Real-time Dispatching and Coordinated Control of Large Capacity Wind Power Integration

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Abstract: Currently, conventional energy generators implement Automatic Generation Control (AGC) to regulate active power disturbance of power system attribute to wind power fluctuation after large capacity wind power integrated into grid. As an auxiliary means, wind farm would follow wind power schedule, adjust output plan in short-term and adopt emergency control in order to reduce the effect of wind power fluctuation on system stability and security. The performance of power system Peak load regulation and frequency control is increasingly affect by wind power's 'peak-valley reversal' and high ramp rate, especially in high wind power penetration area. Therefore, it is necessary to improve and optimize power system active power dispatching strategy and AGC strategy to advance system admitting wind power ability. This article analyzes influence after large capacity wind power integrating on system active power dispatching and control first. Then, a real-time dispatching strategy is proposed which contains regulation volume distribution strategy and active power balancing model to resolve deviation of wind power output from wind power prediction in order to satisfy system real-time active power regulation requirement in operation. In the meantime, dispatching centre should properly utilize system regulation resource and acquire forecast information of wind power fluctuation in certain period of the future to reduce AGC adjusting pressure in regulating system unbalance between load and generation. Real-time dispatching Furthermore, coordinated control strategy between real-time dispatching of AGC is proposed to solve real-time dispatching order conflict to AGC order in operation and AGC regulation volume insufficiency. The approach and strategy are serving wind power reasonable integration and secure and stable operation of power system.

Keywords: Wind power integration, real-time dispatching, coordinated control, active power control

1 Introduction

In the background of energy supply increasing tension and environment degradation, wind power generation with the most mature generation technology and the most promising developing in the scale, is on the list of developing priority in most countries of the world. Wind power gradually becomes an important component of electricity production with the environmentally friendly manner. Wind power's fluctuation, intermittence and less controllability increase difficulty of system operation, dispatching and control. China wind power is developing in 'large-scale and centralized integration, long distance and high voltage level transmission' measure, which incurs region penetration rate increasing significantly and integration difficulty. Therefore, it is necessary to advance flexibility of system dispatching and control to promote system ability of handling complex situation.

Research mainly concentrates on two aspects in dispatching and control after large-scale wind power integration: operation and control of wind turbine or the whole wind farm in wind farm level; optimal decision of active power dispatching in system level. The former is to promote wind farm controllability achieved by fully utilizing active power regulating ability of wind turbine and installing energy storage device to decrease the influence of wind power fluctuation. The latter is to improve dispatching approach of resource to adjust system disturbance achieved by fully utilizing conventional energy of interconnected electrical network and expanding power and electricity balancing region. The two above study aspects have developed and achieved some research results to a certain extent.

Wind turbine adopts torque control and pitch angle control to realize wind generator active power limiting control and output fluctuation restrictions, which further to implement power reserve and incorporate into system primary frequency control [10, 11]. After large-scale wind power integration, wind power tracking schedule first and frequency control as supplementary in system dispatching and control framework. A centralize control model coordinates interconnected networks and optimal dispatching method to reasonable admit more wind power. Considering China present situation, the hierarchical coordination control model aims at centralized control as transition between present system and the final system [3]. Wind farm tracks the secure area cure for wind power plant's active power determined by wind prediction, load prediction, tie-line plan and system security constrains [5]. Short-term adjustments and sufficient liquidity in spot and intraday markets are necessary for

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large amount of wind power absorb [15]. For increasing wind power penetration in several Europe countries, well functioning balancing markets containing market incentive and risk balance will reasonably control wind power integration cost and decrease active power balancing press [17, 18].

Present researches are mainly on operation areas coordinate of interconnect network and optimal resource dispatching to improve system response to wind power fluctuation and system disturbance. This paper illustrates necessity of real-time dispatching for high wind power penetration area and analyzes active power allocation strategy and balancing method of real-time dispatching first. Then proposes real-time dispatching and AGC coordinate strategy to solve conflict between real-time dispatching command and AGC command in frequency resume period after system disturbance and restore AGC regulation volume by transfer regulation volume to real-time dispatching generators after disturbance regulation and frequency resume to normal.

2 Real-time dispatching strategy

After large-scale wind power integrating into grid, traditional active power dispatching and control scheme could not properly satisfy system active power regulation requirements. Given that, the variability and limited predictability of wind generation, former dispatching and control scheme should add short term and ultra-short term wind power prediction to minimize wind power uncertainty influence. Wind power prediction accuracy is gradually improving with prediction time scale becoming short.

