Simulation study on parameters of steam turbine governing system based on power grid stability analysis

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Abstract. Limited to the general software model of power grid stability analysis can not be changed and added, the parameter setting of steam turbine regulating system is improper, and it will be difficult to model and simulate if it does not conform to the relevant software model; moreover, improper parameter setting of steam turbine regulating system will also cause large fluctuation of generator output power in the process of unit primary frequency regulation, which will affect the stable operation of power grid. In this paper, through the simulation analysis and experimental research of the turbine governing system, the relevant control parameters are changed and optimized, so that the actual unit governing system model is consistent with the general calculation software model of power grid stability, so as to meet the technical requirements of power grid stability analysis and generator unit access to the grid; at the same time, the stability and rapidity of the unit participation in power grid primary frequency regulation are improved.

1. Introduction

Improper parameters and equipment of steam turbine regulating system will not only affect the stability of unit operation, but also easily lead to grid frequency oscillation, which can not meet the requirements of power plant and grid safe operation. Several papers have studied these problems, mainly involving the optimization of primary frequency regulation under the implementation of two detailed rules of power grid [1-3], the treatment of frequent load fluctuation and slow response of boiler regulating circuit during primary frequency regulation action [4], the realization mode of primary frequency regulation function, frequency signal accuracy, setting of speed unequal rate, valve tube of digital electro-hydraulic regulation system (DEH) relevant parameters of the management module , and prevention and cure of power grid oscillation are set to meet the requirements of grid frequency regulation and safe operation of the unit [5-8], as well as to prevent the swing of the high-voltage regulating valve [9], etc. However, there are not many researches on the parameters optimization simulation or test of the steam turbine regulating system, which meet the requirements of the grid connected operation of the generating units and combine with the calculation and analysis of the power grid stability.

2. Existing problems

For the modeling and parameter testing of steam turbine and its regulating system, the general software (BPA) model of power grid stability analysis cannot be changed or added, and the actual control model of steam turbine regulating system cannot be completely covered. For example, the
command of primary frequency control valve position to PID lag link of load controller makes the
general calculation software unable to reflect the actual control model in the simulation calculation. At
the same time, when the turbine governing system is in coordinated (CCS) operation mode, its control
cycle is about 1 s, making the regulating system become a discrete mathematical model under the CCS
operation mode. When the parameters are set improperly, the discreteness of the actual control is quite
different from the continuity of the simulation. The existence of these conditions makes not all the unit
operation modes can be simulated, which increases the difficulty of modeling and parameter testing.
During the field test, it was also found that the parameters of the regulating system were not set
properly when the unit took part in the primary frequency regulation of the power grid. There was a
large amplitude of generator power fluctuation in the process of the unit taking part in the primary
frequency regulation of the power grid. During the primary frequency regulation of a 660MW steam
turbine generator unit, the generator output power fluctuated obviously. The wave recording curve of
the generator power change during the operation is shown in Figure 1. The generator power fluctuation is
very unfavorable to the stable operation of the power grid frequency, which may become
the external inducement of the low-frequency oscillation of the power grid; for the unit, it is easy to
cause the alternating torque of the turbine and generator shaft. In order to maintain the stability of
the power grid, the safety of the generator set, and to provide the model and parameters suitable for the
calculation and analysis of the power grid stability, it is necessary to carry out the simulation and
experimental research on the parameters optimization of the steam turbine regulating system to find
effective countermeasures.

![Figure 1. Recording curve of generator power.](image1)

![Figure 2. Model of turbine governing system change during primary frequency modulation.](image2)
3. Model construction of turbine governing system

In this paper, a 660 MW unit with large fluctuation amplitude of generator output power during the primary frequency modulation operation of steam turbine generator unit is studied. Its turbine model is N660-24.2/566/566, including one intermediate reheat, single shaft, three cylinder four exhaust, double back pressure, pure condensing turbine. The turbine adopts Guodian Zhishen digital electro-hydraulic DEH regulation system. When the primary frequency modulation operation condition of the unit is in the coordinated (CCS) mode, and the grid frequency changes Δω beyond the dead zone (± 2.0 r/min), the output is divided into two ways after the speed deviation amplification factor K conversion, one way is converted by the feed-forward coefficient K₂, and then the output of the steam turbine regulating valve control command Pcv is output to make the regulating valve act quickly; the other way is converted to the success rate command through the speed deviation amplification factor K. When there is a deviation between the actual unit load and the total load command, the actual load of the unit is adjusted and converted by the load controller PID, and then the control command Pcv of the turbine governing valve is output. The two control loops work together to make the actual load of the unit consistent with the total load command. By combining feedforward and load PID, the unit can participate in the primary frequency regulation of the power grid quickness and stability after action. The specific control transfer process model structure is shown in Figure 2. In the figure, P_ref is the generator power command of CCS operation mode, and Pe is the generator power feedback value.

