Research on Stability of the Power System

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Abstract. In order to maintain the stability of the power system, a suitable stability analysis method must be adopted. Firstly, the eigenvalue analysis method is studied, and the process of judging the stability of the system according to the small signal stability analysis criterion is given. Then, the system stability under the interference of a stochastic small signal is analyzed, and the analytical method to judge the system stability based on the mean stability criterion and the mean square stability criterion is presented. Finally, the concrete measures to improve the static stability and transient stability of the power system are put forward.

1. Introduction
The stability is an important guarantee for the safe and reliable operation of the power system, it is a decisive factor to limit the transmission distance and conveying capacity of the power system. Therefore, various measures must be taken to improve the system stability. The stability of the power system includes power angle stability, voltage stability and frequency stability. Among them, the power angle stability includes static stability and transient stability.

Considering the importance of stability to the power system, the power system stability analysis methods and the measures to improve the power system stability is studied, so as to provide some useful reference for the safe and reliable operation of the power system.

2. Small signal stability analysis methods of the power system
The power system will be interfered by many factors, the vast majority of which are small signal interferences. We can obtain the system unstable way by establishing an appropriate small signal stability analysis model and analysing the stability of the power system, and then we can study the preventive measures of instability to improve system stability. Therefore, the small signal stability analysis of the power system is of great significance, this paper will study two commonly used methods of small signal stability analysis.

2.1. Eigenvalue analysis method
Before the eigenvalue analysis method is elaborated, the criterion of small signal stability analysis is introduced. Because the power system comprises a plurality of nonlinear electromechanical equipment, its dynamic behavior is expressed as the following nonlinear differential algebraic equations:

\[
\begin{align*}
\dot{x} &= f(x, y) \\
0 &= g(x, y)
\end{align*}
\]

Where \(x\) is a state vector and \(y\) is an algebraic vector.

In order to analyse the small signal stability of the system, the state equation and the algebraic equation of Eq.(1) are linearized at the given operating point \((x_0, y_0)\):
Further elimination of algebraic variables in Eq.(2), we get $\Delta x = S \Delta t$, where $S = ABD^{-1}C$ is the state matrix of the system. According to the eigenvalues distribution of the system state matrix $S$ in the complex plane, we can get the criterion of small signal stability analysis: if all the eigenvalues of $S$ are in the left half complex plane, the power system is stable under the small interference. If the state matrix $S$ has a real eigenvalue or a pair of conjugate eigenvalues are located in the right half complex plane, the power system is unstable under the action of small interference. If the state matrix $S$ has eigenvalues on the imaginary axis, the system is critical stable under the action of small interference.

Eigenvalue analysis is the most widely used method in small signal stability analysis. The method firstly builds a model of the power system and linearizes it at the equilibrium point, and uses the state equation to express the linear model of the power system, then obtains the system state matrix and calculates the state matrix eigenvalues and eigenvectors, finally the system stability under the small interference is judged according to the above-mentioned criterion of small signal stability analysis.

Lyapunov's first law is the basis of the eigenvalue analysis method, the power system is presented in the state space by linear model, and the calculation is simplified by the algebraic equations. Eigenvalue analysis has many advantages, it can accurately reflect the frequency and damping and the frequency attenuation curve when the system is under oscillation mode, thus we can understand the situation of an oscillatory system to find the strategy to reduce the system oscillation. At the same time, the eigenvalue analysis can also master the controller parameters of the system in order to adjust them in a timely manner.

2.2. Stochastic small signal stability analysis method

As in the previous section, before the description of stochastic small signal stability analysis method, the stochastic small signal stability analysis criterion is briefly introduced. Considering the dynamic system which has gauss white noise disturbance, its motion differential equation is

$$dX(t) = F(X(t), t)dt + G(X(t), t)dB(t), \quad X(t_0) = X_0$$

(3)

Where $X(t) = [X_1(t), X_2(t), \ldots, X_n(t)]^T$ is a n-dimensional vector composed of random state variables, $F(X(t), t)$ is an n-dimensional vector, which is called the drift vector of the equation; $G(X(t), t)$ is a n×m matrix, called the diffusion matrix of the equation; $B(t)$ is the m-dimensional vector Wiener process.

The stochastic small signal stability analysis criteria include the mean stability criterion and the mean square stability criterion, which are defined as follows.

The mean stability criterion: if the solution $X(t)$ of stochastic differential equation (3) satisfies

$$\lim_{t \to \infty} E\|X(t)\| < C, \quad C > 0,$$

then the system is mean stable.

The mean square stability criterion: if the solution $X(t)$ of stochastic differential equation (3) satisfies

$$\lim_{t \to \infty} E\|X(t)X^T(t)\| < C, \quad C > 0,$$

then the system is mean square stable.

