Configuration method of PSS lead-lag compensator parameters

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Abstract. Power System Stabilizer (PSS) is an important measure to increase damping and suppress low frequency oscillations of power system. During PSS test, the time constant of lead-lag compensator need to be configured, considering the inefficiency and optimization problem when configuring parameters empirically, this paper proposes automatic configuration method of PSS parameters based on Matlab, by setting the expected phase value at each frequency and constructing the objective function with the sum of phase differences square, the automatic calculation of PSS parameters under specific phase requirements at each frequency can be realized, the detailed steps of this method are given, and the method is verified during the PSS test of an 300Mw thermal-power generating unit finally.

1 Introduction

Low-frequency oscillation largely affects the stable operation of the power system. The main reason of low-frequency oscillation are negative-damping mechanism\textsuperscript{[1]}, forced-oscillation mechanism\textsuperscript{[2]}, nonlinear-mechanism\textsuperscript{[3]} and strong-resonance mechanism\textsuperscript{[4]}, the negative-damping mechanism is a classic theory when studying low-frequency oscillation. Due to the phase-lag characteristics of the automatic regulator, excitation system and generator rotor winding, negative-damping torque is produced, which bring negative-damping of power system. For this reason, the power system stabilizer (PSS) is usually added to the regulator. PSS is an additional control device that adjusts the output rotor voltage with automatic-regulator to achieve the purpose of damping power system and other oscillations.

Currently, PSS2B model is widely used in the world. The PSS2B model has two input signals: speed and electric power. Only by correctly configuring the lead-lag time constant of the PSS2B model, can PSS have its due effect. At present, EXCEL table is often used to adjust the time constant during PSS test, which takes a lot of time and can not get the best effect. This paper proposes an automatic calculation method based on Matlab, and the new method is verified during PSS test.

2 Introduction of PSS2B Model

2.1 The Transfer Function of PSS2B Model

PSS2B model’s transfer function is shown in Figure 1. \( \omega \) is signal of generator’s speed, \( Pe \) is signal of generator’s power, \( T_{o1} \sim T_{o4} \) is time constants of blocking compensator, \( T_1 \sim T_3 \) and \( T_{o6} \) are time constants of lead-lag compensator (two or three-order compensation compensator may be used), \( T_6 \) \( T_7 \) are inertial time constants, \( T_8 \) \( T_9 \) are time constants of torsional vibration filter, \( T_{11} \sim T_{14} \) are lead-lag time constants of automatic voltage regulator, \( M, N \) are the orders of torsional vibration filter, \( P_M \) is mechanical input power, \( P_a \) is accelerating power, \( K_{di} \) is gain of PSS, \( K_{d2} \) is gain of inertial compensator, \( K_{d3} \) is gain of power combination, \( K \) is gain of automatic voltage regulator, \( K_A \) is gain of excitation system’s power, \( K_G \) is gain of generator, \( T_A \) is the time constant of power amplification compensator, \( T_d \) is time constant of generator, \( T_f \) is time constant of the total shaft, \( T_e \) is sampling time constant of generator’s output voltage.

The accelerating power variation \( \Delta P_a \) can be synthesized using signals of output power variation \( \Delta P \) and speed variation \( \Delta \omega \). \( \Delta P \) is input signal of the three-order lead-lag compensation compensator, \( U_{psc} \) can be got from the output of three-order lead-lag compensation compensator, which is added to the voltage reference value of the automatic voltage control loop. Physical concept of PSS2B model is clear, three-order lead-lag compensator has strong ability of phase correction and strong practicality.

2.2 The phase compensation principle of the PSS2B model

The phase relationship of each physical quantity in the PSS2B model is shown in Figure 2. Without compensation, as a result of the automatic voltage regulator control, the electromagnetic torque \( \Delta T_e \) lags the power \( \Delta \delta \). Component of the torque in the \( \omega \)-axis direction is negative, providing negative damping. PSS provides \( \Delta U_{psc} \) signal which is added to automatic voltage regulator by sampling and processing some input signals. The \( \Delta U_{psc} \) signal can provide positive damping through the lagging of the excitation system of
electromagnetic torque $\Delta T_{\text{PSS}}$ in $\Delta \omega$ axis component is positive.

