WIND GENERATION RAMPING COORDINATED CONTROL

Yongzhi Qi, Yutian Liu

Key Laboratory of Power System Intelligent Dispatch and Control of Ministry of Education (Shandong University), Jinan 250061, China

Keywords: wind generation ramping; ramping control; wind generation automatic generation control; joint power generation unit

Abstract

This paper proposes a ramping coordinated control strategy which considers the temporal and spatial difference of wind farm group and the AGC ability of wind farms. According to certain grouping principles, wind farms in wind farm group are divided into several joint power generation units, to which the dispatching centre distributes its scheduling plan, while wind farms in each joint power generation unit coordinate to split the dispatching plan. In order to improve the control ability of wind farms, a new kind of wind generation automatic generation control strategy is proposed in which response speed is promoted. Simulation results show that the proposed strategy can improve the output characteristics of wind power.

1 Introduction

Wind ramping, the event that wind power changes in short time and large scale, can cause great impact to the power system safety and stability, as well as power balance [1,2,9]. The wind ramping can be dealt with by the regulation of conventional units which will increase the operation cost of conventional cost and reduce the efficiency of power system. In order to reduce the pressure of conventional unit and the harm of the wind ramping, research on the coordination control among wind farms is urgent to develop.

As wind farm group has a wide distribution area, wind farms in this group have great output differences in time and space dimension. The complementary output of wind farms has laid a good foundation for the coordination control among wind farms [15]. The wide area also reduces the wind power forecast error, makes the system scheduling plan more reasonable and easier to be completed.

Advanced doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG) have quick regulation below the maximum power and better control performance to track the reference instruction, which technically increase the possibility for wind farm to participate in automatic generation control (AGC) [5,6,4,12].

Currently the main control methods of wind farms are output limitation control, smooth control, ramping rate control and automatic generation control [14,10,3,13,11]. Jiuquan wind power base in northwest China mainly adopts the output limitation control [15, 16], in which the wind farms hold their output power below the output limitation scheduled by the dispatching center. Through this method, wind farms can be involved into system dispatching. However, wind farms with good potential cannot be fully used to cope with wind ramping and this method limits the output power of wind farms that have better wind speed condition and control performance.

Considering the temporal and spatial difference of wind farm group output and the AGC ability of wind farms, a ramping coordinated control strategy is proposed. According to certain grouping principles, wind farms in the group are divided into several joint power generation units, to which the dispatching center distributes its scheduling plan, while wind farms in each joint power generation unit coordinate to split the dispatching plan. In order to improve the control ability of wind farms, a new kind of wind generation automatic generation control strategy is proposed in which response speed is promoted. This method can improve the output characteristics of wind power and develop the control potential of wind farms which have better control performance.

2 Ramping coordinated control strategy

In order to improve the output power characteristics of wind ramping, the ramping coordinated control strategy is presented. Considering the temporal and spatial difference of wind farm group output, wind farms are divided into different joint power generation unit to be given a more reasonable scheduling plan. Considering the control ability of advanced wind turbines and the characteristics of wind ramping, a new kind of automatic generation control strategy is proposed. Through joint power generation unit and automatic generation control strategy, the coordination between different wind farms is realized.

2.1 Ramping coordinated control method

The dispatch centre formulates scheduling plan for the joint wind power generation unit according to wind prediction and the load of power system[7]. The joint wind power generation unit gets the output regulation of wind farms according to the scheduling plan and real-time output power, and at the same time formulates the maximum ramping rate according to the requirement of power system[8]. Wind farms respond to output regulation immediately based on wind speed and send regulation error to joint power generation unit. Figure 1 shows the flowchart of coordinated control.

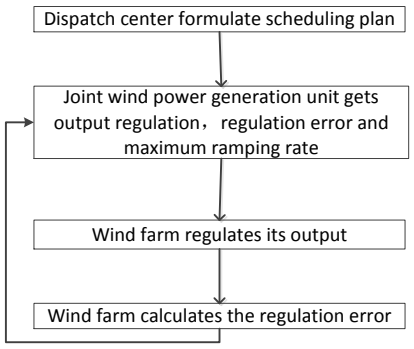

Figure 1: Flowchart of coordinated control

In the process of control, in order to avoid excessively low output of wind farms, leading too much tripping and reducing self-regulation speed, the minimum technical output is set up, below which wind farms can refuse to regulate[17].

2.2 Joint power generation unit

Wind farms grouping has several schemes, the main three are as follows.
Scheme 1. Wind farms that aggregated into one bus station formed as a joint wind power generation unit, shown as Figure 2.

