Study on AGC Emergency Adjustment Technology of Thermal Power Units for Suppressing Power Grid Fluctuation

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Abstract. Due to the increasing scale of new energy and the increasingly close interconnection of regional power grids, higher requirements are put forward for the adjustment of active power under power grid faults. Automatic generation control (AGC) is an important function of the energy management system (EMS), it controls the output of the frequency modulation units, and keeps the system in a safe and stable operating state. By analyzing the basic principle and assessment index of AGC control, combined with AGC control process, the emergency active power control strategy of thermal power unit is proposed. By cooperating with AGC of superior dispatching, the effective suppression of power grid fluctuation is realized, which provides effective protection for grid security control.

1. Introduction
With the increasing scale of new energy and the new situation of the interconnection between the UHV power grid and the regional power grid, the power grids at all levels are increasingly closely connected. The requirements for the coordination and cooperation between the power grid and the unit are also increasingly high. Due to the volatility and intermittency of the output power of wind power and other new energy sources, the power grid needs to keep enough rotating reserve to complete the regulation of the system on the fluctuating energy in order to ensure the stable and safe operation of the power grid. The acceptable wind power capacity of the power grid mainly depends on the peak and frequency regulation capacity of the regional power grid. Considering the fast change rate of wind power output, the AGC regulation rate of the regional power grid is particularly important. At the same time, when the power grid fails, such as UHV DC single and double pole lockout and other large-scale power gap accidents, the power grid frequency will drop rapidly and greatly [1]. For example, at 21:58 on September 19, 2015, Jinsu DC double-pole blocking resulted in a loss of 5.4 million kilowatts of power, and the lowest frequency fluctuation of east China power grid was 49.563Hz, which was restored to 49.80Hz after 221 seconds. For such large-scale power gap in the power grid frequency fluctuations, the primary frequency modulation of the thermal power unit needs to be fast, and the unit is required to increase the load at a faster adjustment rate, so that the frequency can quickly return to 50Hz. The thermal power unit, especially the steam drum furnace unit, has a certain heat storage capacity, and can increase or decrease the load at a faster adjustment rate within a certain period of time, that is, the regulation rate of the unit can exceed the grid connection...
management issued by the power grid. Therefore, how to reasonably adjust the adjustment rate of thermal power units to ensure their stable operation and improve their dynamic adjustment ability of power grid frequency is a major demand for the rapid development of power grid.

2. AGC Control Principle and Assessment Index

At present, in China’s power grid structure, thermal power generation occupies the largest share of power generation capacity. Therefore, in order to ensure the safe and stable operation of the power grid, all large thermal power units are required to put into AGC function. Large thermal power units often operate in a wide load range, generally ranging from 50% to 100% of the rated load, and are required to have quick, accurate and stable response to load changes.

2.1. AGC Control Principle

The control objective of grid AGC is to control the grid frequency and the net exchange power in the control area within the allowable range through the active power output of the EMS, that is, to limit the area control error(ACE) caused by load change or power output fluctuation[2-4]. Conventional ACE calculation method is

\[ ACE_i = K_i \left( f - f_0 \right) + \left( P_{tie,r} - P_{tie,s} \right) = K_i \left( \Delta f + \Delta P_{tie,i} \right) \]  

(1)

In formula (1), \( f \) is the actual grid frequency, \( f_0 \) is the rated frequency 50Hz, \( K_i \) is the frequency deviation coefficient, \( P_{tie,r} \) is the actual tie-line power for the tie-line planning power, power to the outflow area is positive. After the large disturbance, the power generation capacity needed to be adjusted in each region satisfies the following formula

\[ \int ACE_i dt + \Delta P_i = 0 \]  

(2)

According to different control purposes, there are a variety of AGC regional control modes. At present, there are mainly three control modes are mainly used. Flat frequency control(FFC) is the main control system that maintains the system frequency constant and is suitable for independent or combined systems[5,6]. Flat tie-line control(FTC) is a subsystem that maintains constant exchange line power and is suitable for joint systems. Tie-line load & frequency bias control(TBC) is to control both the system frequency and the exchange power. With proper parameters, it can maintain the local balance of power generation and load in the control area.

2.2. AGC Assessment Index

The three main index of AGC assessment are adjustment rate, adjustment accuracy and response time. Adjustment rate is \( K_1 \). According to the requirement of grid, the adjustment rate of pulverizing system and drum boiler unit is 1.5% of unit’s rated power, thermal power units with intermediate storage pulverizing system is 2% of unit’s rated power, circulating fluidized bed coal-fired units is 1%, super-critical once-through boiler unit is 1.0% of unit’s rated power.

\[ K_i^{+j} = 2 - \frac{V_{S_{i,j}}}{V_{i,j}} \]  

(3)

\[ V_{i,j} = \frac{P_{E_{i,j}} - P_{S_{i,j}}}{T_{E_{i,j}} - T_{S_{i,j}}} \]  

(4)

In formula(3) and (4), \( v_{i,j} \) is the adjustment rate of the jth adjustment of unit i. \( P_{E_{i,j}} \) is the output power when it ends the response process. \( P_{S_{i,j}} \) is the output power when it starts to response the AGC demand. T is the AGC process time. \( V_{S_{i,j}} \) is the standard adjustment rate.

Adjustment accuracy is \( K_2 \). 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 power.
Response time is $K_3$. After the EMS system sends AGC commands, the time that the unit’s output reliably adjusts across the adjusting dead zone is the response time. The AGC response time of a thermal power unit should be less than 60 seconds, usually is 30-40 seconds.

The comprehensive performance index is $K_P$. $K_P = K_1 \times K_2 \times K_3$, which represents the overall adjustment ability of the unit’s AGC performance. The grid management department evaluates the AGC performance of the unit mainly according to $K_P$.

