Fig. 7. From Fig. 7, it can be seen that during the simulation time, the output power of the wind-solar hybrid generation station fluctuates from about 5MW to 15MW, but through the BESS absorbing or releasing energy, the output power of the WSBHGS can closely track the power generation schedule and its fluctuations are less than 1%. Therefore, the output power of the WSBHGS can not only be smoothed but also be scheduled by the BESS.

Fig. 7. The curves of the dynamics of the active power of the WSBHGS.

Secondly, simulations are also carried out to simulate the dynamics of the WSBHGS when its power generation schedule is 12MW and the rated charge capacity of each BESE is only 500kWh. The dynamics of the active power of the WSBHGS using the BESS control without the control strategy of SOC for battery and with the SOC control strategy are shown in Fig. 8 (a) and Fig. 8 (b) respectively. Fig. 8 (a) shows that within the initial 40 minutes, the output power of the WSBHGS can closely track the power generation schedule through the BESS releasing energy. But later the output power of the WSBHGS is equal to that of the wind-solar hybrid generation station, because the BESS works at the over-discharge protection mode and no longer provides energy to add the power gap between the power generation schedule and the output power of the wind-solar hybrid generation station. From Fig. 8 (b), it can be seen, although

the output power of the WSBHGS can not track the power generation schedule because of the capacity shortage of the BESS, the output power of the WSBHGS can be smoothed by the control strategies with the SOC control of the BESS, which is of beneficial to the stability of grid system.

(a). Without the control strategy of SOC for battery.

(b). With the control strategy of SOC for battery.

Fig. 8. The curves of the dynamics of the active power of the WSBHGS using the BESS control.

6. CONCLUSIONS

In the paper, the BESS has been applied to smooth the output active power and improve the schedulability of the WSBHGS, and the control of the BESS is the key element in realizing that goal. Therefore, the control architecture and the control strategies of the BESS are researched and proposed. Meanwhile, the control strategies are tested by simulation. The simulation results show that the BESS with the proposed control strategies can make the output power of the WSBHGS become smooth and track closely the power generation schedule, if the power generation schedule is within the range of the output power of the WSBHGS. From the simulation results, it also can be seen that if the power generation schedule is beyond certain range, the BESS with the control strategies proposed can smooth the output power of the WSBHGS yet, and the fluctuations of the output power of the WSBHGS are smaller than that of the wind-solar power station, which is beneficial to the stability of grid system.

Acknowledgement: This work was supported by the National Mega-Projects of Science Research for the 11th Five-year Plan of China (No.2008BAA13B06), the National Natural Science Foundation of China (No.60974036, 61074100), and the Doctoral Fund of Ministry of Education of China (No.20090092110020).

REFERENCES

- Abbey, C., Strunz, K., and Chahwan, J. (2007). Impact and control of energy storage systems in wind power generation. *Proceedings of the 4th Power Conversion Conference*, 1201-1206, Nagoya, Japan.
- Azmy, A.M., and Erlich, I. (2005). Impact of distributed generation on the stability of electrical power system. *IEEE Power Engineering Society General Meeting*, 1056-1063, San Francisco, CA, United States.
- Barton, J.P., and Infield, D.G. (2004). Energy storage and its use with intermittent renewable energy. *IEEE Trans on Energy Conversion*, 19(2), 441-448.
- Boyles, J. D., and Clark, N.H. (2000). Technologies for energy storage: flywheels and superconducting magnetic energy storage. *Proceedings of 2000 IEEE Power Engineering Society Summer Meeting*, Vol. 3, 1548-1550, J Seattle, WA, USA.
- Erlich, I., Rensch, K., and Shewarega, F. (2006). Impact of large wind power generation on frequency stability. *IEEE Power Engineering Society General Meeting*, Montreal, Canada.
- Gao, Z.H., Teng, X.L., and Zhang, X.B. (2010). Solution of active power dispatch and control scheme for interconnected power grids with large-scale wind power integration. *Automation of Electric Power Systems*, 34(17), 37-41.
- Hochheimer, J. P. E. (2006). Wind generation integration & operation-technical challenges/issues. *IEEE Power Engineering Society General Meeting*, Montreal, Canada.
- Kobayashi, K., Goto, M., and Wu, K. (2003). Power system stability improvement by energy storage type STATCOM. *Proceedings of 2003 IEEE Bologna Power Tech Conference*, Bologna, Italy.
- Sun, Y.Z., Wu, J., and Li, G.J. (2007). Influence research of wind power generation on power systems. *Power System Technology*, 31(20), 55-62.