The solution about primary frequency modulation of thermal power generating units is proposed based on the smart grid

Chang Qing Yao¹, En Ren Liu², Xiang Kun Pang³, Ying Kun Han⁴
Shandong Electric Power Research Institute, Jinan250002, China
e-mail: zaihuadianzhuce@163.com

Abstract. The performance of primary frequency modulation of thermal power generating units taking part in power grid is good or bad which may bring a direct impact on the stability of the power grid frequency. The main problem from the function of primary frequency modulation about thermal power generating units is studied in this paper, and feasible rectification solution for the pressure in front of turbine and steady-state speed regulation is proposed, which provides some technical support for vigorously developing smart grid in our country.

1. Introduction
As new energy grids, load growth and grid size continue to increase. Under the new situation of UHV grid and regional power grid interconnection, the links between power grids are getting closer and closer, and the requirements for coordination between power grids and units are getting higher and higher.

The primary frequency modulation of the generator is an necessary function of the steam turbine generator. When the grid is abnormal, by adjusting the intake control door of the DEH system and utilizing the boiler heat storage, the unit can respond quickly to the requirements of the grid and stabilize the grid frequency.

2. Analog control system of unit unit
The unit's analog control system is divided into four layers: load management center, coordinated control system, boiler and steam turbine control system, control object.

As figure 1, the main function of the load management center is to generate load commands, and accept the instructions given by the grid dispatching center or the operator. Then the actual load signals that the unit can bear are sent to the boiler and steam turbine subsystems, each subsystem issues an instruction to act on the control object.

When the frequency of the grid changes, the unit will immediately act, and the command will be sent directly to the controller. The actuator will drive the valve to complete the conversion of thermal energy to electric energy.
3. Analysis of primary frequency modulation problem of thermal power unit

Due to the inconsistency of the dynamic characteristics of the thermal power unit during operation and the change of operating parameters, the existing primary frequency control strategy cannot meet the response capability of the next frequency modulation of different parameters of the unit, resulting in insufficient or excessive adjustment of the primary frequency response.

The main reason is that the amplitude of the primary frequency modulation is a response under the rated parameters of the unit, but in the actual operation process, due to the influence of the operating parameters of the unit, the operation mode and the operating state of the boiler, the pressure in front of the turbine does not meet the corresponding requirements.

In addition, the influence of the non-linear characteristics of the DEH control value flow on the primary frequency modulation performance of the unit is often neglected. Many units fail to regularly adjust the valve flow compensation curve, which causes the steam turbine’s frequency modulation performance is nonlinear at different opening degrees. The local speed unequal rate will change accordingly, so that the actual amplitude of the primary frequency modulation is not adjusted enough or overshoot is generated, and it is difficult to balance the primary frequency modulation capability of the entire range of the load.

4. Primary frequency modulation correction on the DEH side

After theoretical research and a large number of experiments, a function is proposed to perform load compensation correction for one frequency modulation. The logic scheme adopted is as shown in Figure 2.

The primary frequency power compensation amount is corrected by multiplication with the correction function. The correction function is a function composed of the front pressure, the rated pressure and the valve flow characteristic correction coefficient. When the primary frequency modulation does not operate, the correction function performs real-time calculation according to the state of the unit. After a frequency modulation action, the following switching block 5 generates a self-holding loop, maintains the state parameters of the unit during the first frequency modulation operation, keeps the correction function unchanged, avoids a certain swing of the load, and maintains the stability of the primary frequency modulation action.
Figure 2. Power correction for primary frequency modulation on DEH side.

1-Multiplier, 2-Switch block, 3-Limiter, 4-Adder, 5-Switch block, 6-Correction function

The correction process used in Figure 2 uses the correction function \( f(x_1, x_2) \). It consists of valve flow characteristic correction factor \( \rho \), pre-turbine pressure \( x_i \) and unit rated pressure \( x_2 \).

\[
\rho = \max(\frac{\delta_i}{\delta_N}, i = 1, 2, 3, \ldots, n)
\]

\( \delta_i \): Speed unequal rate of load \( i \) segment,
\( \delta_N \): Rated speed unequal rate;

Figure 3 shows the load compensation curve for primary frequency modulation operation:

\[
\Delta P = \frac{P_c}{n_0 \times \delta_N} \times \Delta n
\]

\( \Delta P \): Power compensation,
\( P_c \): Unit rated power,
$n_0$: Rated speed.
$\Delta n$: Speed deviation,
$\delta_N$: Rated speed unequal rate;

after deal with equation correction function and the equation $(2)$, the correction command $\Delta P$:

$$\Delta P = \frac{P_N}{n_0 \times \delta_N} \times \Delta n \times f(x_1, x_2)$$

(3)

The corrected primary frequency modulation power compensation amount will be dealt with limiter, switching block and adder to form valve opening command, control the action of the control valve.

