A Simple Safety Control Method for PSS Critical Gain Test

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Abstract. As an additional control function of the generator excitation system, power system stabilizer (PSS) plays an important role in suppressing the low frequency oscillations of the power system. In this paper, the focus of research lies in PSS field test. For the risk of oscillations that may be triggered in the PSS critical gain test, a simple safety control method is proposed. The critical gain test is performed by temporarily reducing the PSS output limit value to obtain a PSS operating gain more safely. Taking the PSS field test of a grid-connected unit of Hunan Power Grid as an example, the applicability of the method is verified.

1. Introduction

With the interconnection of large-area power grids in China and the large-scale operation of fast and high-gain excitation systems, the increasingly complex system structure and the heavy load of long-distance and large-capacity transmission lines have caused the system damping level decreasing, and increased the risk of dynamic stability of the power system. As an additional control link of the excitation system, the power system stabilizer (PSS) is simple and convenient to implement. It is the most economical and effective technical means to suppress the low-frequency oscillation of the power system \cite{1}-\cite{2}.

PSS is a power technology developed in the 1970s. Engineers analyzed the generator phase relation between each quantity in the process of oscillation, and realized that the phase lag characteristic of generator excitation system was the reason why there was an excessively sensitive voltage regulation. Furthermore, the idea of using an additional signal in the excitation system to generate positive damping torque through phase compensation emerged. Later, the Phillips-Heffron model was adopted to analyze the synchronous torque and damping torque of the generator, and the effect of the excitation system was understood from the physical perspective, so as to analyze the mechanism of suppressing low-frequency oscillation \cite{3}. Nowadays, PSS has developed a complete standard system \cite{4} and a complete field test procedure \cite{5}.

To determine the critical gain in the field test of PSS, the PSS output gain $K_{s1}$ should be gradually increased until the excitation voltage begins to show an oscillatory trend of increasing amplitude. However, this method has the risk that the increased oscillation will lead to generator disconnection. Aiming at reducing the risk of oscillations that may be triggered in the PSS critical gain test, a simple safety control method is proposed in this paper. By temporarily reducing the PSS output limit value, the critical gain test is performed to obtain a PSS operating gain. Taking the PSS field test of a grid-connected unit of Hunan Power Grid as an example, the applicability of the method is verified.
2. PSS Field Test
According to the industry standard, PSS field tests include uncompensated phase-frequency characteristic measurement of the excitation system, the lead-lag time constant setting, critical gain test, step response test on load and inverse-regulation effect test. Here we take the widely used PSS2B as an example.

2.1 PSS2B Mathematical Model
The PSS2B model uses the power and speed signals to synthesize the acceleration power integral signal, and the amplitude limiting output is achieved after the three-stage lead-lag and gain links, as shown in Fig.1.

\[
\frac{\Delta \omega}{P_e} = \frac{1 + sT_1}{1 + sT_2} \frac{1 + sT_4}{1 + sT_5} \frac{1 + sT_6}{1 + sT_7} K_{s1} \rightarrow \Delta \omega_{ps}
\]

\[
\frac{\delta f_{ps}}{U_{g}} = \frac{1}{1 + sT_2} \frac{1}{1 + sT_3} K_{s2} \rightarrow \delta f_{ps}
\]

\[
\frac{\delta f_{ps}}{U_{k_{AVR}}} = \frac{1 + sT_4}{1 + sT_5} \rightarrow \delta f_{ps}
\]

Figure 1. PSS2B Mathematical model

PSS2B has the advantages of easy implementation and low noise. However, its single-frequency structure can only take into account the low and high frequency bands by adjusting the parameters in a balanced way, and the effect of low-frequency oscillation suppression needs to be improved.

2.2 Time Constants Tuning
According to the principle of phase compensation method [3], the additional torque \(\Delta T_{ps}\) generated by PSS should be in phase with the \(\Delta \omega\) axis to generate the maximum positive damping torque. \(T_1 \sim T_4\) and \(T_{10} \sim T_{11}\) are the three-stage lead-lag phase compensation time constants, which need to be obtained by optimizing algorithm to meet the phase compensation requirements of industrial standard [5].

2.3 Critical Gain Test
The PSS critical gain is influenced by the load level, the PSS configuration in the system and other factors, which is determined by the field test after phase compensation. Increase the gain \(K_{s1}\) slowly until oscillation occurs, and take 1/3 ~ 1/5 of the critical gain as the PSS operating gain.

3. The Safety Control Method for PSS Critical Gain Test

3.1 Introduction to Excitation System
Taking the excitation system of No.3 generator in Kongzhou Hydropower Station of Hunan Power Grid as an example, the PSS field test is carried out. The rated capacity of the generator is 31.11 MVA. The excitation system is self shunt and adopts EXC9200 digital excitation regulator by Guangzhou Qingtian Industrial Co. Ltd.

PID control has a long history and is still one of the most widely used control strategies in industrial process control. The PID control block diagram of EXC9200 is shown in Fig.2, where \(U_{gd}\) is terminal voltage reference, \(U_b\) is terminal voltage, \(U_{k_{AVR}}\) is excitation control voltage, and PSS_uk is PSS output.
The EXC9200 is equipped with PSS2B power system stabilizer, and its mathematical model is shown in Fig.3, where USTmax and USTmin are PSS output limit value. Combined with Fig.2 and Fig.3, the PSS output PSS_uk is superimposed on the voltage reference point, so as to suppress the power oscillation by controlling the terminal voltage. The limit value of PSS is usually around ±10%.

3.2 The Proposed Safety Control Method
Since the output amplitude limit of PSS determines the effect of PSS suppressing low-frequency oscillation, the oscillation amplitude of the critical gain test can also be limited by controlling the output amplitude limit of PSS. Assume \( U_s \) is the absolute value of PSS output limit value. The PSS critical gain is carried out under different \( U_s \), as shown in Fig.4. When PSS is on, increase the gain \( K_{s1} \) slowly until oscillation occurs. When PSS is removed, the oscillations disappear. By comparison, when the critical gain is achieved, the larger the limit value of PSS output, the larger the excitation voltage oscillation amplitude be and the faster the divergence be.

Fig.5 shows the excitation control voltage observed by EXC9200 Debug software under different PSS output limit value, which verifies the effect of PSS output limit value on oscillation amplitude again.
Figure 5. $U_{k_{AVR}}$ under different PSS output limit value

Set $U_s$ at 3% and resume the critical gain test. It can be seen in Fig.6 that with the increase of $K_{s1}$, the amplification oscillations gradually appeared but the amplitude is smaller than before the modification of $U_s$, which reduces the risk of generator disconnection.

4. Conclusion

In this paper, a simple safety control method for PSS critical gain test is investigated. By temporarily reducing the PSS output limit value, the critical gain test is performed to obtain a PSS operating gain. Taking the PSS field test of a grid-connected unit of Hunan Power Grid as an example, the risk of PSS critical gain test is reduced due to PSS output value control.

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