$\omega$ input branch is designed to suppress the Counter-modulation of PSS, during oscillation of active power, $\Delta P_m$ equals zero, considering the configuration of PSS parameters is based on $P_e$ axis, so lag angel of PSS itself can be expressed as,

$$\varphi_{\text{phase}} = \varphi_{\text{PSS}} = \varphi_{\text{PSS}} + \varphi_{\text{PSS}}$$

(1)

Where $T_1 \sim T_4$ and $T_7$ are always set as 6 empirically, and the value of $K_2$ is calculated from the inertia moment of total shaft and $T_7$. The phase-frequency characteristic value after compensation has been stipulated clearly in DLT 1231-2018 "Guide for Setting Test of Power System Stabilizer ". The lead-lag compensator time constant $T_1 \sim T_6$ values should be configured during PSS test to meet the requirements. Therefore, how to configure the time constant quickly and effectively is a problem that needs to be studied and solved.

3.1 Multivariate optimization function under constraints

MATLAB fmincon() function can deal with the multivariate optimization problem, fmincon() function is structured as fmincon (FUN, X0, A, B, Aeq, Beq, LB, UB), where FUN is the objective function and X0 is the initial value of the variable to be solved. The inequality constraints to be satisfied for variables is given by A and B (AX < B), the equality constraints to be met for variables is given by Aeq and Beq (AeqX = Beq), and the boundary conditions to be met for variables are given by LB and UB (LB < X < UB).

The optimization results are affected by the form of objective function directly. In this paper, the sum of difference squares between expected phase value and actual phase value at each frequency point is used as the optimization function. The expected phase angle $\varphi_{\text{ref}}$ of $\Delta T_{\text{PSS}}$ lagging $\Delta P_e$ at 20 discrete frequency points between 0.1 ~ 2.0 HZ is set firstly, then the objective function myfun () is defined as sum of difference squares between expected phase value $\varphi_{\text{ref}}$ and actual phase value $\varphi_{\text{act}}$,

$$\text{myfun} = \sum_{f=1}^{20} [\varphi_{\text{act}}(2\pi f) + \varphi_{\text{ref}}(2\pi f) - \varphi_{\text{ref}}(2\pi f)]^2$$

(2)

3.2 Configuration method of PSS2B’s lead-lag compensator time constant

The configuration method of PSS2B lead-lag compensator time constant is shown in Figure 3. The first step is to set the desired phase angle $\varphi_{\text{ref}}$ at each frequency point, Secondly the phase frequency value of the excitation system without compensation $\varphi_{\text{ref}}$ is obtained by frequency sweep and objective function myfun () can be got according to (2), thirdly the optimal value of time constant can be obtained based on section 2.1 by using MATLAB fmincon() function. Fourthly time constants obtained in the previous step are substituted to calculate the actual phase value of each frequency point, whether the actual value meets the requirements is determined in the fifth step, the time constant value can be taken as the PSS setting value when requirements are met, otherwise, the second step is returned to modify the expected value of the phase angle at the frequency point where the requirement can not be met.
Set expected phase \( \phi_{e1} \)

Construct objective function \( myfun() \)

Obtain the time constant value using function of fmincon() in matlab

Calculate actual value of each frequency point, using the time constant value of the previous step

Whether \( \text{can meet the requirements} \)

Modify the expected phase angle value at the frequency point that does not meet the requirements