For advancing system ability on handling complex situation, first and foremost is to improve relative parts of existing dispatching and control scheme using wind power prediction technology; real-time dispatching adjusts deviation between different time-scale wind prediction in 5min~15min cycle by mean of coordinating thermal power and hydropower for operation security, stability, economy and fair. AGC control eliminates unbalance and adopts security corrections control to guarantee system security and power quality. Real-time dispatching and AGC coordinated control could avoid adjust commands reverse and be compatible with each other.

2.1 The impact of large-scale wind power integration on system operation and control

China wind power develops in “large-scale centralize integration” model, other than most Europe countries’ “distributed integration, distributed admit” model. Therefore, China wind power integration and transmission are more inclined to restrict by transmission section, system reserve for peak load regulation and frequency control, etc. The main impacts of large-scale wind power integration could be summarized as follows:

(1) System reserve is required to be notably increase for wind power admitting. Many conventional generators operate inefficiently and adjust frequently which affect system operation cost seriously.

(2) Large wind power fluctuation incurs system active power supply fluctuation that further influences power flow and interconnect grid power supports fluctuating in large range. Despite deficiency or surplus of supply is made up, system security and stability problem would emerge such as transmission line, tie-line overload or transmission section exceeding restricts.

(3) Day-ahead generation schedule and AGC formed dispatching and control scheme could properly satisfy grid active power regulating requirements now. After large-scale wind power integration, former extensive scheme could not properly obtain precise wind power information. Real-time dispatching using wind power prediction could make schedule matching actual grid situation and reduce AGC adjusting pressure in regulating system unbalance.

2.2 Real-time dispatching strategy

Real-time dispatching main task is to adjust deviation between short term and ultra-short term of wind power prediction and allocate regulating volume to conventional generators. Real-time dispatching based on modified day-ahead and intra-day schedule admits predictable part of wind power.

The required real-time generators regulation volume can be calculated by

$$\sum_{j=1}^{n} \Delta P_{Gj} = \Delta P_L + \Delta P_T - \Delta P_{WG} - \sum_{i=1}^{m} \Delta P_{Gi} \tag{1}$$

ΔP_L is deviation correction of different time-scale load prediction; ΔP_T is tie line exchange flow difference to tie line exchange plan; ΔP_{WG} is deviation between ultra-short term and short term of wind power prediction; ΔP_{Gi} is generator output deviation from generation schedule.

The above regulating volume adds to day-ahead or intra-day schedule concluding the real-time dispatching schedule to maintain system active power balancing restricts. Moreover, there should consider other system restricts such as transmission section increment, generator-regulating limits, generator output limits and transmission flow restricts. Figure1 describes the main deviation source.

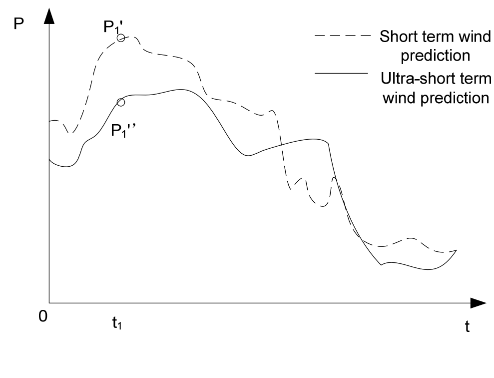

Figure 1 Short term and Ultra-short term of wind power prediction

(1) Allocation strategy based on day-ahead schedule

Allocation of regulating volume confirms by weighing coefficient initially and then adopts regulating according to day-ahead schedule first other allocation strategy as auxiliary.

The allocation strategy follows baseline day-ahead schedule. While system requires increase output, generator whose output below schedule increase in priority or undertakes more regulating volume. While system requires decrease output, generator whose output above schedule decrease in priority or undertakes more regulating volume. The strategy could be describe by

(a) System increase output $\Delta P_L>0$, generator qualification $P_{i,d}(t+1)-P_i(t)>\varepsilon$ ($\varepsilon>0$), allocation factor: $\alpha_i=\dfrac{P_{i,d}(t+1)-P_i(t)-\varepsilon}{\sum_{i\in\Omega}(P_{i,d}(t+1)-P_i(t)-\varepsilon)}$;

(b) System decrease output $\Delta P_L<0$, generator qualification $P_{i,d}(t+1)-P_i(t)<-\varepsilon$ ($\varepsilon>0$), allocation factor: $\alpha_i=\dfrac{P_{i,d}(t+1)-P_i(t)+\varepsilon}{\sum_{i\in\Omega}(P_{i,d}(t+1)-P_i(t)+\varepsilon)}$.

where $P_{i,d}(t+1)$ and $P_i(t)$ stand for the generator day-ahead schedule in time of $t+1$ and generator actual output in time of t, respectively.