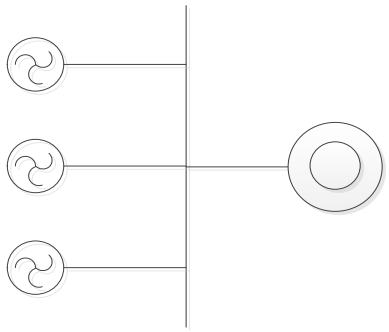
Figure 2: Wind farms that aggregated into one bus station

This kind of grouping is simple, easy to dispatch the scheduling orders, convenient for power system to check the information such as the limits of power delivery and consider the system operating status.
Scheme 2. Wind farms that have lower output correlation formed as a joint wind power generation unit, shown as Figure 3.

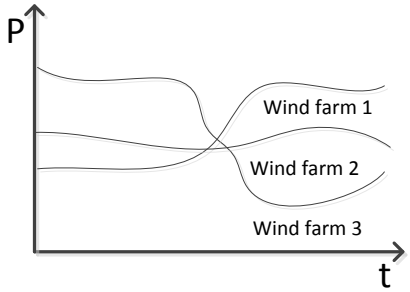

Figure 3: Wind farms that have lower output correlation

This kind of grouping analyses the past output characteristics of wind farms in a unit according to historical data, chooses the wind farms which have lower output correlation, improves the output complementarity, so as to improve the completion of the scheduling orders.
Scheme 3. Wind farms that have the same state classification formed as a joint wind power generation unit, shown as Figure 4.

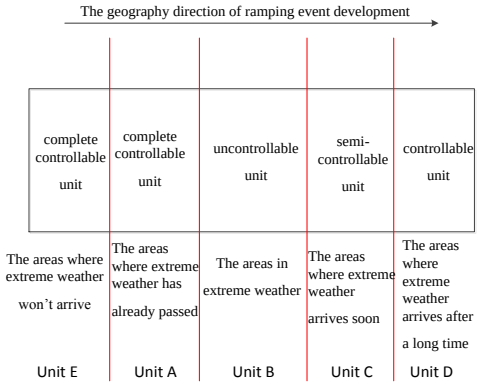

Figure 4: Wind farms that have the same state classification

This kind of grouping divides wind farms through unit state classification. Wind farms in the same state have similar control performance and output characteristics, competition between which can be more fairness.
In the proposed ramping coordination control strategy, scheme 1 and scheme 3 are combined to get a composite grouping, because that unit classification is based on the developing direction of meteorological conditions, leading to higher probability of that wind farms aggregated into one bus station also have the same state classification. Through unit state classification, wind farms that have similar control performance and output characteristics are divided into one group, then, in this group, wind farms aggregated into one bus station can be selected, which fully develops the advantage of both scheme 1 and scheme 3.

3 Wind generation automatic generation control strategy

In order to improve the control ability of wind farms, a new kind of wind generation automatic generation control strategy is proposed in which response speed is promoted. Different coordinated control method is presented according to wind speed, in which wind speed is divided into two type——low wind speed and high wind speed based on rated wind speed.
In low wind speed, optimal output of wind turbine is estimated first and execution wind turbine of wind farms is chosen based on optimal output and current output.
In high wind speed, wind turbine control method presented is different from traditional control method based on variable-pitch control. Variable-speed control is introduced in high wind speed in order to improve the response speed. Execution wind turbines are chosen on the basis of the relationship of current rotation speed and upper or lower rotation speed
The followings are given the detailed wind generation automatic generation control strategy.

The wind turbines output power P_e consists of two parts: the mechanical energy P_{mech} captured directly from wind energy and the kinetic energy P_{rotor} from the variation of rotor.

$$P_e = P_{mech} + \Delta P_{rotor} \quad (1)$$

The wind farm's regulation is calculated from the following equation:

$$\Delta P_f = \sum_{i}^{N} \Delta P_i \quad (2)$$

where ΔP_i is the regulation of wind turbine i.

In the strategy, the control aims are to reduce the number of execution wind turbine in order to reduce the control price. The control objective is shown as equation (3):

$$\min \quad N \quad (3)$$

In low wind speed, when the wind farms intend to increase its output power, the regulation of wind turbine i is calculated by the following equation.

$$\Delta P_i = P_{mech}(\omega_{opt}, 0) + \Delta P_{rotor}(\omega_{opt} - \omega_0) - P_{mech}(\omega_0, \beta_0) \quad (4)$$

where ω_{opt} is the optimal rotor speed; ω_0 is the initial rotor speed; β_0 is the initial pitch angle.

When the wind farms intend to decrease its output power, the regulation of wind turbine i is calculated by the following equation.

$$\Delta P_i = P_{mech}(\omega_{\max}, 0) + \Delta P_{rotor}(\omega_{\max} - \omega_0) - P_{mech}(\omega_0, 0) \quad (5)$$

where ω_{max} is the upper rotor speed.

