Research and Implementation of Rapid Load Regulation of Thermal Power Units Based on Large-scale Renewable Energy

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Abstract. Due to the anti-peaking characteristics of wind power, the power grid system needs to provide corresponding reserve capacity to cope with the fluctuation of wind power output during low valley period. It is pointed out that reasonable reserve capability is essential to secure and stable operation of grids. According to the actual demand of the power grid, the load emergency adjustment method of the thermal power unit AGC mode is proposed. The actual test results show that it can improve the contribution of the thermal power unit to the frequency modulation and peak regulation of the power grid, and quickly and effectively ensure the frequency stability of the power grid system.

1. Introduction

In recent years, China's new energy has developed rapidly, and the cumulative installed capacity of new energy ranks first in the world. The new energy output such as wind power and photovoltaic has randomness and volatility, and the large-scale consumption has always been a worldwide problem. Due to the characteristics of resource distribution, power system conditions and market mechanism in China, the elimination of new energy faces greater challenges, and the problem of abandoning wind and abandoning light has aroused widespread concern. For example, in 2015, the national new energy consumption was 223TWh, and the total amount of abandoned wind and abandoned light was 39TWh. China makes the regulation to ask full consumption new energy.

The main condition for stable operation of the power supply is that the power supply characteristics are consistent with the load characteristics, that is, the power supply is equal to the power load demand, and the maximum load of the power supply is equal to the maximum load demand. For one power system, if one wind power plant is added, in order to ensure the stability of the system, it is necessary to add a unit to maintain the balance of power balance at any time[1-3]. So far, there is no such mechanism to ensure the balance of power consumption. The original spare capacity of the grid will be reduced and the risk of grid operation will increase.

2. Operational Reserve of Power Grid

According to the power grid operation supervision report issued by the National Energy Administration, the installed capacity of wind power in Inner Mongolia etc. is large. In order to ensure the full acquisition and reliability of renewable energy, the grid reserve arrangement is large and the unit load rate is low. Due to the anti-peaking characteristics of wind power, the system needs to provide corresponding reserve capacity to cope with the fluctuation of wind turbine output during low valley period. Combined
with the large start-up mode during the winter heating period, the failure of unit failures and the increased reserve capacity of DC peaking, the spinning reserve capacity of the power grid increased significantly in winter.

The layout of spinning reserve scheme in the environment of electricity market should pay attention to both the reliability and the economy in power system operation. The current reserve capacity is divided into maintenance reserve, emergency reserve and load reserve. The total amount is about 16%-20%. When the reserve rate drops to the red line, it is impossible for the power grid to accept wind power. In addition, due to the different structure and geographical environment of each power network, there are many unadjustable factors. The heat-receiving unit is limited by thermal power, and the operation mode is relatively fixed. The power grid with large thermal power ratio has a large peak intensity of thermal power[4]. In winter, when the incoming water from hydro-power unit is low, the output characteristics become worse. It can even be said that in a system, when the scale of wind power eats the reserve rate lower than the regulations, the power cut and the wind are inevitable.

2.1. Operational Reserve Type
Operational reserve can be divided into spinning reserve capacity and emergency reserve capacity, which should be configured separately according to regulations.

Spinning reserve refers to the additional active power output of one normally running generation that maintains the rated speed and can be connected to the grid at any time, or is connected to the grid at any time but only takes part of the load. It can be used at any time and meet the requirements of load fluctuation, load prediction deviation, unexpected shutdown of equipment, etc..

Emergency reserve refers to the generation reserve capacity and load control capacity that can be started and connected in a short time. The reserve capacity of power generation shall be fully mobilized within 10 minutes and meet the constraints of the grid stability limit, and shall last for at least 2 hours or more. Load control capacity shall be in place within 10 minutes through load control means.

2.2. Spinning Reserve Principles
The implementation rules for the auxiliary service management of the regional grid-connected power plant stipulate that the spinning reserve capacity is measured by the power plant. According to the statistics difference of the unit’s peak maximum adjustable capacity and actual output value, the dispatch automation SCADA system determines the unit’s spinning reserve capacity. Among them, the value of peak period is determined by the power dispatching mechanism according to the load characteristics of each province.