4. Research on model simulation of regulation system

For the model of turbine governing system shown in Figure 2, only the parameters of feed-forward system K₂ and load controller PID can be adjusted, and other parameters are determined by the characteristics of speed measuring device and generator power measuring device and cannot be changed. In order to understand the response characteristics of the model after the adjustable parameters change, the simulation calculation is carried out based on the domestic recognized power system calculation and analysis software BPA.

| Symbol | Name | Unit | data |
|--------|------|------|------|
| T₁     | Time constant of speed measurement link (dead zone of speed deviation) | S    | 0.02  |
| ε      | Standard value (relative to the unit value of system frequency, the dead zone is ± 0.5 ε) |       | 0.0013 |
| K      | Speed deviation magnification | nothing | 17.73 |
| Kₚ     | PID proportional link multiple | nothing | 0.10  |
| K₃     | PID integral link multiple | nothing | 0     |
| Delay1 | Pure delay time of frequency input signal (S) |       | 0.148 |
| Delay3 | Pure delay time of power feedback signal (S) |       | 0.0471 |
| Tₚ     | The time constant of the first order inertia link corresponding to the power feedback signal | S    | 0.6222 |

Table 1. Values of relevant parameters in the model in simulation calculation.

Take different values of feed-forward coefficient K₂ for simulation calculation, other parameters are shown in Table 1, and simulation calculation results are shown in Figure 3. The simulation curve shows that the larger the K₂ is, the more the overshoot of the generator power output in the early stage is. The K₂ can quickly reach the required primary frequency modulation power value. However, the unit load fluctuates greatly, and the stability time is too long. The smaller the K₂ is, the opposite trend is. The simulation of the influence of load controller PID parameters on the generator power is shown in Figure 4, Figure 5 and Figure 6 respectively. The feedforward system K₂ is 1.255. Because the load controller PID differential link in the turbine regulating system does not work, no research is made in the simulation. From Figure 4, it can be found that when the integral link multiple Kₚ is constant, the
larger the proportional link multiple $K_P$ is, the larger the overshoot of generator output power will be at the initial stage of grid frequency change, and even a spike will be generated, and the stability process is basically the same. It can be seen from Figure 5 that under the condition of constant $K_P$, the larger the $K_I$, the faster the generator output power can be stabilized, but at the initial stage when the grid frequency changes, the generator output power overshoot is too large. Through the above analysis, it can be found that $K_2$, $K_P$ and $K_I$ can be optimized according to the above rules, so that the generator power can reach the required regulation and be fast and stable. Figure 6 shows the simulation effect of quick and stable generator power by reducing $K_P$ and improving the optimization combination of $K_I$. 

![Figure 3](image1.png)  
**Figure 3.** Simulation of the influence of feedforward coefficient $K_2$ on generator power.

![Figure 4](image2.png)  
**Figure 4.** Simulation diagram of spike value produced by over $K_P$ of load controller PID.

![Figure 5](image3.png)  
**Figure 5.** Simulation of the influence of integral link multiple $K_I$ of load controller PID on generator power.

![Figure 6](image4.png)  
**Figure 6.** Simulation of the influence of load controller PID on generator power.
5. Parameter setting of regulating system
According to the simulation results of the turbine governing system model, the output power of the generator set can be quickly stabilized by properly reducing the feed-forward coefficient $K_2$ and $K_P$ in the load controller PID and increasing $K_I$ in the load controller PID. In order to solve the problem that the generator power fluctuates greatly when the unit participates in the primary frequency regulation of the power grid, the parameters of the primary frequency regulation of the control system are adjusted. The $K_P$ and $K_I$ in the load controller PID are adjusted from 0.45 and 0.0222 to 0.05 and 0.0666 respectively. At the same time, the feed-forward coefficient $K_2$ of the control system is reduced by changing and adjusting the control curve corresponding to the speed and valve position command. The comparison before and after the control curve adjustment is shown in Figure 7. After optimizing and improving the primary frequency modulation parameters of the control system, the corresponding test is carried out. During the test, the lag time from valve position command to load controller PID is changed from 1s to 0s. Since the general software for power grid stability analysis (BPA) GJ/GJ+ model has no lag link between valve position command and load controller PID, changing from 1s to 0s will make the actual control form consistent with the GJ/GJ+ model of BPA, so as to be suitable for power grid stability analysis and simulation analysis. After the modification, the primary frequency regulation performance of the unit is obviously improved, and the power fluctuation of the generator is obviously improved. The change curve of generator output power before and after PID setting of load controller is shown in Figure 8. By optimizing the parameters of the control system, the hidden danger of low-frequency oscillation of the power grid caused by the generator unit side is eliminated, the threat of alternating torque impact on the turbine and generator shaft is reduced, and the effective measures to deal with the generator power fluctuation in the process of primary frequency modulation performance are found.

