Optimize research of turbine speed governing system modeling method based on power grid stability analysis

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Abstract. The optimization idea and method for model construction and model parameters simulation was introduced which based on the general requirements of power grid stability analysis. In the process of parameter identification, a identification method based on genetic algorithm was adopted and implemented using Matlab and its simulation toolbox. Meanwhile, it introduce “turbine speed governing system collaboration curve” in order to adapt the diversity and strong nonlinear characteristics of thermal power units. From the situation of the modeling test in some thermal power generating unit, the Model parameters can satisfy the requirement of power grid stability analysis.

1. Introduction
The generator set and its control system are the most important dynamic components in the power system. The model parameters have a decisive influence on the stability calculation results. For a long time, the dynamic stability of the power system generally ignore the turbine speed governing system, the mainly reason is the old mechanical hydraulic governor have slow response and larger dead zone, it have little effect on the dynamic stability. At present, the thermal power generating units have the electro-hydraulic governor with fast response speed and high regulation precision, which can respond to the small power system disturbance. In addition, the modeling and simulation technology have also been greatly improved, can establish more accurate model, which makes it necessary to consider the modeling of speed governing system in power system stability analysis.

The modeling of turbine speed governing system based on the analysis of power system stability is a very practical application. It has its own requirements for the model structure. How to establish a speed governing system model to meet the demand of power grid stability analysis has become a current problem, this paper will focus on this research [1].

2. Key points of turbine speed governing system modeling
The calculation results of grid stability analysis will be directly applied to the grid safety assessment. Therefore, the accuracy of model parameters is the most basic requirement, and it must reach a certain accuracy before it can be used in analysis and calculation. Turbine speed governing system parameters measurement and modeling include model construction and model parameter simulation verification [2].

The construction and measurement of the model are the key points. The outstanding problems are that the model is not clear enough, the contradiction between field operability and data validity, the model construction is not meticulous.
The verification of the model parameters is to prove the model which is correct or wrong.

3. System model construction and parameter measurement method optimization

Through the theoretical analysis of the turbine speed governing system model, the typical thermal power turbine system can be divided into control system, actuator, prime mover and governor. (“Fig. 1”). The purpose of the modeling experiment is to obtain the model parameters of the three parts of the structure, and check of the link. Finally, It combine the measured results of all the parts to obtain the overall model parameters.

Figure1. Typical thermal power turbine speed governing system block diagram

3.1 Control system model construction and measuring method optimization

Due to the complex control logic of thermal power units, the control methods of different units are also different. In order to obtain accurate modeling results, we must first simplify its control logic, comprehensive understanding the key control methods and switching conditions, read carefully SAMA diagram. Focus on the main line, the normal operating conditions have nothing to do with the control links are ignored. The control system is simplified into a frame structure consisting of a delay module, a first-order inertia module, a rate limiting module and a PID module.

Secondly, due to the inconsistency between the operation formulas of PID modules of different DCS manufacturers, the PID parameters are not consistent with the actual computing results, so PID parameter calibration is necessary. That is, the PID control loop is separately set as P, I and D links, and PI, PD and PID links. Forced PID input, measured PID output. Observe whether the waveform is consistent with the set parameters, if not, you need to find the actual parameters of the PID required for modeling.

Finally, in order to test whether the control system model is accurate, the frequency modulation function verification simulation must be carried out. That is, the frequency deviation is used as the input, and the step disturbance is performed. The output of the power control is collected by the equipment. The delay module, the first-order inertia module, the rate limiting module and the PID module are connected in series to perform an overall static simulation verification to ensure that the simulated and measured deviation values are within the allowable range.

3.2 Actuator model construction and measuring method optimization

The actuator model is mainly to measure the electro-hydraulic conversion control part of the actuator, the actuator opening time constant $T_o$, the actuator closing time constant $T_c$ and the actuator limits and other related parameters.

The "black box" method is used to decouple the actuator model. That is, some of the parameters are considered as "black boxes", and the parameters outside the black box are measured, in order to achieve stepwise acquisition of the model parameters. The specific implementation method uses the actuator of large step disturbance and small step disturbance.

The large step disturbance of the actuator means that the electro-hydraulic conversion control part of the actuator is regarded as a black box (the control part does not work when the actuator is drastically moved), usually the disturbance is greater than 60%. By measuring the actuator displacement curve, to obtain the close-time constant $T_c$ and open-time constant $T_o$. Meanwhile, it can obtain the upper and lower actuator amplitude. (“Fig. 2”). When the actuator is large disturbed, it is easy to enter the non-linear area of the valve (such as valve zero position, full open limit), the
measured time is no longer the time constant for normal switching. If this happen, it is necessary to avoid the non-linear position, and only get the middle of the substantial disturbance.

![Diagram](image1)

**Figure2. Actuator decoupling block diagram (Time constants and limits)**

The small step disturbance of the actuator means that the zero, full open position limit and limit speed of the actuator are regarded as a "black box", and the actuator is slightly disturbed (usually less than 20%). Measure the actuator displacement curve, and check the electro-hydraulic conversion controller parameter. (Due to the different definition of the module parameters, the values read in the DEH valve position controller module configuration often deviate from the actual values, and small step disturbances are obtained for the true control parameters.) (“Fig. 3”)

![Diagram](image2)

**Figure3. Actuator decoupling block diagram (control parameters)**

### 3.3 Prime mover - governor model construction and measurement method optimization

Turbine prime mover-governor model construction and measurement, include construct the high pressure chamber volumetric time constant $T_{CH}$, reheater volumetric time constant $T_{RH}$, low pressure communication tube volumetric time constant $T_{CO}$ and turbine rotor ascent time $T_a$. (“Fig. 4”).