For example, the spinning reserve capacity of the Northwest Power Grid should be configured according to the following principles: not less than 5% of the maximum power load of the whole network; not lower than the rated capacity of the largest single generation in the whole network; No less than the maximum power of the wind farm group centrally connected in the same region(the wind farm group with relatively concentrated geographical location, similar characteristics of wind resources, high simultaneous power generation rate); not less than the maximum power of the photovoltaic power station group with centralized access in the same area; not less than the power reduced by bipolar latching when the same DC channel is energized; not lower than the maximum power of the power plant connected through a single outgoing line (including double circuit of the same tower).

3. Thermal Power Unit Spinning Reserve Capacity Improvement
Emergency spinning reserve units are required to be able to quickly, accurately and stably improve the load of the units. Units are required to have a wider regulation space and a faster regulation rate to ensure the effectiveness of power grid load adjustment and the stability of power grid frequency[5-7]. Thermal power unit, especially steam drum furnace unit, it’s boiler has a certain capacity of heat storage, can be in a certain period of time to adjust the rate of load increase or decrease, that is to say, the unit regulation rate can exceed the grid management requirements. Therefore, the adjustment rate of thermal power unit
can be reasonably adjusted to ensure its stable operation and improve its dynamic adjustment ability of power grid frequency[8,9].

3.1. Current Management Regulations
When the thermal power unit is connected to the power grid, the control mode is generally at AGC mode. Traditional AGC in the power plant control structure is shown as figure 1. The standalone AGC commands from EMS(energy manage system) of dispatch center will be sent to RTU(remote terminal unit) of power plant, then by the RTU via I/O hard-wired to send to unit CCS(coordinated control system), to complete the adjustment task of unit's AGC system[10-12].

![Figure 1. Dispatch center control schematic diagram of a single thermal power unit](image)

Adjustment rate, adjustment accuracy and response time is three main criteria of AGC assessment. Adjustment rate K1. According to the requirement of dispatch center, in general, the adjustment rate of pulverizing system and drum boiler unit is 1.5% of unit’s rated active power, thermal power units with intermediate storage pulverizing system is 2% of unit’s rated active power, circulating fluidized bed coal-fired units is 1%. super-critical once-through boiler unit is 1.0% of unit’s rated active power.

Adjustment accuracy K2. It is the difference between the actual output of unit and the set point of EMS when unit work stably after a response, permissible deviation is 1% of unit's rated active power.

Response time K3. Response time refers to, after the EMS system send commands, the time that the output of unit reliably adjusts to across adjusting dead zone. The AGC response time of thermal power unit should be less than 1 minute.

![Figure 2. ACE and AGC correlation curve](image)

3.2. Statistical Analysis of Adjustment Interval
Taking a typical 330MW thermal power unit as an example, ACE value and AGC instruction value of the unit were extracted from the provincial regulating D5000 system. As shown in figure 2, it can be seen that in the low load range 150-210MW and the high load range 290-330MW, the frequency of the action of the final AGC command value assigned to the unit by the grid is greatly reduced, that is to say, in the part of intervals, the load command of the unit is basically unchanged or less changed. Therefore, the analysis and optimization of CCS control system should focus on the 210-290MW load interval.

4. Optimized Control Scheme Design

4.1. Increase Machine-network Coordination Signals

In order to control the deviation of the power grid according to the size of the grid ACE(area control error), the unit power should be adjusted quickly and accurately, and the interaction signal should be added between the thermal unit and power grid. Based on the ACE and frequency deviation, the total regulation power is corrected to be more suitable for CPS. Signal functions are specified as follows:

- **The unit has the ability to climb with one command.** Whether the unit has the ability to climb with one command, that is, the unit reports one switch quantity and monitors the unit's adjustment capability.

- **Unit load regulation rate.** According to the actual working condition and equipment state of the unit, the maximum load regulation rate of the unit can be reported, i.e., an analog signal is uploaded to the power grid.

- **One-key climbing instruction.** One-key climbing instruction signal is issued, i.e., one switch quantity is issued, and the unit load regulation rate is switched to the expected value of the power grid.

