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Low frequency oscillations in power system

***Abstract**. The paper presents some information about low frequency oscillations in power system and method of estimated of frequency value of these oscillations. Sometimes these oscillations lead to very dangerous failures in the power system. For this reason, utilization of Lyapunov exponent as an early signal of blackout is proposed.*

Keywords: power system, frequency, oscillation, Lyapunov exponent.

Introduction

Each disturbance in the electric power system is accompanied by the appearance of oscillations associated with electromechanical phenomena. Most of them are damped oscillations. But sometimes there are cases, that instead of decreasing, the amplitude of the oscillations increases. This leads to very dangerous failures in the power system. Fortunately, large blackouts in power system are rare, but they are very costly for distribution companies and affect millions of people.

The typical blackout takes place in two stages. The first stage lasts quite a long time, from several dozen minutes to several hours. The threat grows slowly. There are only small fluctuations in voltage and frequency in the network. There is a lot of time to take action but there is a problem with identifying the danger. The second stage has a very fast, cascading course. It starts when the critical parameters of the power system operation are exceeded and there is no time for any action. Therefore, it is important to be able to identify the threat in the first stage.

In the further part of the article, the use of Lyapunov exponents as a criterion for blackout threat detection is proposed.

Low frequency oscillations in power system

As mentioned above, each disturbance in the electric power system is accompanied by the appearance of oscillations associated with electromechanical phenomena. Calculation of the exact frequency value of these oscillations is practically impossible due to the complexity of the mathematical model. Nevertheless, taking the simplest model of the power system, and assuming some simplifications, it can be estimated the frequency of these oscillations as follows:

$$f = \frac{1}{2\pi} \frac{U}{\sqrt{\frac{X}{\omega_s} S_N T_m}}$$

where: U – voltage, S_N – apparent power of subsystem, T_m - mechanical time constant, X - reactance of the line connecting the subsystem with the power system, ω_s - synchronous pulsation.

For example, for subsystem $S_N = 25\ GVA, T_m = 8\ s, U = 400\ kV$ which is connected with power system by overhead line $l = 100\ km, X_j = 0.32\ \Omega/km$ the frequency of oscillation is equal to $f = 0.45\ Hz$. This is a typical value for this type of oscillations [1, 2].

Lyapunov exponents as a criterion for the stability of the power system

Lyapunov exponents are a measure of dynamical system sensitivity to initial conditions and represent the average rate of separation of infinitesimally close trajectories. It is shown in the Fig. 1.

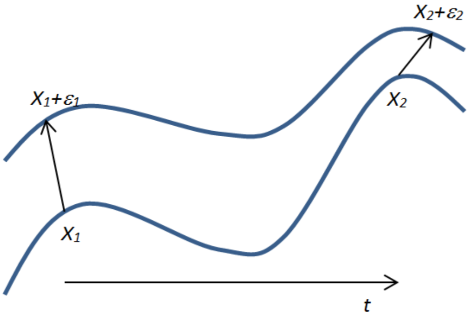

Fig.1. Graphical interpretation of the Lyapunov exponent.

Two trajectories in phase space with initial separation ε_1 diverge at a rate given by
$\varepsilon_2(t) = \varepsilon_1 e^{\lambda t}$
where: λ - Lyapunov exponent.
The maximal Lyapunov exponent can be defined as follows [3]:

$$\lambda = \lim_{\substack{t \to \infty \\ \varepsilon_1 \to 0}} \frac{1}{t} ln \frac{|\varepsilon_2(t)|}{|\varepsilon_1|}$$

In practice, numerical methods are used to calculate Lyapunov exponents [4].

Lyapunov exponents can be used as a criterion for the stability of the power system. In a big simplification, if the dynamic system is stable all exponents are less than zero. However, if the sum of the exponents is greater than zero the system is unstable. In practice, in order to early detect the possibility of blackout the value of the largest Lyapunov exponent can be observed. If the value of the exponent is approaching zero it is an early signal of blackout.

Conclusion

The paper presents method of control of power system stability by using Lyapunov exponents. If the power system is stable the largest Lyapunov exponent is less than zero, while at the point of bifurcation the exponent is equal to zero. This change of value of exponent can be used as an early signal of blackout.

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