The Research on Delay Suppression of Steam Turbine Overshoot Coefficient Feedforward Control

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***Abstract*—In the steam turbine speed control system, time delay of system links will affect the stability of the power grid, even worse it will result in low frequency oscillation of the power grid. Considering that the overshoot coefficient in the turbine model is equivalent to the differential action but it does not have the characteristics that the differential link's sensitivity to the deviation. Therefore, the proportional feedforward in the traditional steam turbine model is replaced by feedforward control with overshoot coefficient. Firstly, the influence of delay on the damping characteristics of the governing system is derived by frequency domain analysis. Then, the single-machine infinite coupling model of the steam turbine with nonlinear links is established in MATLAB/SIMULINK to simulate the system, which is under frequency disturbance. It is found that the overshoot coefficient feedforward control robust much more to the delay in the system. When the delay is large, the electric power output attenuate more quickly, which is beneficial to improve the stability of the power system.**

Keywords—steam turbine governor; SIMULINK; DEH feedforward; frequency domain analysis

I. INTRODUCTION

With the occurrence of wear and and oil leakage in steam turbine DEH equipment, the delay problem in the steam turbine governor will getting more and more obvious [1, 2, 3]. Wang Guanhong found that the delay in the steam turbine regulation system lag the phase. The longer the delay time, the larger the phase angle of the the mechanical torque will lag. When the phase lags to a certain extent, the mechanical torque provides negative damping to the grid,causing low-frequency oscillation[4].

For latency issues, pinghua AN designed a damping controller with partial State parameter and delay[5], which can not only suppress low-frequency oscillation but also ensure the maximum delay time of the system. Weiran LIU designed the GPSS controller to suppress the influence of delay on the grid through phase compensation, and discussed the method of obtaining GPSS parameters and the response boundary of GPSS[6].

The research on delay suppression of electrical power feedback, speed feedback and Oil actuator in DEH system is still in the exploration stage. In this paper, the characteristics of the equivalent differential action of the overshoot coefficient in the steam turbine are considered, and the proportional feedforward control mode is changed to the overshoot feedforward control mode. Through theoretical analysis and simulation verification, the inhibition of delay by this feedforward method is discussed.

II. INFLUENCE OF DELAY ON DAMPING CHARACTERISTICS OF SPEED CONTROL SYSTEM

To illustrate the issue, this paper simplifies the turbine governor and steam turbine model[7]. Assume that the parameters in the speed control system are set properly, ignoring the dead zone, Amplitude limit, delay, and volume and time constants of the medium-low pressure cylinders. The simplified model is shown in Figure 1.

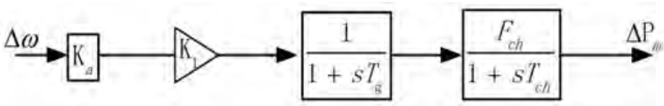

FIGURE I. PROPORTIONAL FEEDFORWARD TURBINE GOVERNOR AND TURBINE MODEL

In Figure 1, K_a is the reciprocal of speed-changing rate, K_1 is the speed controller feedforward coefficient usually set to 1; Because the speed of the electro-hydraulic converter move faster than the oil actuator, its time constant can be neglected; T_{ch} is the inlet chamber volume-time constant; F_{ch} is the power proportional coefficient of the high pressure cylinder

The transfer functions of the simplified models are shown in the formula (1):

$$G_1(s) = -\frac{K_a K_1 F_{ch}}{(1 + sT_g)(1 + sT_{ch})} \tag{1}$$

Substituting $s = j\omega$ into formula (1), (2) , that we can have the result shown in formula (2):

$$-P_{m1} = G_1(s)\Delta\omega = K_{Dm1}\Delta\omega + K_{sm1}\Delta\delta \tag{2}$$

K_{Dm1} is the mechanical damping coefficient of the speed control system, K_{sm1} is mechanical synchronous coefficient. Considering that the delay link $G_{delay} = e^{-\tau s}$ in the turbine regulation system will deteriorate the damping of the regulation system, the delay link $G_{delay} = e^{-\tau s}$ in the turbine regulation system is expanded according to the following Taylor formula:

$$G_{delay} = e^{-\tau s} = 1 - \tau s + \frac{\tau^2}{2} s^2 - \cdots + \frac{(-\tau)^{n-1}}{(n-1)!} s^{n-1} + \cdots \quad (3)$$