The above criteria can be used to determine the power angle stability of the power system under stochastic small disturbances. Taking the single machine infinite system as an example, the rotor motion equation of the generator is

$$\begin{align*}
\dot{\delta} &= \omega \\
\dot{\omega} &= \frac{E}{T} \left(\sin \delta_0 - \sin \delta\right) - \frac{D}{T} (\omega - \omega_0) + \frac{\sigma}{T} W(t)
\end{align*}$$

(4)

Where $E$ is the internal potential of the generator, $U$ is the infinite bus voltage, $T$ is the inertia time constant, $X$ is the total reactance, $D$ is the damping coefficient, $\delta$ is the power angle, $\omega$ is the rotational speed, $\delta_0$ and $\omega_0$ are the steady-state values of $\delta$ and $\omega$ respectively, $W(t)$ is the stochastic excitation, $\sigma$ is the strength of $W(t)$. 


the matrix form of Eq.(4) is as follows.

\[
\begin{bmatrix}
\delta \\
\omega
\end{bmatrix} = \begin{bmatrix}
0 & 1 \\
-\frac{E U}{T X} & -\frac{D}{T}
\end{bmatrix} \begin{bmatrix}
\delta \\
\omega
\end{bmatrix} + \begin{bmatrix}
0 \\
\frac{E U}{T X} (\delta + \sin \delta_0 - \sin \delta) + \frac{D}{T} \omega_0
\end{bmatrix} + \begin{bmatrix}
0 \\
\frac{\sigma}{T}
\end{bmatrix} W(t)
\] (5)

Eq.(5) can be written as

\[
X = AX + h(X) + M \cdot dB(t)
\] (6)

Where \( X = \begin{bmatrix} \delta \\ \omega \end{bmatrix} \), \( A = \begin{bmatrix} 0 & 1 \\ -\frac{E U}{T X} & -\frac{D}{T} \end{bmatrix} \), \( h(X) = \begin{bmatrix} 0 \\ \frac{E U}{T X} (\delta + \sin \delta_0 - \sin \delta) + \frac{D}{T} \omega_0 \end{bmatrix} \), \( M = \begin{bmatrix} 0 \\ \frac{\sigma}{T} \end{bmatrix} \).

The solution of Eq.(6) is

\[
X = e^{At}X_0 + \int_0^t e^{A(t-s)}h(X(s))ds + \int_0^t e^{A(t-s)}M \cdot dB(s)
\] (7)

After obtaining the solution of the rotor motion equation, the power angle stability of the power system under the action of stochastic small interference can be judged by the mean stability criterion and the mean square stability criterion.

3. The measures to improve the power system stability

3.1. The measures to improve the static stability

3.1.1. Adopting automatic regulating excitation device for generator. If the generator is equipped with an automatic regulating excitation device that maintains the terminal voltage constant of the generator, the result is equivalent to the cancellation of the equivalent generator reactance, so that the "electrical distance" between the power supply is greatly shortened, which has a significant effect on improving the static stability of power system. In addition, the increased investment due to use of automatic regulating excitation device, is far less than that of other measures. Therefore, among various measures to improve static stability, always first consider the installation of automatic regulating excitation device.

3.1.2. Reducing the line reactance. Reducing the line reactance can strengthen the connection between the system, so that the static stability limit and stability level of the power system are improved. The main way to reduce the line reactance is to use the bundle conductor.

3.1.3. Increasing the line rated voltage level. Increasing the rated voltage level of the line is also one of the common ways to increase the stability of the power system. However, this approach requires a certain increase in operating costs of electricity, and requires the system to have sufficient power to support the operation.

3.2. The measures to improve the transient stability

3.2.1. forcing excitation. When the generator terminal voltage is reduced due to the external short circuit, so that its output electromagnetic power is reduced, the forced excitation device can be used to increase the output electromagnetic power and reduce the unbalanced power of the rotor. Usually the automatic regulating excitation system of the generator has forced excitation device. When the generator terminal voltage is lower than 85% of the rated voltage, the low voltage relay is operated, and the regulating resistance of the excitation device is forced to be short connected through the
intermediate relay, so that the excitation current of the exciter is greatly increased. Thus, the excitation current and the excitation voltage of the generator are rapidly increased, so as to improve the generator potential and increase the output electromagnetic power.

3.2.2. Connecting the transformer neutral point to ground by a small resistor. When an asymmetrical ground short fault occurs in a neutral point grounded power system, a zero sequence current component is generated. If the transformer neutral point of the star connection system is grounded by a small resistance, the zero sequence current will generate power loss when the current flows through this resistor. This power loss can reduce the unbalanced power of the rotor and facilitate the transient stability of the system. At the same time, the small grounding resistor is reflected in the positive sequence augmented network, which is equivalent to increase the additional impedance, reduce the system connection impedance, but also improve the output electromagnetic power of the generator. The size and location of the grounding resistor should be determined by calculation, and generally the value of the grounding resistor is approximately the same as that of short-circuit reactance of the transformer.

4. Conclusion
With the rapid development of power industry, the size of power system is increasingly large and it is becoming more and more complex, the reliability and stability of the system operation is getting more and more attention. Small signal stability analysis is an important method to maintain the stability of power system. In this paper, two commonly used methods of small signal stability analysis, i.e. eigenvalue analysis and stochastic small disturbance stability analysis, are presented, the method of judging the system stability based on the corresponding criterion is given. In addition, this paper puts forward the concrete measures to improve the stability of the power system, which provides a useful reference for the safe operation of the power system.

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