Generator output schedule in real-time dispatching is

$$P_{i,p}(t)=P_{i,d}(t)+\Delta P_{Gi}=P_{i,d}(t)+\frac{\alpha_i}{\sum_{j=1}^{n}\alpha_j}\sum_{j=1}^{n}\Delta P_{Gj} \quad (2)$$

If regulating volume of generator is less than regulating dead band, this allocation will not deliver to this generator. While generator adjustment could not fulfill regulating requirement, decrease coefficient ε to increase number of generator incorporating into regulating unbalance.

(2) Allocation strategy based on generator clusters

According to amplitude of regulating volume, real-time dispatching chooses the regulating generator cluster. The adjustment priority of generator cluster is local resource first in principle, fully utilizes high quality regulating resource in neighboring network to admit wind power disturbance quickly. The generator clusters can be described below:

(a) Prior regulating generator cluster

Thermal and hydropower generators locate in the region of wind power centralize integration or the same transmission section of wind power. In addition to hydropower generator, thermal and gas turbine generator in high quality are indirect connection to wind power transmission line. These generators regulate wind power fluctuation incurred supply variation to guarantee electricity-transporting plan. System refreshes this cluster regulating ability information including regulating velocity and regulating volume real time. If the required regulating volume exceeds this cluster regulating ability, regulating clusters expand to other clusters.

(b) Sub-prior regulating generator cluster

Generators in high quality regulating ability locate in the neighborhood region interconnect wind power region with transmission line or tie line. Large active power deficiency or surplus could be supported by interconnect network to eliminate system disturbance. This cluster regulating process should consider Transmission section restricts and tie line control model. When regulating volume is insufficiency, regulating clusters expand to normal regulating generator cluster.

(c) Normal regulating generator cluster

Generators locate in wind power region or neighborhood region, which is conventional generator tracking schedule, or wind farm with regulating ability. Generators in this cluster only engage in system active power emergency control. When system frequency exceeds upper limit, wind farm outage could be the better choice to make frequency back to normal.

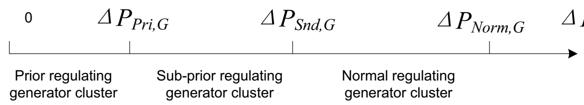

Figure 2 The regulating sequence of generator clusters

Considering transmission section restricts:

$$\sum_{i\in RD}S_{ij}\Delta P_i+\sum_{j\in NRD}\Delta P_j\le T_{L,i\max}-T_{L,i} \quad (3)$$

$$\sum_{i\in RD}S_{ij}\Delta P_i+\sum_{j\in NRD}\Delta P_j\le T_{L,igoal}-T_{L,i} \quad (4)$$

S_{ij} is sensitivity coefficients of real-time dispatching generator i to branch j. ΔP_j is non-real time dispatching generator adjustment affection to transmission section. $T_{L,imax}$ is transport upper limit of transmission section. $T_{L,i}$ is power flow in transmission section. $T_{L,igoal}$ is transport goal in transmission section.

(3) Power balancing model

Power balancing in the whole grid expands balancing range of electricity and power. Generators all gird adjust wind power fluctuation incurred disturbance, optimizes allocation method to fully utilizing system excellent resource. Interconnect grid resolves wind power fluctuation, could decrease short-term active power regulation of local grid in short term especially in region lack of regulating resource, and reduce risks of exceeding regulation volume limits and ramp limits.

Traditional provincial grids maintain active power supply and demand balance by themselves, source matching load and tracking exchange plan. Power balancing in the whole grid fully utilizes regulation resource in interconnect network and relaxes tie line transport restricts to be support by neighborhood network which could affect tie line electricity and power exchange deviate plan. Therefore, dispatching should consider tie line plan to adopt method as that promote priority of generators in less power sending (more power receiving) grid or more power sending (less power receiving) grid while output is requiring to increase or decrease.

3 Coordinated control of real-time dispatching and AGC

After large scale wind power integrate into grid, real-time dispatching introduces ultra-short term prediction of wind power to modify former schedule; thereby it could properly match to grid actual regulating situation. However, wind power and load prediction errors' ineluctable characteristics, network fault, generator outage and load sudden changes incurring disturbance could only be resorts to AGC. Coordinated control of real-time dispatching and AGC is essential in respect that the two links interact with each other in the process of dispatching and control flow.

Coordinated control of real-time dispatching and AGC includes two aspects: one is method to solve real-time dispatching order conflict to AGC order in frequency recovers process; the other is method to transfer regulating volume from AGC to real-time dispatching for AGC regulating volume recovery after frequency back to normal.

3.1 Coordinated control model of real-time dispatching and AGC

Generators with AGC function or power control governor adopt real-time dispatching orders which is transmit by AGC RTU (Remote Transmit Unit) or specified channel for dispatching order transmit. Coordinated control model includes three models as below:

(a) Real-time dispatching generators are transferred from AGC generators. Other AGC generators maintain former function.

