The Impact Research of Delay Time in Steam Turbine DEH on Power Grid

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Abstract: The effects of different link's delay time in steam turbine DEH (Digital Electric Hydraulic Control System) on electric power unit are not exactly the same. Through the analysis of the main controller of the steam turbine governor, electro-hydraulic mechanism, steam turbine and the single-machine infinity model, we establish the single-machine infinite power system with simulink. The delay time of the electric power feedback, the speed feedback, the oil actuator and the displacement sensor link in the model is changed to explore the influence of different delay times on the power output of the power system. The results show that the electric power feedback, the speed feedback, the oil actuator and the delay time of the displacement sensor will increase the overshoot of the electric power response curve and increase the time to reach the stability, but their influence degree is different, the level of influence from low to high is: speed feedback delay, electric power feedback delay, displacement sensor delay, oil actuator delay.

1. Introduction
In recent years, with the increasing demand of electric power in China, the scale of power system is becoming larger and larger, and the power transmitted on the main transmission lines is also increasing. However, the operating conditions of the whole power system are getting worse, and low-frequency oscillation occurs frequently, which has become one of the important factors that affect the safe operation of the power grid.

The inadequate ability to deal with sudden load changes is the main factor affecting the stability of the power grid, and the primary frequency can effectively solve this problem, because it can quickly suppress the frequency and power fluctuations caused by load changes under disturbance. In this way, the control level of power quality and grid frequency can be improved [1-5].

With the development of power system, more and more attention has been paid to the stability of power grid. Many factors can affect the stability of power grid, some of them not only cause power grid oscillation, but also may lead to major blackouts. In order to improve it's stability, different factors need to be further studied.

Zhang Jiawei [6] et al. Studied the effect of primary frequency modulation on isolated network control mode in high frequency condition. Dynamic simulation model of thermal power units is estab-
lished by RTDS. The simulation results show that, the lower frequency limit of primary frequency modulation can effectively reduce the maximum frequency of the isolated network. Sheng Kai [7] proposed a power control strategy based on internal model control under the existing control system conditions and the operation characteristics and characteristics of the actual unit. The simulation results show that this strategy can improve the control quality of the existing system.

Li Yanghai [8] studied the influence of turbine control parameters on power grid low-frequency oscillation from the angle of mechanical damping torque. A single machine infinite bus system model and a multi machine system model are established. This article proposed an effective parameter tuning method, which take mechanical damping coefficient as one of the evaluation criteria of power grid stability.

In addition, in various indicators of the performance of turbine control system, speed inequality, delay rate and load variation amplitude also have important influence on performance of primary frequency modulation and the transient stability of power grid.

In summary, researchers have done lot of research on the influence of power stability, whether from the grid side or the turbine side. However, there is still a lack of research results on the effect of each link's delay time of DEH system on power stability. This article established a single machine infinite integral power system model, and discussed the influence of delay time of different links on the stability of power system By simulating the delay time of each link in power frequency control mode of steam turbine DEH system.

2. Typical mathematical model of steam turbine DEH system

Digital electro-hydraulic control system (DEH) is usually used to control the power and speed (frequency) of the turbine when it's connected to the grid. The speed difference is obtained by subtracting the actual speed value and the given speed value. When the speed difference exceeds the set dead zone, the power deviation is calculated according to the unequal rate of speed regulation. The power deviation is added to the set value of the power, and the actual value of the power is obtained. After the given value is compared with the actual power, a power difference is output to the PID controller for subsequent calculation. When DEH is in remote control mode, the controller exists in CCS system. Because the control principle is similar, its mathematical model can also refer to DEH power control mode.

DEH operating instructions under different control modes are shown in Figure 1:

![Figure 1: Schematic diagram of different control modes of DEH.](image)

- $\Omega$ - Actual speed, $\omega_0$ - Speed setting value, $s$ - Laplace operator, $T_{\omega}$ - Time constant of speed transmitter, $R$ - Unequal rate of speed regulation, $K_p$ - PID ratio coefficient, $K_i$ - PID integral coefficient, $K_d$ - PID differential coefficient, $Transport\ Delay1$ - Delay time of speed feedback, $Transport\ Delay2$ - Delay time of electric power feedback.

In the power feedback mode, the active power $P_E$ is compared with the given power, and the difference value of power is sent to the power regulator for the next calculation. The command signal of the valve is output to the electro-hydraulic servo. The opening of the valve is controlled by the actuator to change the steam intake and output the required power. The control valve command signal is ob-
tained, and this command is output to the electro-hydraulic actuator, the opening of the control valve is changed, thus the steam intake of the turbine is changed, and the required power is sent out.