The second-order differential like $G_{delay} = 1 - \tau s + \frac{\tau^2}{2} s^2$ can be obtained from the above formula Substituting it into (1):

$$-P_{m11} = G_1(s) G_{delay}(s) \bullet \Delta\omega \quad (4)$$

Substituting $s = j\omega$ into formula (4), the mechanical damping coefficient is obtained under the affection of delay:

$$K_{Dm11} = \frac{(1 + [-\frac{\tau^2}{2} - T_g T_{ch} - \tau(T_g + T_{ch})]\omega^2 + \frac{\tau^2}{2} T_g T_{ch} \omega^4) K_a K_1 F_{ch}}{(1 + T_g^2 \omega^2)(1 + T_{ch}^2 \omega^2)} \quad (5)$$

Substituting $K_a = 20$, $T_g = 0.75$, $T_{ch} = 0.1$, $F_{ch} = 0.32$ into formula (5), Figure 2 shows the difference of damping characteristics between the two feedforward modes of the governor system with or without delay.

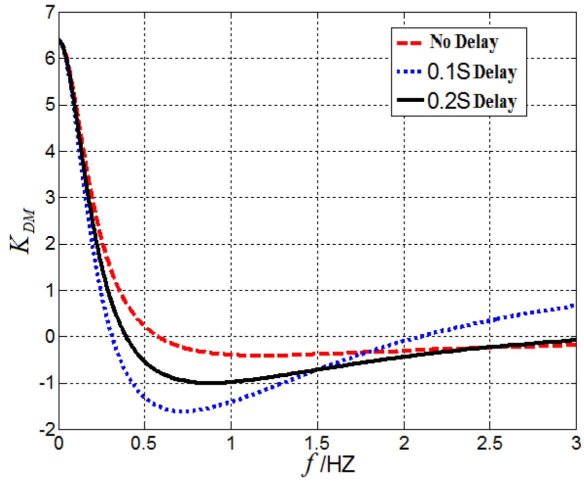

FIGURE II. DAMPING CHARACTERISTICS UNDER PROPORTIONAL FEEDFORWARD WITH/WITHOUT DELAY

From the above figure, as the delay increases, the mechanical damping characteristic curve decreases rapidly, and the boundary frequency under the proportional feedforward mode becomes smaller as the delay time increases, resulting in deterioration of the stability of the system.

III. TYPICAL STEAM TURBINE DEH SYSTEM MODEL

In this paper, the digital electro-hydraulic control system (DEH) is used to control the power frequency of the steam turbine. The over-feeding feed-forward diagram is shown as follows:

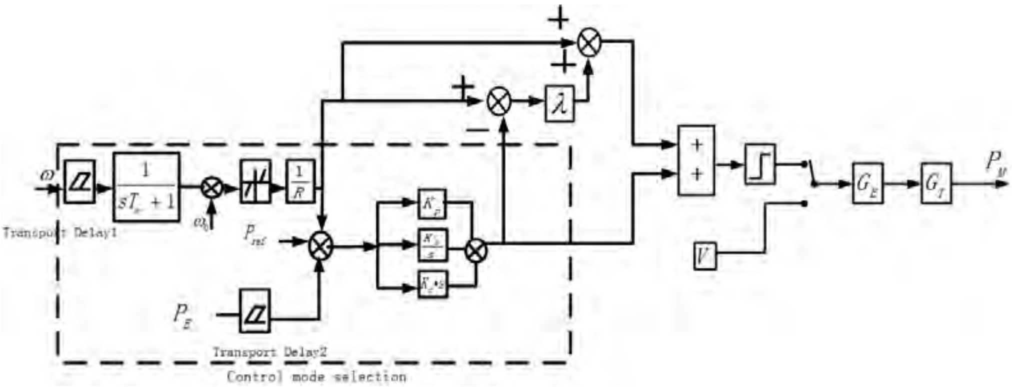

FIGURE III. POWER FREQUENCY CONTROL SCHEMATIC DEH

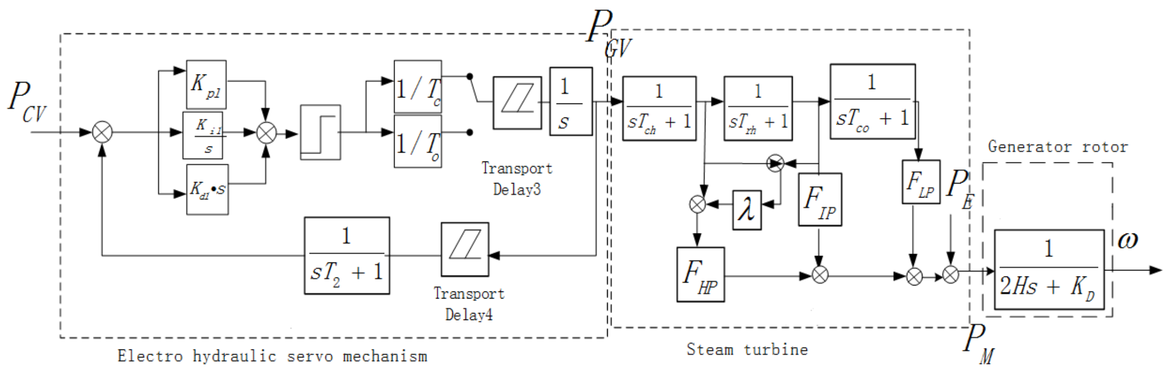

FIGURE IV. ACTUATORS AND STEAM TURBINE MODEL

TABLE I. TURBINE REGULATION SYSTEM TYPICAL PARAMETERS

Symbol	λ	T_{ch}	T_{rh}	T_{co}	F_{HP}	F_{IP}	F_{LP}	K_p	K_i	K_d	R	T_ω	K_{p1}	K_{i1}	K_{d1}	T_o	T_2
Typical parameters	0.888	0.1	12	1	0.32	0.68	0	1	0.05	0	20	0.02	9	0	0	1.33	0.02

TABLE II. SINGLE INFINITY MODEL TYPICAL PARAMETERS

Symbol	K_1	K_2	K_3	K_4	K_5	K_6	K_A	H	K_D	T_R	T_3
Typical parameters	1.591	1.5	0.333	1.8	0.12	0.3	200	4.5	10	0.02	1.91

The DEH system actuator consists of electro-hydraulic servo and oil actuator. The model is shown in Figure 4.

The grid model use the single-machine infinite grid model which is provided by reference [9]. As shown in Figure 5:

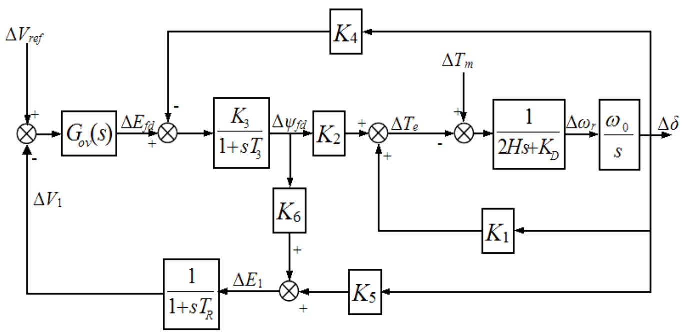

FIGURE V. SINGLE-MACHINE INFINITE POWER GRID MODEL

The parameters used in the above model are based on the industry standards and the parameters in the existing literature [10]. Selecting the parameters in appropriate range, As shown in table1 and table2:

IV. SIMULATION AND RESEARCH

In the single-machine infinity overall model, the model parameters are set according to Table 1 and Table 2. According to the current technical standards, the dead zone is set to 0.0333 Hz, which the standard value is ±0.000666. The pulse disturbance is given to the speed feedback signal, whose amplitude is 0.01.The disturbance is cut in 4s and cut off in 6s, and the delay of each link is 0.1S. In the following figures, the abscissa is the simulation time, and the ordinate is the value of the electrical power response increment.

It can be seen from Fig. 6 that when the electric power feedback delay for 0.1S, the overshoot of the electric power curve under the overfeed feedforward control increases slightly, but the overshoot feedforward curve can reach the stability quickly.

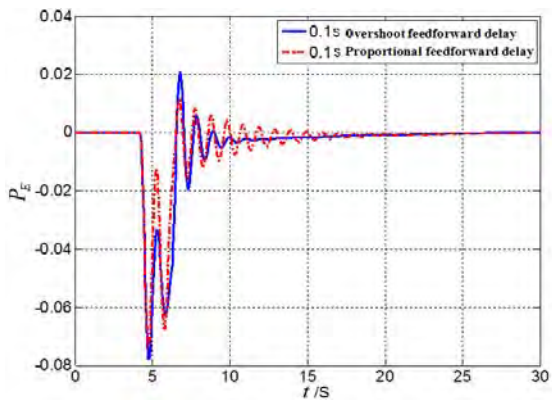

FIGURE VI. EFFECT OF OVERSHOOT FEEDFORWARD CONTROL ON ELECTRICAL POWER FEEDBACK DELAY

It can be seen from Fig. 7 that when the delay is 0.1S in the speed feedback delay, the overshoot of the electric power curve under the overshoot feedforward control is smaller, which attenuate more quickly.