(b) AGC generator output power comprises base power P_B from real-time dispatching and regulation power from AGC. These generators regulating scope of AGC lies in neighborhood space of base power.

(c) Active power adjustment separates regulating process base on schedule, and then groups and sorts AGC generators, finally compare priority of dynamic allocation. Generators with output above schedule are in high priority in system increase power supply; generators with output below schedule are in high priority in system decrease power supply.

The coordinated control model are coordinating in different generators, orders in same AGC generator and regulating process separately.

3.2 Coordinated strategy for real-time dispatching and AGC orders conflicts

Real-time dispatching is in accordance with ultra-short term prediction of wind power and load. Even dispatching is approaching system operation situation, the fact would cause real-time dispatching deviate from system active power regulating requirement that prediction error could not be eliminate. It is possible that dispatching and AGC order reverse or syntropy. For AGC is lagged control function, reverse between orders of dispatching and AGC influence is not obvious in minor disturbance, but reverse in large disturbance adjustment would prolong frequency recovery time and waste limited regulating source. Therefore, it is necessary to coordinate real-time dispatching and AGC regulating order to accuracy respond to system active power balancing situation, especially when ultra-short wind prediction with large error.

Real-time dispatching is opened loop schedule deliver course, which is not likely AGC closed loop control course. AGC control Area Control Error (ACE) to certain extent to meet to control performance standard, directly reflect regulation requirement of system frequency and interconnect grid power exchange. Therefore, AGC is in higher priority and not intervened in coordinated control course; modified real-time dispatching is adopted in below three conditions:

(a) In frequency recovery duration, distinguish from normal active power dispatching and control;

(b) Real-time dispatching power changing direction reversal to AGC regulating direction as the conflict symbol;

(c) Regulating extent of real-time dispatching should to be closedown with output remain, when real-time dispatching adjustment exceeds the threshold.

The reversal symbol defines as:

$$D_M = \begin{cases} 1 & \Delta P_{AGC} \cdot \Delta P_D < 0 \\ 0 & \Delta P_{AGC} \cdot \Delta P_D > 0 \end{cases} \tag{3}$$

ΔP_{AGC} and ΔP_D stand for regulating volume of AGC and real-time dispatching, respectively.

When frequency deviation $|\Delta f| > \varepsilon$, reversal symbol D_M=1, real-time dispatching adjustment $|\Delta P_D| > P_\delta$, closedown real-time dispatching with its command remain, real-time dispatching generator tracks modified schedule. Coefficient ε and P_δ are determined by grid scale or statistical operation data. If system is not accord with anyone of the three conditions, real-time dispatching implement as normal.

Real-time dispatching relieves closedown back to former schedule when AGC enters into regulation dead band.

3.3 Coordinated strategy for AGC regulating ability recovery

After AGC active power regulation, real-time dispatching modifies schedule for AGC adjustment recovery. Real-time dispatching assumes disturbance from prediction and exchange adjustment in 5minutes to 15minutes, however AGC assumes disturbance in 10 seconds to several minutes. After large-scale wind power integration, AGC undertakes large proportion in adjustment. Real-time dispatching makes allowance for guaranteeing AGC sufficient regulation volume to deal with fluctuation of wind power.

The real-time dispatching regulating volume can be described as Expression (1). $\sum_{i=1}^{m}\Delta P_{Gi}$ represents adjustment of no real-time dispatching generators. The adjustment includes adjustment of AGC generators in frequency control duration. After disturbance eliminates, adjustment of AGC gradually releases to real-time dispatching generators. The requirement regulation volume for AGC generators operating point return to maximum regulation capacity,

$$\Delta P_{Gi} = P_{Gi} - \frac{(P_{Gi,\max} + P_{Gi,\min})}{2} \tag{3}$$

P_{Gi} is real-time dispatching operating point; $P_{Gi,max}$ and $P_{Gi,min}$ represent upper and lower limits of AGC generator regulation.

Expression (3) substitute AGC generator ΔP_{Gi} in Expression (1). The strategy realizes real-time dispatching regulating system unbalance purpose. Both of the two coordinated strategies are not contradictory strategy aiming at different situation of system frequency control.

4 Conclusion

This paper illustrates the impact of large-scale wind power integration on dispatching and control. China's wind power particular developing method brings difficulty in system security and operation requiring large-scale conventional source to resolve wind power fluctuation. Then allocation methods and balancing model are to utilize excellent resource from interconnected network to eliminate disturbance quickly. Coordinated control between real-time dispatching and AGC mainly resolves commands reversal and AGC insufficient adjustment in complex situation. All above strategies and control methods supply as solution for large-scale wind power integration.

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