Under the power feedback mode, the following transfer functions can be derived:

\[
-P_M = \left( \frac{1}{s T_\omega} \right) + P_E G_{pid} G_E G_T = G_{GOV1} \cdot \omega + G_{GOV2} \cdot P_E
\]

(1)

Where \( P_E \) represents active power, \( P_M \) represents mechanical power, \( G_{pid} \) represents transfer function of PID in power control, \( G_E \) represents transfer function of electro-hydraulic servo mechanism, \( G_T \) represents transfer function of steam turbine, \( G_{GOV1} \) represents transfer function of Speed, \( G_{GOV2} \) represents transfer function of power.

The command signal output from DEH system is converted into the opening of the regulating door by the actuator, which determines the output power of the unit. The actuator is composed by electro-hydraulic servo and oil actuator[10-14], Its model is shown in Figure 2.

\[ K_d \cdot \text{Differential coefficient of PID in electro-hydraulic servo system}, \]
\[ T_c \cdot \text{Close time constant of hydraulic actuator}, \]
\[ T_o \cdot \text{Open time constant of hydraulic actuator}, \]
\[ T_{ch} \cdot \text{Steam chamber volume time constant}, \]
\[ T_{rh} \cdot \text{Reheater volume time constant for intake pipe of low pressure cylinder}, \]
\[ F_{HP} \cdot \text{Share of the high pressure cylinder power in total output power}, \]
\[ F_{LP} \cdot \text{Share of the medium pressure cylinder power in total output power}, \]
\[ F_{IP} \cdot \text{Share of the low pressure cylinder power in total output power}, \]
\[ \lambda \cdot \text{Natural overshoot coefficient of high pressure cylinder power}, \]
\[ H \cdot \text{Rotor inertia time constant}, \]
\[ K_D \cdot \text{Damping torque coefficient}, \]
\[ \text{Transport Delay} 3 \cdot \text{Action delay time of hydraulic actuator}, \]
\[ \text{Transport Delay} 4 \cdot \text{Delay time of displacement sensor}. \]

Figure 2 Mathematical model of the actuator and the steam turbine.

Ignoring the nonlinear links, the following transfer functions can be derived.

\[
G_E = \frac{P_{GV}}{P_{CV}} = \frac{(s K_{p1} + K_{n1})}{s^2 T_T (s T_2 + 1) + (s T_{p1} + K_{n1})}
\]

(2)

\[
G_T = \frac{P_{PM}}{P_{GV}} = \frac{((1+\lambda)(1+T_{rh}s)(1+T_{cos}s)F_{hp} + (F_{ip} - AF_{hp})(1+T_{cos}s) + F_{lp})}{((1+T_{ch}s)(1+T_{rh}s)(1+T_{cos}s))}
\]

(3)

\[
(P_M - P_E) \cdot \frac{1}{2H + K_D} = \omega
\]

(4)

The power grid model adopts the Single machine infinite bus network model provided in reference [15]. As shown in Figure 3.
K1,K2,K3,K4,K5,K6 - Ratio coefficient, ΔTm - PID integral coefficient of Electro-hydraulic servo, ΔTe - Variation of electromagnetic power, ΔE1 - Variation of voltage sensor input, Δψfd - Flux variation of excitation loop, ΔEfd - Variation of exciter output voltage, TR - Time constant of voltage sensor, T3 - Time constant of excitation circuit.

Figure 3 Mathematical model of a single machine infinity power grid.

In the simulation, the typical parameter in Table 1 and Table 2 is used [8]:

Table 1 Typical parameters of steam turbine regulating system.

| Symbol | λ | Tch | Trh | Tco | FHP | FIP | FLP | Kp | Ki | Kd | R | To | T2 |
|--------|---|-----|-----|-----|-----|-----|-----|----|----|----|---|----|----|
| Typical parameters | 0.8 | 12  | 0.1 | 1   | 0.32| 0.68| 0.44| 1  | 0.05| 0  | 20 | 0.02| 9   |

Table 2 Typical parameters of a single machine infinity model.

| Symbol | K1 | K2 | K3 | K4 | K5 | K6 | K7 | H | Kd | TR | T3 |
|--------|----|----|----|----|----|----|----|---|----|----|----|
| Typical parameters | 1.591| 1.5 | 0.333| 1.8| 0.12| 0.3| 200| 3 | 0  | 0.02| 1.91|