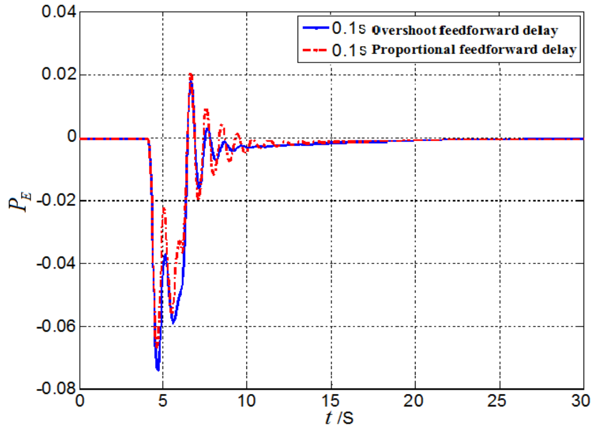

FIGURE VII. EFFECT OF OVERSHOOT FEEDFORWARD CONTROL ON SPEED FEEDBACK DELAY

It can be seen from Fig. 8 that the electric power curve under the overshoot feedforward control attenuate more quickly when the same delay exists in the oil actuator. Under the same delay, the proportional feedforward control has been unstable and occur to oscillation.

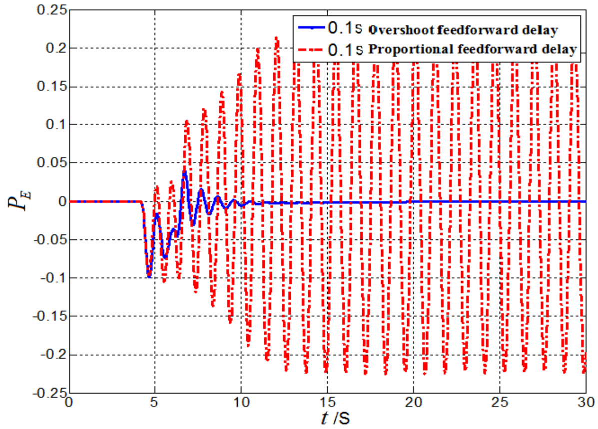

FIGURE VIII. EFFECT OF OVERSHOOT FEEDFORWARD CONTROL ON OIL ENGINE ACTION DELAY

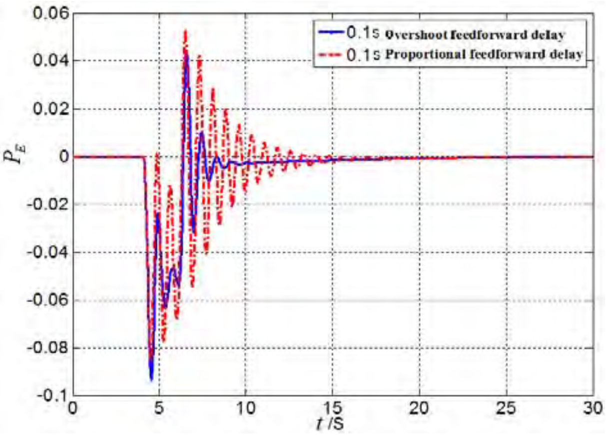

FIGURE IX. EFFECT OF OVERSHOOT FEEDFORWARD CONTROL ON DISPLACEMENT SENSOR DELAY

It can be seen from Fig. 9 that when the displacement sensor delay for 0.1S, the overshoot of the electric power curve under the overshoot feedforward control is smaller, which attenuate faster, and the settling time is shorter.

V. CONCLUSION

In summary: Overshoot feedforward control can be more robust to delay in the speed control system. When delay exist in the speed feedback, electric power feedback, oil actuator, and displacement sensor link, the electric power curve attenuate more quickly to achive stablisation. Finally, the power of the power grid can be stabile even delay exist.

ACKNOWLEDGEMENT

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