In high wind speed, the optimal rotor speed is larger than the upper rotor speed, and wind turbine operates around upper rotor speed (point C), as shown in Figure 5. In this situation, the variable-speed control cannot come into role and the output of wind turbine can be regulated only by variable-pitch control which decreases the response speed of wind turbine. In order to improve the response speed, a new control method in high wind speed in presented. The operation point is moved from point C to point D, in order to give the wind turbine the up and down regulation space. Through this strategy response speed is promoted in high wind speed.

Based the control method presented in high wind speed, the followings give the way to determine the regulation of wind speed.

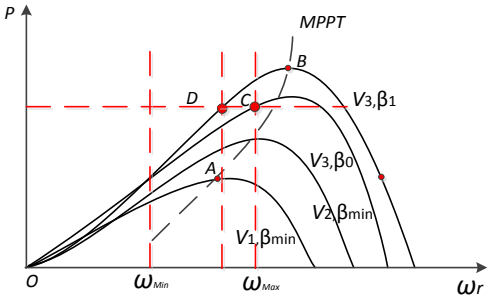

Figure 5: Variable-speed control scheme in high wind speed

When the wind farms intend to increase its output power, the regulation of wind turbine i is calculated by the following equation.

$$\Delta P_i = \min\{P_{mech}(\omega_{\max}, \beta_0) + \Delta P_{rotor}(\omega_{\max} - \omega_0) - P_{mech}(\omega_0, \beta_0), P_{\max} - P_{mech}(\omega_0, \beta_0)\} \quad (6)$$

When the wind farms intend to decrease its output power, the regulation of wind turbine i is calculated by the following equation.

$$\Delta P_i = P_{mech}(\omega_{\min}, \beta_0) + \Delta P_{rotor}(\omega_{\min} - \omega_0) - P_{mech}(\omega_0, \beta_0) \quad (7)$$

4 Simulation

The simulation contains three wind farms. Each wind farm has an installed capacity of 198MW. The initial output power of wind farms is 170MW and in the end it reaches around 20MW. The technical output power of wind farms is 10MW and the forecast error of wind generation is 10%.

The maximum power point (MPP) and forecast power of each wind farm and joint power generation unit is shown in Figure 6 and Figure 7 separately. According to wind forecast power and the operation states of power grid, dispatching centre makes scheduling plan of joint power generation unit. The joint power generation unit calculates the total power regulation and basic regulation and sends them to wind farms. The three wind farms respond to power regulation actively as shown in Figure 8. At the beginning of wind ramping, every wind farm has a certain reservation and can increase its output power as quickly as possible which makes the output of joint power generation unit in accordance with scheduling plan. At the time point of 100 second, the output power of wind farm 1 falls rapidly and largely which makes the joint power generation unit new power regulation, but the wind farm 2 and wind farm 3 still have reservation and they coordinate with each other to regulate their output immediately. Through coordination, it guarantees that the output of joint power generation slightly differs from the scheduling plan as shown in Figure 9.

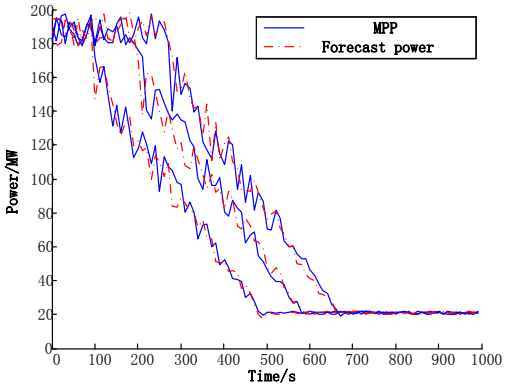

Figure 6: MPP and forecast power of wind farms

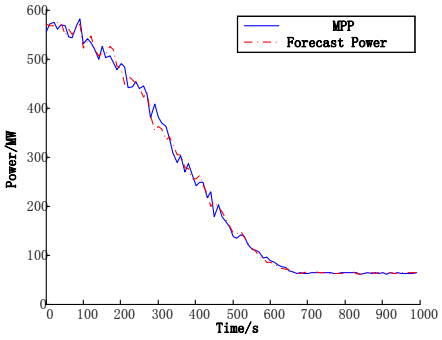

Figure 7: MPP and forecast power of joint power generation unit

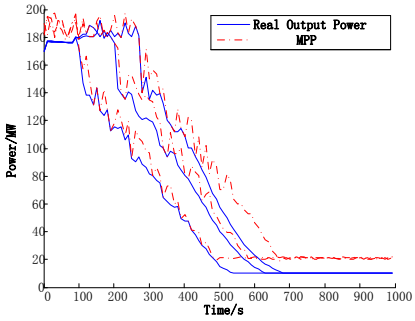

Figure 8: MPP and real output power of wind farms with control

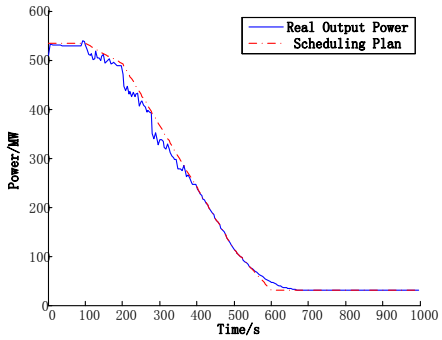

Figure 9: Scheduling plan and real output power of joint power generation unit with control