Use the calculated time constant value as the setting value

**Figure 3** Configuration method of PSS model’s lead-lag compensator time constant

### 4 Test Verification

The proposed configuration method of PSS lead-lag compensator time constant is verified in the PSS test of a 1000 MW generator unit. The main parameters of the unit are shown in Table 1, the uncompensated phase-frequency characteristics of the excitation system are shown in Table 2. [6] stipulated that should be bigger than 60° at 0.1 ~ 0.2Hz, so the expected angle can be set as 80°; within the range of 0.3 ~ 2.0 Hz, should be larger than 70° and smaller than 135°, so the expected angle value at each frequency point between 0.3 ~ 2.0 Hz can set as 100°. Using the method in Section 2, the following results can be obtained: \( T_1 = 0.1, T_2 = 0.01, T_3 = 0.30, T_4 = 0.02 \) (two-order lead-lag compensator is used), and the actual phase value after compensation is calculated. It is verified that the lead-lag angle of each frequency point meets the requirements, which can be used as the time constant of the PSS lead-lag compensator. The other parameters of PSS model are as follows: \( T_1 = T_2 = T_3 = T_4 = 1, T_0 = 0, T_5 = 0.5, M = 5, N = 1 \), \( K_s3 = 1 \), all of which are empirical defaults. \( K_{s3} = \frac{1000 - T_{1} - S_{2}}{2.74 - GD^2 \omega} \), combined with table 1, it can be calculated that \( K_{s3} = 0.061 \). Figure 4 shows the waveform of field voltage when \( K_{s1} = 32 \). As can be seen from figure 4, the field voltage diverges to a certain extent, so the critical gain of \( K_{s1} = 32 \). Generally, \( 1/3 \sim 1/5 \) of the critical gain is taken as the value of \( K_{s1} \), so \( K_{s1} \) is set as 8.

**Tab1** parameters of a 1000Mw generator unit

| Parameter                        | Unit | Value | Parameter                        | Unit | Value |
|----------------------------------|------|-------|----------------------------------|------|-------|
| Rated capacity \( S_{1} \)       | MW   | 1111  | Rated speed \( n \)              | r/min| 3000  |
| Power factor(\( \cos \phi \))     | /    | 0.9   | Generator flywheel torque \( GD^2 \) | /    | 68    |
| Generator unit voltage \( U_{0} \) | Kv   | 27    | Steam turbine flywheel torque \( GD^2 \) | /    | 373.8 |

**Tab2** Phase frequency characteristics with PSS compensation of a 1000Mw unit

| Frequency (Hz) | Angle without compensation \( \phi_{e1} \) (°) | Angle of PSS \( \phi_{ps} \) (°) | Angle with PSS compensation \( \phi_{ps} \) (°) |
|----------------|-----------------------------------------------|----------------------------------|-----------------------------------------------|
| 0.1            | 26.7                                          | 46.7                             | 73.4                                          |
| 0.2            | 50.4                                          | 48.5                             | 98.9                                          |
| 0.3            | 63.2                                          | 41.9                             | 105.1                                         |
| 0.4            | 64.7                                          | 34.2                             | 98.9                                          |
| 0.5            | 70.3                                          | 26.8                             | 97.1                                          |
| 0.6            | 81.2                                          | 20.1                             | 101.3                                         |
| 0.7            | 82.1                                          | 14.1                             | 96.2                                          |
| 0.8            | 86.8                                          | 8.8                              | 95.6                                          |
| 0.9            | 85.5                                          | 4.1                              | 89.6                                          |
| 1.0            | 93.2                                          | 0.0                              | 93.2                                          |
| 1.1            | 113.5                                         | -3.8                             | 109.7                                         |
| 1.2            | 114.6                                         | -7.1                             | 107.5                                         |
| 1.3            | 115.7                                         | -10.0                            | 105.7                                         |
| 1.4            | 116.8                                         | -12.7                            | 104.1                                         |
| 1.5            | 118.3                                         | -15.1                            | 103.2                                         |
| 1.6            | 108.8                                         | -17.2                            | 91.6                                          |
| 1.7            | 115.6                                         | -19.1                            | 96.5                                          |
| 1.8            | 117.4                                         | -20.9                            | 96.5                                          |
| 1.9            | 121.4                                         | -22.4                            | 99.0                                          |
| 2.0            | 115.2                                         | -23.8                            | 91.4                                          |

**Figure 4** field voltage when \( K_{s1} = 32 \)

**Figure 5** step test without PSS
As can be seen from figure 5 and figure 6, under the same generator voltage change, the amplitude and times of active power oscillation are greatly reduced with PSS, indicating that the PSS lead-lag time constant configuration method proposed in this paper is effective.

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