![Figure 7. Comparison chart of control curve before and after adjustment of feedforward coefficient $K_2$.](image)

![Figure 8. Power curve of generator before and after parameter setting of PID load controller.](image)

6. Simulation and test verification after model parameters optimization

6.1. Comparison of simulation and measurement results
After the optimization and improvement of the primary frequency regulation parameters of the turbine governing system, the modeling, simulation and test verification of the turbine and its governing system are carried out. The established power grid stability analysis model and its parameters simulation fully reflect the primary frequency regulation test results of the field units. The simulation calculation is based on the domestic recognized power system calculation and analysis software BPA, and GJ, GJ+, GA, GA + and TB cards are selected for stability calculation. In BPA, a single machine infinite model is established. The parameters of generator and excitation system model are obtained from actual test and identification. The rotor inertia of turbogenerator is calculated from the measured data of 50% rated load rejection of the unit. The primary frequency regulation step-up test is carried
out for the unit under the coordinated (CCS) operation mode, and the frequency regulation reference is from 3000 r/min step to 3011 r/min. The comparison between the simulation results and the measured results of the generator output power is shown in Figure 9.

![Figure 9](image.png)

**Figure 9.** Comparison of step simulation results and measured results on coordinated (CCS) operation mode.

6.2. **Simulation error analysis**

It can be seen from Figure 9 that the trend of simulation results is basically consistent with that of actual measurement results. According to the step from 3000 r/min to 3011 r/min, the error analysis is made between the simulation results of generator power and the measured results. The comparison of maximum output increment of HP cylinder $P_{HP}$, peak power time of HP cylinder $T_{HP}$ (s) and adjustment time $t_s$(s) between the simulation results and the measured results is shown in Table 2. According to the calculation results in Table 2, the deviation is within the allowable deviation range. The simulation results reflect the action characteristics of primary frequency regulation under CCS operation mode, and the established model can be used for power grid stability calculation and analysis.

| Power closed-loop | Maximum output increment of HP cylinder $P_{HP}$ (MW) | Peak power time of HP cylinder $T_{HP}$ (s) | Adjustment time $t_s$ (s) |
|-------------------|--------------------------------|--------------------------------|-------------------|
| Measured curve    | 40.0                          | 2.189                           | 11.455            |
| Simulation curve  | 36.0                          | 2.097                           | 11.364            |
| deviation         | 11.1%                         | 0.092                           | 0.091             |
| Allowable deviation [10] | ± 30%                        | ± 0.2 s                         | ± 2 s             |

6.3. **Primary frequency modulation response analysis**

According to the analysis of primary frequency recording data, the lag time and stability time of step primary frequency response in coordinated (CCS) operation mode of the unit are 0.277s and 11.732s, respectively, which meet the requirements that the lag time of primary frequency modulation response is less than or equal to 3s, and the stability time is less than or equal to 60s; the variation amplitude of primary frequency modulation load also meets the requirements that the unequal rate is less than 5% [11].

7. **Conclusions**

Although the modeling and parameter testing of steam turbine and its regulating system are limited by the problems such as unable to change and add the general software model of power grid stability analysis, the parameters of steam turbine regulating system can be changed and optimized to make the actual unit load control model consistent with the general software model of power grid stability.
analysis, so as to meet the requirements of power grid stability analysis. At the same time, the adjustment and optimization of the parameters of the steam turbine regulating system can improve the stability and rapidity of the unit’s participation in the primary frequency regulation of the power grid, and meet the requirements of the power industry standards. Through the adjustment and optimization of the parameters of the turbine regulating system, this paper finds a remedy method to overcome the problems such as the large fluctuation of the generator output power and the lack of the general software model of the power grid stability analysis during the process of the unit participating in the primary frequency regulation of the power grid, so that the unit can participate in the primary frequency regulation of the power grid better, meet the relevant technical requirements of the power grid, and maintain the safe and stable operation of the power grid stability analysis provides accurate and reliable model and parameters of steam turbine and its governing system. When the unit is in CCS operation mode and the control period is about 1s, the control model of the turbine governing system becomes discrete mathematical model, and the parameter setting is improper, which leads to the great difference between the discreteness of the actual control model and the continuity of the simulation, the optimal control parameters can be found by combining the modeling and the actual measurement.

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