5 Conclusion

This paper proposes a ramping coordinated control strategy. According to certain grouping principles, wind farms in wind farm group are divided into several joint power generation units, to which the dispatching centre distributes its scheduling plan, while wind farms in each joint power generation unit coordinate to split the dispatching plan. In order to improve the control ability of wind farms, a new kind of wind generation automatic generation control strategy is proposed in which response speed is promoted.The simulation results shows that the proposed coordinated control strategy can well improve the characteristics of wind generation and make the wind farms respond to dispatching plan from power grid actively. Wind generation automatic generation control strategy promotes the response speed of wind farm to guarantee the wind farm to respond to scheduling plan.

Acknowledgements

This work was supported by Project Supported by National Basic Research Program of China （ 973 Program ）（2012CB215101）

References

[1] Greaves B, Collins J, Parkes J, et al. “Temporal forecast uncertainty for ramp events”, *Wind Engineering*. **33**, pp. 309-319 (2009)

[2] Ferreira C, Gama J, Matias L, et al. “A survey on wind power ramp forecasting”, Argonne National Laboratory (ANL), (2011).

[3] Hansen A D, S O Rensen P, Iov F, et al. “Centralised power control of wind farm with doubly fed induction generators”, *Renewable Energy*, **31**, pp. 935-951, (2006).

[4] Feng Yuchang, Teng Xianliang, Tu Liqun. “Real-time calculation of regulation speed and regulation precision on AGC software”, *Automation of Electric Power System*, **28**, pp. 75-77. (2004).

[5] Gao Zonghe, Teng Xianliang, Tu Liqun. “Hierarchical AGC mode and CPS control strategy for interconnected power systems”, *Automation of Electric Power System*, **28**, pp. 78-81, (2004).

[6] Gong Chenxiong, Yao Jiangang, Yang Xiangui, ea al. “Evaluation method of auxiliary service examination and compensation of AGC units”, *Proceedings of the CSU—EPSA*, **23**, pp. 137-141, (2011).

[7] Tande J O G, Korpås M, Uhlen K. “Planning and Operation of Large Offshore Wind Farms in Areas with Limited Power Transfer Capacity”, *Wind Engineering*, **36**, pp. 69-80, (2012).

[8] Kasem A H, El-Saadany E F, El-Tamaly H H, et al. “Power ramp rate control and flicker mitigation for directly grid connected wind turbines”, *Renewable Power Generation, IET*, **4**, pp. 261-271. (2010).

[9] Freedman J, Markus M, Penc R. “Analysis of West Texas wind plant ramp-up and ramp-down events”, AWS truewind (2008)

[10] Rodriguez-Amenedo J L, Arnaltes S, Rodriguez M A. “Operation and coordinated control of fixed and variable speed wind farms”, *Renewable Energy*, **33**, pp. 406-414, (2008).

[11] Rodriguez Amenedo J L, Arnalte S, Burgos J C. “Automatic generation control of a wind farm with variable speed wind turbines”, *IEEE Transactions on Energy Conversion*, **17**, pp. 279-284, (2002).

[12] Jaleeli N, Vanslyck L S. “NERC's new control performance standards”, Power Systems, *IEEE Transactions on*, **14**, pp. 1092-1099, (1999).

[13] Qiao Ying，Lu Zongxiang. “Wind Farms Active Power Control Considering Constraints of Power Grids”, *Automation of Electric Power System*, **33**, pp. 88-93, (2009).

[14] Senjyu T, Tokudome M, Uehara A, et al. “A new control methodology of wind farm using short-term ahead wind speed prediction for load frequency control of power system”, *PECon 08*, pp. 425-430, (2008).

[15] Xiao Chuangying，Wang Ningbo，Zhi Jing，et al. “Power Characteristics of Jiuquan Wind Power Base”, *Automation of Electric Power System*, **34**, pp. 64-67,(2010).

[16] Xiao Chuangying, Wang Ningbo, Ding Kun, et al. “System Power Regulation Scheme for Jiuquan Wind Power Base”, *Proceedings of the CSEE*, **30**, pp. 1-7, (2010).

[17] Zou Jianxiao, Li Dan, Zheng Gang, et al. “An Active Power Control Scheme for Wind Farms Based on State Classification Algorithm”, *Automation of Electric Power System*, **35**, pp. 28-32, (2011).