Research on Screening Method of Synchronous Generator Dominant Parameters Based on Trajectory Sensitivity

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ABSTRACT

In order to reduce the complexity of synchronous generator dynamic parameter identification, the screening method of synchronous generator dominant parameters based on trajectory sensitivity is proposed. The mathematical model of trajectory sensitivity is established by the model and parameters of the generator. The influence degree of each parameter on the trajectory is calculated. According to the sensitivity of the trajectory, the sensitivity of dominant parameters Xd, Xq, Xd' and Xd'' of the generator is analyzed, and then the results of the trajectory sensitivity are verified by time domain simulation of IEEE 3-machines 9-node system.

Keywords: Synchronous generator, Dominant parameter, Trajectory sensitivity, Screening.

INTRODUCTION

The rapid expansion of power system scale and the application of new technologies in power grids have greatly increased their own complexity. The security of power systems has become increasingly prominent. The accuracy of the generator model and parameters not only directly affects the stability of the power system, but also affects the control decision [1][2].

The generator parameters are the basis of identification, and the dominant parameters screened by trajectory sensitivity can be applied to generator parameter identification. The generator parameter identification methods mainly include frequency domain response method [3][4] and time domain analysis method [5]-[8], which are generally applied to off-line identification. Off-line identification is not adapted to the requirements of cyclical identification. In addition, due to the large number of generator identification models, if all the parameters are considered, the identification algorithm will be complex and the identification results will be unstable.

According to the trajectory sensitivity method, the effect of synchronous generator parameters on the trajectory is calculated, and the dominant parameters that have a great influence on the dynamic process of synchronous generator are identified [9]. The dominant parameters can be used to simplify the identification complexity.

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SYNCHRONOUS GENERATOR MODEL

Considering the transient effect of the damped windings and excitation windings, a 6-order BPA practical model is used as the model of the synchronous generator [10].

\[
\begin{align*}
V_q &= -R_i q + E'' - X''_d i_d \\
V_d &= -R_i d + E'' + X'_d i_q \\
T_{d0}' \frac{dE''}{dt} &= [E' - E'' - (X'_d - X''_d) I_d] \\
T_{q0}' \frac{dE'}{dt} &= [V_f - E'_q - (X'_d - X''_d) (E'_q - E''_q)] \\
T_{d0}' \frac{dE'}{dt} &= [E'_d - E''_d + (X'_q - X''_q) I_q] \\
T_{q0}' \frac{dE'}{dt} &= [E'_q - (X'_d - X''_d) (E'_d - E''_d)] \\
T &= E'_d I_d + E''_q I_q + (X'_q - X''_q) I_d I_q
\end{align*}
\]

The rotor operating equation is:

\[
M \frac{d^2 \delta}{dt^2} + D \frac{d \delta}{dt} = T_M - T_E
\]  

Since mechanical power is not measurable, only the electrical parameters are discussed in this paper. Based on the simplification of Park's equation, 11 electrical parameters of the synchronous generator are obtained, which are synchronous reactance of \( X_d \) and \( X_q \), transient reactance of \( X'_d \) and \( X'_q \), sub-transient reactance of \( X''_d \) and \( X''_q \), transient open circuit time constant \( T_{d0}' \) and \( T_{q0}' \), sub-transient open circuit time constant of \( T_{d0}'' \) and \( T_{q0}'' \), and generator saturation coefficient \( K_G \). As the generator stator resistance \( R_a \) is small, it is assumed to be zero.

THE METHOD OF TRAJECTORY SENSITIVITY AND DOMINANT PARAMETER ANALYSIS

Trajectory sensitivity analysis is a powerful tool in the field of differential dynamical systems. It can calculate the sensitivity of parameters to dynamic response of generator, and it can calculate the sensitivity of parameters along the trajectory of the system. It reveals the dynamic behavior of the system. The trajectory sensitivity method is different for different practical problems. Based on the formulas (1) and (2) of the synchronous generator parameters, the dynamic sensitivity of the power phase angle can be obtained. The dominant parameters which have a great influence on the power angle fluctuation of synchronous generator are also screened out. The general expression of generator characteristics can be written as:

\[
\begin{align*}
\dot{x}(t, p_0) &= f(x(t, p_0), y, p_0) \\
0 &= g(x(t, p_0), y, p_0)
\end{align*}
\]  

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or
\[
\begin{align*}
\dot{x}(t, p_0) &= F(p_0) \\
0 &= G(p_0)
\end{align*}
\] (4)

Where: \( x, y, p_0 \) are the state vector, the algebraic vector, the parameter vector.

