Research on the Unit’s Control Strategy of On-line Primary Frequency Modulation

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Abstract. This paper introduces the basic principle and control structure of primary frequency modulation on the thermal power units, at the same time gives the forming method of primary frequency modulation compensation instruction. Combined with the actual power production and aiming at the actual problems of primary frequency modulation, this paper presents the flexible limiting control method of primary frequency modulation instruction and on-line automatic correction method, which can effectively improve the primary frequency modulation performance on the thermal power units and ensure the safe operation of power grid. This scheme provides reference for other units to improve the primary frequency modulation optimization.

1. Introduction
The coal-fired power generating units occupies an important place in the electric power production. With the construction of the large capacity generating units, UHV, and new energy power generating units, the frequency modulation of power grid is more and more difficult, especially in some place where has not some units with flexible frequency modulation ability, such as hydro-electric generating units and gas-fired power generating units. The coal-fired power generating units need more and more flexible frequency modulation function. However, the reality is that due to the influence of fuel quality, operating mode, power generation equipments and other factors in power production, the primary frequency modulation (PFM) performance of some units cannot achieve predetermined frequency modulation compensation, which affecting the frequency modulation capacity of the power grid.

2. Principle of Primary Frequency Modulation
When a small and periodic frequency change of the power grid happens, the coordinated control system (CCS) and DEH control system must adjust the unit’s load according to the grid frequency or turbine speed, in order to improve the power quality and the control performance of the grid frequency. The primary frequency modulation command must be added to the turbine control instruction of the coordinated control circuit and DEH valve control instruction at the same time, which can adjust the turbine output and change the unit power load in order to complete the primary frequency compensation. The typical control structure schematic diagram of PFM is shown in figure1.
3. The Main Problem of the PFM on Unit’s Operation

There are clear requirements for the primary frequency modulation capability design of coal-fired power generating units. The unit's primary frequency modulation capability is designed according to the unit's rated capacity. The dynamic response time of PFM must meet the operation requirements of the power grid. However, the PFM capability is affected by many factors, such as the fuel change and the operation mode. According to the current PFM design of the unit, when the unit is running in sliding pressure mode, especially when the unit's control valve is wide open, the unit's PFM capacity will be decreased, and the design output cannot be completed, which affects the power supply quality of the power grid.

Considering the safe operation of thermal power generation unit and ensuring the design capability of PFM is the key problem which should be solved in the design of the control system.

4. The Control Scheme of On-line PFM

The design of the control scheme can solve some main problems: First of all, the flexible limiting of PFM to ensure the unit load work in a controllable range; Second, according to the unit operation process real-time parameters, it can automatic calculate the PFM instruction, which can ensure the unit PFM output is satisfied. At the same time, it can stable the running frequency of power grid. The PFM control structure diagram is shown in figure 2.

Figure 2 The PFM control structure diagram

Notes:

L: instantaneous power load command
L0: Rated Load capacity
L1: PFM instruction upper limit
L2: PFM instruction lower limit
$\Delta f/\Delta n$: The frequency fluctuation difference/ the turbine speed fluctuation difference
$\Delta L_{\text{max}}$: PFM ideal maximum load command, $\Delta L_{\text{max}} = L_0 \times k$

\[
k = \begin{cases} 
10\% & \text{if } 0 < P_0 < 250 \text{MW} \\
8\% & \text{if } 250 \text{MW} \leq P_0 \leq 350 \text{MW} \\
7\% & \text{if } 350 \text{MW} < P_0 \leq 500 \text{MW} \\
6\% & \text{if } P_0 > 500 \text{MW}
\end{cases}
\]

$\Delta L_{\text{min}}$: PFM ideal minimum load command, $\Delta L_{\text{min}} = -\Delta L_{\text{max}}$

SUB: Subtraction module
MAX: Two input variables, the output of the large computing module
MIN: Two input variables, the output of a small computing module
MUL: Multiplication module
H/L: Limit the output value to a fixed range.

F1 (x): PFM command calculation function

According to the speed governing droop and L0, it can calculate the PFM compensation instruction. For example, the unit rated load capacity is 600MW. Its PFM control mode use DEH+CCS. According to the related technical requirements of power grid, speed governing droop is set to 5%. At same time, speed dead zone is set to $\pm 2 \text{RPM} (\pm 0.033 \text{Hz})$. The maximum compensation requirement of PFM is 6$L_0$. The set value of PFM command function is shown in table 1.

Table 1 The set value of PFM command function

| Input(x) | $\Delta n$ (RPM) | Output F1(x) | Load compensation command (MW) |
|---------|-----------------|--------------|-------------------------------|
| x0      | -150            | F1(x0)       | -36                           |
| x1      | -11             | F1(x1)       | -36                           |
| x2      | -2              | F1(x2)       | 0                             |
| x3      | 2               | F1(x3)       | 0                             |
| x4      | 11              | F1(x4)       | 36                            |
| x5      | 150             | F1(x5)       | 36                            |

The setting curve of PFC function is shown in figure 3.

Figure 3 the Setting Curve of PFC Function on 600MW Units

4.1. PFM compensation instruction limit
According to the instantaneous generation load instruction L of the unit, the upper limits L1, the lower limits L2, the PFM compensation load limit value is automatically calculated through the SUB, MAX and MIN modules to set the high and low limit value of the H/L amplitude limiting module. The operation of the power grid frequency fluctuation difference (or use the turbine speed fluctuation difference).
instead of grid frequency fluctuation) by setting function F1 (x) calculate the unit load values, the theory of PFM by H/L limiter modules guarantee system with frequency modulation is not more than the normal adjustment range, limit compensation unit primary frequency control instructions in (-ΔL ~ ΔL) between, prevent a sharp disturbance, guarantee the safe and stable operation of units.

4.2. PFM compensation On-line correction

According to the unit operation process real-time main steam pressure, the first stage pressure and the main steam temperature, it can calculate the correction coefficient of the unit PFM instructions through the F2 (x), which correct instruction of primary frequency output, ensure its PFM action under various operating conditions meet the design requirements, fixed grid frequency fluctuation as soon as possible, ensure the quality of power supply.

The control structure is implemented as shown in figure 2. The specific function F2(x) expression is as follows:

\[ F2(x) = k_2 \times \frac{P_0}{P} \times \left( 2 - \frac{P_1}{P_{10}} \right) \times \sqrt{\frac{P_0 - P}{T_0}} \]

Notes:
- \( P_0 \): Rated main steam pressure
- \( P \): Actual main steam pressure
- \( P_{10} \): Rated first stage steam pressure
- \( P_1 \): Actual first stage steam pressure
- \( T_0 \): Rated main steam temperature
- \( T \): Actual main steam temperature
- \( k_2 \): Proportional correction factor, 0.7 ≤ \( k_2 \) ≤ 1.3

5. Conclusion

Frequency stability is one of the main technical indexes of the safe and stable operation of power grid. The primary frequency modulation is the main means of correction. The reasonable control strategy of PFM on the generating units can effectively promote primary frequency control ability and ensure the quality of power supply.

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