5. Engineering test under CCS+DEH
The primary frequency test should be carried out under 60%, 75%, and 90% load conditions. We select a frequency-adjusted experiment under 75% load. The unit operation mode is CCS+DEH, and the optimization scheme proposed in this paper is adopted. The test object is a subcritical unit with a rated output of 330 MW, a high-medium pressure combined cylinder, an intermediate reheating two-cylinder double-row steam condensing steam turbine, a high-intermediate cylinder with a closed-cylinder reflux structure, and a low-pressure cylinder with a two-layer split structure. The eight-stage non-adjusted regenerative extraction steam turbine has a rated speed of 3000r/min.

When the speed unequal rate is 5% and the speed difference is $\pm 12 r/min$, the power compensation amount $\Delta P=26.4 MW$ is calculated according to formula (1) without considering the primary frequency modulation dead zone.

When the speed difference is $+12 r/min$, the load reduction process curve is shown in figure 4 below.

![Figure 4. Real-time curve of some parameters about primary frequency compensation in the load-reduction process.](image)

1- Condenser, 2- Boiler outlet temperature, 3- Rotating speed, 4- Main steam pressure, 5- Unit load, 6- Steam drum water level, 7- Furnace negative pressure, 8- Valve position feedback

When load is 75%, rotating speed difference is $+12 r/min$, the experimental data is recorded as follows:

| time (s) | rotating speed difference (r/min) | Frequency difference (Hz) | Unit load (MW) | Load change (MW) |
|---------|----------------------------------|---------------------------|----------------|-----------------|
| 0       | -2                               | -0.033                    | 253.127        | 0               |
| 3       | 14                               | 0.233                     | 250.979        | 2.148 $> 0$     |
It can be seen from Fig 4 and Table 1 that during the operation of the load reduction process, the static frequency index, the dynamic index or the load variation range meet the requirements of the performance index.

When the speed difference is -12 r/min, the load lifting process curve is shown in figure 5 below.

![Figure 5](image)

**Figure 5.** Real-time curve of some parameters about primary frequency compensation in the load-increase process

1- Condenser 2- Boiler outlet temperature 3-Rotating speed 4- Main steam pressure 5- Unit load 6-steam drum water level 7- Furnace negative pressure 8- Valve position feedback

When load is 75%, rotating speed difference is -12 r/min, the experimental data is recorded as follows:

| time (s) | rotating speed difference (r/min) | Frequency difference (Hz) | Unit load (MW) | Load change (MW) |
|----------|----------------------------------|--------------------------|----------------|------------------|
| 0        | 1                                | 0.017                    | 221.198        | 0                |
| 3        | -14                              | -0.233                   | 223.998        | 2.800>0         |
| 15       | -14                              | -0.233                   | 242.660        | 21.462>ΔP*75%   |
| 30       | -14                              | -0.233                   | 247.174        | 25.976>ΔP*90%   |

It can be seen from Fig 5 and Table 2 that during the operation of the load-lifting process, the static index, the dynamic index or the load variation range meet the requirements of the performance index.

6. conclusion

The frequency performance of the grid-connected unit directly affects the stability of the grid frequency, affects the balance between the active power and the load of the power generation, causing the power grid to lose its balance and generate system frequency fluctuations. Therefore, it is particularly important to study the primary frequency modulation function of the unit and improve the performance of the unit's primary frequency modulation. In this paper, based on the frequency modulation principle of the unit and the dynamic characteristics of the unit operation, a correction formula for improving the performance of the primary frequency modulation of the unit is proposed, which has important reference significance for the improvement of the primary frequency modulation of the thermal power generation unit under the smart grid.
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