When the turbine is shut down, modify the control system configuration and apply step disturbance directly to the valve position command, make the actuator open at the fastest speed, it can obtain better data waveform and improve the accuracy of the result, it is conducive to identify model parameter.

The prime mover modeling measurement should be carried out in the turbine valve-control mode [4]. Before the measure, the unit load is more than 80%, the unit pressure should be kept steady. During the modeling measurement, the upper and lower steps of the actuator command should be triggered, cause the load change less than 3%. Measure the parameters include main steam pressure, hot re-pressure and so on. Identify $T_{CH}$, $T_{RH}$, $T_{CO}$ and other related parameters by BPA or PSASP tool-box.
The main purpose of the load dump test is to test the turbine rotor ascent time $T_a$. Since this parameter has a great influence on the dynamic characteristics of the turbine, it needs to be actually measured. However, for reasons of safety and economy, sometimes the power plant will request that the test should not be conducted and the parameters can not be directly measured. If it is, the theoretical value or approximate value can only be obtained by theoretical calculation. The calculation of turbine rotor ascent time $T_a$ can be obtained from the following formula, as in (1) and (2).

$$T_a = \frac{J\omega_0}{M}$$  \hspace{1cm} (1)

$$M \approx 9550 \times \frac{P}{n_0}$$  \hspace{1cm} (2)

- $P$ is the rated power of the turbine, kW;
- $M$ is the rated torque of the steam turbine, N•m;
- $n_0$ is the rated speed of steam turbine, r/min;
- $J$ is the moment of inertia of steam turbine, kg•m$^2$;
- $\omega_0$ is the rated angular velocity of steam turbine rotor, rad/s.

### 3.4 model parameter identification method optimization

Model parameter identification is a key part of modeling, and the identification method has a great influence on the results. Ordinary time domain or frequency domain identification method is usually adopted for identification. This method need high requirements for the test disturbance signals. It requires that the disturbance must be a step signal; it is usually cannot meet the conditions. Therefore, genetic algorithm can be used for parameter identification which does not require a high level of disturbance signal.

Genetic algorithms use the point of view of the biological population to look at problem. It regards any point in the solution space of the problem as an individual. Certain numbers of individual form a population. It simulates the biological world by defining a fitness function. Under the influence of various genetic operators, it will evolve from generation to generation, and finally obtain a satisfactory solution to the problem.

We can use Matlab and its simulink toolbox to realize the parameter identification of the speed governing system based on the genetic algorithm. The principle is as follows: First, use the simulink toolbox to create a system model with unknown parameters; then, use a genetic algorithm to obtain all of the unknowns. In this way, a model with a structure and parameters determined is obtained; Next, the excitation signal obtained from the field sampling is added to the relevant input point in the model, and the relevant output is obtained through the matlab simulation operation; The overall model error is calculated by comparing the simulation output and the actual measuring value, and then the genetic
algorithm is continuously used to optimize. Finally, the optimal model parameters with the smallest model error are obtained.

Take some power plant #2 unit as an example, a simulation speed governing model is set up (such as “Fig. 4”), which contains unknown parameters and is replaced by array element P(i). Taking the data of load disturbance test as identification data, genetic algorithm is applied to optimize and calculate the unknown parameters contained in model, and the identification results are shown in Table I. The size of the group is 50 and the evolutionary algebra is 150.

| No. | Variable name | Identification result | Variable description |
|-----|---------------|-----------------------|----------------------|
| 1   | P(1)          | 0.1033                | Actuator opening time constant To |
| 2   | P(2)          | 0.1249                | Actuator closing time constant Tc |
| 3   | P(3)          | 0.7084                | High pressure chamber volumetric time constant TCH |
| 4   | P(4)          | 0.8761                | Reheater volumetric time constant TRH |
| 5   | P(5)          | 12.4543               | Low pressure communication tube volumetric time constant TCO |

4. Model results verification method optimization

Turbine speed governing system model parameters have been identified, in order to ensure the accuracy and reliability of parameters, the model must be closed-loop verification.

When the running unit is in coordinated operation mode, the frequency disturbance test shall be carried out. The frequency disturbance should be no less than 0.15Hz and the load is not less than 5%, collect the related parameters curve such as the main pressure, load and so on. The measured parameters are used in the simulation of the unit in the BPA or PSASP, and compared with the actual parameter curve.

In view of the variability and strong non-linear characteristics of thermal power plant operation, how to accurately reproduce complex models is the main problem that should be considered in the verification. Considering the difference between the unit type, capacity diversity, a unit of the same load but the valve position at different mode (single valve, sequence valve). The results of typical turbine tests show that the steam turbine speed governing system presents a strong non-linearity. Therefore, we introduce "Turbine speed governing System Coordination Curve" (5) to modify the system model so as to adapt to the whole working conditions Frequency response of the system. ("Fig. 5")

![Figure 5. Correction of the turbine speed governing system model](image)

According to the parameter identification results shown in Table I, with reference to “Fig. 5” revised model, we verify the results. The actual data selected a curve with a disturbance load of 6%, and the time interval was 120s.

Compare results between the true generator load and the output of the simulation system (“Fig. 6”). After analysis numbers, the maximum dynamic difference between the simulation results and the true measured data is 0.541%, and high simulation accuracy is obtained, which can meet the needs of scientific research.
5. Conclusion
According to the general requirements of the power system stability calculation for the model of the speed governing system, it expounded the key points of the modeling construction and measurement. Based on this, the optimization ideas and methods of the modeling test are put forward. From the implementation of the turbine speed governing system modeling experiment in some thermal power generating unit, the above method is feasible and the model parameters obtained are accurate and reliable.

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