3. Simulation Research

The turbine model, single-machine infinite-bus model, electro-hydraulic converter model and governor model are connected to establish a single-machine infinite-bus model. According to the current technical standards, the dead zone of primary frequency modulation is set at 0.0333 Hz, i.e. the standard unitary value (+0.000666). The step perturbation of the speed signal with a unit value of 0.001666 is given in 4-6 seconds, The control mode is power-frequency feedback mode. The model parameters are set according to table 4 and table 5. The speed feedback, electric power feedback, oil drive action and delay time of displacement sensor are respectively changed. The simulation time is set as 60 seconds to study the influence of different delay time on power stability under the condition of stable load within 60 seconds stipulated by industry standard. For convenience of observation and comparison, the abscissa and ordinate coordinates in all the following figures are the simulation time, and the ordinate coordinates are the scalar unitary values of the increment of the electric power response.

When the power feedback delay time is 0.01 seconds, 0.05 seconds and 0.1 seconds respectively, the influence on power stability is shown in Figure 4.
As Fig. 4 shown, when there is a delay in the power feedback, with the increase of the delay time, the disturbance caused by the curve delay signal increases, the electric power oscillation intensifies, the curve attenuates slowly, and the time to reach stability prolongs.

The influence on power stability is shown in Fig. 5 when the speed feedback delay time is 0.01 seconds, 0.1 seconds, 0.3 seconds and 0.5 seconds respectively.

As Fig. 5 shown, the curves coincide basically when the speed feedback delay time less then 0.3S, and the influence of the speed feedback delay is small. As the delay time increase, the curve oscillation intensifies and the stable time increases.

Fig. 6 shows the effect on power stability when the action delay time of the oil motor is 0.01 seconds, 0.03 seconds and 0.05 seconds respectively.

As Fig. 6 shown, with the increase of the delay time, the fluctuation amplitude of the curve increases, the electric power oscillation intensifies, and the time to reach stability also increases with the increase of delay time. When the delay time of the oil drive action is 0.03 seconds, the electric power curve oscillates at the same amplitude and can not reach a stable state.

Fig. 7 shows the effect of the delay time of the displacement sensor on the power stability at 0.01 seconds, 0.03 seconds and 0.05 seconds, respectively.
Figure. 7 Influence of delay of displacement sensor on power stability.

As shown in Fig. 7, the overshoot of the curve increases with the increase of the delay time, and the time to reach stability increases with the increase of the delay time. When the delay time of the displacement sensor is greater than or equal to 0.05 seconds, the power oscillation is obviously forced, and the amplitude increases with the delay time, resulting in serious instability of the system.

Figure. 8 Influence of delay of displacement sensor on power stability.

Table. 3 Comparison of grid stability effects of various links under 0.03s delay

| 0.03s in different links | Overshoot | Frequency of fluctuation | Stabilization time |
|-------------------------|-----------|--------------------------|-------------------|
| Speed                   | 0.019     | 11                       | 17s               |
| Electric power          | 0.021     | 19                       | 24s               |
| Oil drive action        | 0.028     | Infinity                 | >60s              |
| displacement sensor     | 0.039     | 23                       | 26s               |

As Fig. 8 and Table. 3 shown, the power curves of the same delay in different links are different. When the delay is 0.03s, the influence on power stability arrives from small to small in order: speed feedback delay, power feedback delay, displacement sensor delay and oil motor action delay.

4. Conclusions

The results show that, the effects of electric power feedback, speed feedback, oil motor and displacement sensor delay on the power stability are similar. The increase of delay time will aggravate the oscillation of electric power response curve, increase the time to reach stability and deteriorate the stability, but the influence degree of different link delays is different. The sensitivities from small to large are: speed feedback delay, electric power feedback delay, displacement sensor delay and oil motor delay.

Through study the influence of each link's delay time on the power stability of the whole system, it is found that the robustness of different links to the delay is obviously different, serious delay may even lead to low frequency oscillation. This research result can not only lay a foundation for the follow-up theoretical research, but also can focus on restraining the delay which has a great impact on the grid when there are delays in different links. The next step is to carry out the research on the method of restraining the delay in the power grid.

Acknowledgment

Fund Project: China Southern Power Grid Corporation Science and Technology (GDKJXM0000007)
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