- **ACE instruction.** AGC instructions received by units operating in AGC mode are calculated and distributed based on the ACE of the power grid. In other words, the action direction and amplitude of units in AGC mode are determined by ACE when there is no abnormal condition.

Through the optimization control of generator turbine technology, and failure of the compensating regulator viscosity control method, weakens the dampers nonlinear characteristics and actual situation of adverse influence on the dynamic control performance, the flow of steam, fuel generating units, air, water and other main variables to obtain good dynamic performance. As shown in figure 3, by adjusting the load adjustment rate, the unit can increase or decrease the load at a faster adjustment rate within a certain period of time when the power grid have further request.

![Figure 3. Emergency load adjustment rate control logic](image_url)

4.2. Control Logic

Whether the unit has one-key climbing ability focuses on whether the main steam pressure deviation of the unit exceeds the limit, whether the main steam temperature exceeds the limit, whether the furnace
negative pressure deviation exceeds the limit, whether the drum water level deviation exceeds the limit, and whether the unit main control command exceeds the limit, at the same time, in order to fully consider the safety of the test, the operation personnel manual control is designed to determine whether a unit with one-key climbing ability.

At the same time, as shown in figure 4, for the ACE and the unit adjustment rate, the boiler main controller parameters are dynamically adjusted and optimized, the wind coal response amplitude is reasonably configured, and the main steam pressure is stabilized to ensure the AGC regulation performance.

![Figure 4. Boiler main control parameter switching logic based on ACE](image)

5. Tests and results
After the implementation of the project, the AGC performance assessment indicators issued by the dispatch control center are shown in the table 1. It can be seen that in the process of the unit's load regulation rate rising from 5MW to 9MW in the dispatching main station, although the load regulation rate increased by 80%, the regulation rate K1, the regulation accuracy K2 and the response time K3 all maintained the original level. The maximum deviation of the main steam pressure of the unit is 0.44mpa, which meets the requirement of 0.5mpa fluctuation range of the main steam pressure of 300MW class units as stipulated in DL/T774 ‘Overhaul & operate of thermodynamic automatic system in fossil fuel power plant’. Drum water level, furnace negative pressure and other important parameters are consistent with normal AGC regulation and meet the requirements of safe operation.

| Date   | K1   | K2   | K3   | Comprehensive Index | Integrated Depth | Regulation |
|--------|------|------|------|--------------------|------------------|------------|
| 10-30  | 1.200| 1.262| 1.795| 2.719              | 6494.61          |            |
| 10-31  | 1.200| 1.240| 1.788| 2.661              | 6521.18          |            |
| 11-01  | 1.200| 1.253| 1.798| 2.703              | 6824.92          |            |
| 11-02  | 1.200| 1.240| 1.783| 2.654              | 6862.20          |            |

It can be seen from Table 1 that K1 remains unchanged at 1.20, K2 fluctuates slightly, but remains above 1.24, K3 is above 1.78, and the comprehensive performance index is in the forefront level in this area power grid.

In figure 5, the running time of the unit is more than 4 hours per day, meeting the requirement of spinning reserve. It can be clearly seen from the figure 5 that with the synchronous increase of the load
regulation rate of the dispatching main station side and the power plant substation side, the Integrated regulation depth of the unit shows an upward trend. On the one hand, it can increase the economic benefits of the unit within the same time. On the other hand, it can lay a solid foundation for the emergency adjustment of the power grid and accelerate the grid frequency return to 50Hz.

6. Conclusion
According to the actual demand of the power grid, the load emergency adjustment method of the thermal power unit AGC mode is proposed. When the power grid has a power gap accident, according to the size of the value of ACE, the acceleration load adjustment working mode can be started to ensure the safe operation of the power. The thermal unit can increase or decrease the load at a faster adjustment rate within a certain period of time, and can flexibly and quickly adjust the adjustment rate of the thermal power unit, improve the contribution of the thermal power unit to the frequency modulation and peak regulation of the power grid, and quickly and effectively ensure the frequency stability of the power grid system.

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