3. AGC Control System
AGC is one of the important measures to regulate the frequency and active power and ensure grid security and economic operation. It is mainly realized by the power regulation of the power supply.

3.1. Grid AGC
The power supply reference point of the unit is determined by the grid dispatch control center through the ultra-short-term load and wind power forecasting information in the planning process. The basis point and participation factor of each unit are the results of the planned output optimization, and the rolling optimization is performed every 15 minutes. At the same time, the ACE value is allocated to the unit in AGC mode according to certain control strategy, and the AGC unit will eliminate this part of power deviation, so as to ensure the stability of the power grid frequency[7,8]. According to the ACE, the number of units in AGC mode is limited within a certain time.

![Figure 1. Grid AGC and ACE control structure](image)

The computer system of grid dispatch center runs all the application software of the EMS, which mainly includes three parts, supervisory control and data acquisition(SCADA), real-time network analysis and grid AGC. The real-time data flow between them is shown in Figure 1. The grid AGC obtains the real-time measurement data of the grid from SCADA, and obtains the sensitivity of the network loss to the unit output from the real-time network analysis, and then obtains the unit network loss correction coefficient required in the economic dispatch, also called the penalty factor. Grid AGC obtains other sensitivity information for safety control, etc. Grid AGC also sends unit’s planning information to real-time network analysis.
3.2. Power AGC

The implementation of grid AGC depends on the response of power AGC to the control command, and the response characteristics of the unit could be influenced by many factors. When the unit work in AGC mode, the unit load demand is the sum that the value through rate limitation of AGC command and the frequency modulation. In CCS mode, the turbine control according to the bias that given value and the actual value of load to adjust can realize quick response. As shown in Figure 2, when the unit works in AGC mode, the unit demand is the grid AGC demand from the grid dispatch center EMS through the remote terminal unit (RTU).

4. Control Scheme and Application Effect

AGC control belongs to lag control. When the system frequency and tie line switching power deviate from the planned value, the AGC system issues control commands to the controllable unit according to the regional control deviation ACE, so as to restore the system frequency and tie line switching power to the original planned value. This is a process in which the grid generates an ACE and then adjusts it. Therefore, in the case of a large power gap, the unit is required to have a faster regulation rate.

4.1. Control scheme design

Under the condition of ensuring stable operation of the unit, according to the size of ACE, unit start the acceleration load modulation working mode. It can enable the unit to increase or decrease the load in a certain period of time at a relatively fast regulation rate and improve the accuracy of the unit’s response to the change of power grid frequency.

After the power grid has a power gap accident, it is determined whether the regional control deviation value exceeds the first setting range and the main steam pressure deviation value exceeds the second setting range. If the ACE value exceeds the first setting range and the main steam pressure deviation value does not exceed the second setting range, an artificial acceleration load adjustment is performed. If the ACE value does not exceed the first setting range, the load is automatically adjusted. If the ACE value exceeds the first setting range and the main steam pressure deviation value exceeds the second setting range, the load is automatically adjusted.
The first setting range is set according to the grid emergency capability, and the second setting range is set according to the power industry DL/T 657. When the power grid fails, such as UHV DC single pole lockout and other large scale power gap accidents, the ACE value of the regional power grid dispatching end will jump to a larger difference. The selection of the first setting range is based on the tolerability or emergency response capability of the grid. The second setting range can be set according to the DL/T 657 ‘Code for acceptance test of modulating control systems in fossil fuel power plant’. As is shown in the Figure 3, it is emergency load adjustment device schematic diagram under AGC mode.

4.2. Application and results

Taking a 300MW unit as an example, the regulation rate is $300 \times 1.5\% = 4.5\text{ MW/min}$, that is, the standard regulation rate set in the analog quantity generator A1 is 4.5, that is, the load regulation rate of the unit during normal AGC regulation. The upper limit H and lower limit L of HLALM are set as 0.6 and -0.6 respectively. The unit through field performance test, load regulation rate is not greater than 8MW/min, the main steam pressure and other main parameters can be controlled within the specified range, so function generator A2 is set as $8 \div 4.5 = 1.77$. When the power grid fails, the switching signal ‘on/off signal of power grid failure unit emergency mode’ sent by the power grid to the unit changes to high level 1, which makes the unit enter the mode of rapid adjustment.

| Date   | Grid AGC Regulation Rate | $K_1$ | $K_2$ | $K_3$ | $K_P$ |
|--------|--------------------------|-------|-------|-------|-------|
| 10-30  | 5                        | 1.200 | 1.262 | 1.795 | 2.719 |
| 10-31  | 6                        | 1.200 | 1.240 | 1.788 | 2.661 |
| 11-01  | 7                        | 1.200 | 1.253 | 1.798 | 2.703 |
| 11-02  | 8                        | 1.200 | 1.240 | 1.783 | 2.654 |

After the implementation of the project, the AGC performance assessment indicators issued by the grid 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 8MW in the grid dispatch center although the load regulation rate increased by 80%, $K_1$, $K_2$ and $K_3$ all maintained the original level. The comprehensive performance index $K_P$ is in the forefront level in this area power grid.
5. Conclusion
With the rapid development of electric industry, smart grids is an energy internet where energy flows from suppliers to customers. The generation of power grid interconnection will cause the ACE. How to effectively control the ACE is the key to ensure energy interconnection. For the original ACE control scheme, the study was perfect for the power grid to lay a solid foundation for frequency stability. By analyzing the basic principle and assessment index of AGC control, combined with AGC control process, the emergency active power control strategy of thermal power unit was proposed. By cooperating with AGC of superior dispatching, the effective suppression of power grid fluctuation is realized, which provides effective protection for grid security control.

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