It is assumed that there is a small perturbation \( \varepsilon \) at the parameter \( p_0 \), and the perturbed parameters is defined as \( p, p = p_0 + \varepsilon \).

\[
\begin{align*}
\nu(p) &= \nu(p_0 + \varepsilon) = \dot{x}(t, p) \\
F(p) &= F(p_0 + \varepsilon) = f(x(t), y, p) \\
G(p) &= G(p_0 + \varepsilon) = g(x(t), y, p)
\end{align*}
\] (5)

Equation (5) can be written as:
\[
\begin{align*}
\nu(p_0 + \varepsilon) &= F(p_0 + \varepsilon) \\
0 &= G(p_0 + \varepsilon)
\end{align*}
\] (6)

Expand the Taylor series of (6) at \( p_0 \) and ignore the quadratic term:
\[
\begin{align*}
\frac{\partial \nu}{\partial p} &= \left. \frac{\partial F}{\partial p} \right|_{p = p_0} \\
0 &= \left. \frac{\partial G}{\partial p} \right|_{p = p_0}
\end{align*}
\] (7)

Due to:
\[
\begin{align*}
\frac{\partial F}{\partial p} &= \frac{\partial f}{\partial x} \frac{\partial x}{\partial p} + \frac{\partial f}{\partial y} \frac{\partial y}{\partial p} + \frac{\partial f}{\partial p} \\
\frac{\partial \nu}{\partial p} &= \frac{\partial x(t, p)}{\partial p} = \frac{d}{dt} \left[ \frac{\partial x(t, p)}{\partial p} \right] \\
\frac{\partial F}{\partial p} &= \frac{\partial f}{\partial x} \frac{\partial x}{\partial p} + \frac{\partial f}{\partial y} \frac{\partial y}{\partial p} + \frac{\partial f}{\partial p}
\end{align*}
\] (8)

Substituting equation (8) into equation (7) yields the trajectory sensitivity of parameter \( p \) to the dynamic response. Let \( S = \frac{\partial x(t, p)}{\partial p} \), the iterative formulas of trajectory sensitivity are:
\[
\begin{align*}
\dot{S} &= \frac{\partial f}{\partial x} S + \frac{\partial f}{\partial y} \frac{\partial y}{\partial p} + \frac{\partial f}{\partial p} \\
0 &= \frac{\partial g}{\partial x} S + \frac{\partial g}{\partial y} \frac{\partial y}{\partial p} + \frac{\partial g}{\partial p}
\end{align*}
\] (9)

Since \( S \) is constant at steady state, the initial values of \( S \) and \( \frac{\partial y}{\partial p} \) are given by:
Through formula (9) and formula (10), the trajectory sensitivity of the dynamic response can be solved by iteration.

\[
\begin{aligned}
0 &= \frac{\partial f}{\partial x} S + \frac{\partial f}{\partial y} \frac{\partial y}{\partial p} + \frac{\partial f}{\partial p} \\
0 &= \frac{\partial g}{\partial x} S + \frac{\partial g}{\partial y} \frac{\partial y}{\partial p} + \frac{\partial g}{\partial p} \\
\end{aligned}
\]

(10)

As can be seen from Figure 1, the trajectory has significantly changed by the parameters of the horizontal axis synchronous reactance \(X_q\), the vertical axis transient reactance \(X_d\)', the vertical axis sub-transient reactance \(X_d''\), and the vertical axis synchronous reactance \(X_d\).

The trajectory can be slightly changed by the parameters of the horizontal axis transient open circuit time constant \(T_{q0}'\), the vertical axis time transient open circuit time constant \(T_{d0}'\)', the horizontal axis time transient open circuit time constant \(T_{q0}''\).

It is obvious that the sensitivity curves have the feature of time-domain. The fault has an obvious effect at the moment of its occurrence, but this effect decays rapidly with the increase of time. This corresponds to the transient and steady-state of the generator.

**VALIDATION OF DOMINANT PARAMETERS BY TIME DOMAIN SIMULATION**

When the three-phase short circuit fault occurs in the power grid, the active power of the system is out of balance, which causes relative sway between the generators' rotors and corresponding fluctuations at the output power angle of the generator. The influence of generator parameters on the output power angle are observed and the trajectory sensitivity of the generator parameters verified by simulation.

Take BPA 3 generator 9-node classic system (IEEE 9-node system) as an example, the system structure is shown in Figure 2. The load uses a constant power load model.

Take the generator G1 as a reference generator and the parameters of the generator G3 as screening targets. For $X_d$, $X_q$, $X_d'$, $X_q'$, $X_d''$, $X_q''$, $T_{d0}'$, $T_{q0}'$, $T_{d0}''$, $T_{q0}''$, the ten parameters are superimposed by 20% deviation, which get the generator power angle change data. The power angle data is used to verify the parameters which screen by the trajectory sensitivity method.

As can be seen from Figure 3, synchronous reactance $X_q$ affects the power angle value of the generator initial stability, which leads to the greater sensitivity of the trajectory. It is
consistent with the trajectory sensitivity analysis. In addition, the corresponding stability curves of $X_d$, $X'_d$ and $X''_d$ are relatively large in deviation from the original curve, which is in agreement with the trajectory sensitivity analysis.

CONCLUSION

In this paper, trajectory sensitivity method is used to screen dominant parameters of synchronous generator. The trajectory sensitivity of generator parameter is calculated and the generator parameter with high sensitivity is selected as the dominant parameter. Time domain simulation is performed using BPA to validate the results of sensitivity analysis. By selecting and determining the dominant parameters therein, the identification complexity caused by excessive generator parameters is reduced.

REFERENCES