Dynamic Identification of Equivalent Parameters of Mathematical Models of Power Electrical Equipment of Electromechanical Power Systems

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Abstract. The article describes a method for dynamic identification of AC and DC hybrid power network parameters. The inaccuracy of the parameters of the electromechanical transient simulation model of the power system has caused the obvious difference between the simulation results and the actual measurement, which has restricted its online application. Over the years, the dynamic parameter identification technology based on field test and test has made great progress, but it is far from satisfactory and accurate. There is still a long research journey for the requirements of performance. The online identification method based on the actual dynamic parameters of the power system is a way to solve the problem. The article includes the main microprocessor modules for system parametric identification of load (SIP L) and an overhead power transmission line (SIP TL). The article will analyze the active electrical network and passive electrical network

1. Introduction

For the parameter identification of power dynamic systems, the problem of electrical parameters (R, L and C) of some equivalent (load, generators, etc.) of an electrical network connected to the buses of an electric power system (EPS, figure 1). In the nonlinear differential equations, substitute the instantaneous voltage u(t) and current i(t) signals of the power equipment to obtain the parameters of the equivalent model. The block diagram of the identification of the electrical parameters of the power electrical equipment of the power transmission is shown in figure 1. A distinctive feature of the design of the microprocessor system for parametric identification of the equivalent load is the absence of additional microprocessor devices and the integration of measurement and information modules (current and voltage sensors, ADC) as part of the SIP L device (figure 1). It should be noted that in order to determine lower costs of the subsystem for identifying the parameters of power transformers, measurement and information modules can also be integrated in one microprocessor device without the use of auxiliary blocks (additional SIP 1, 2, figure 1).
2. Mathematical Method and Description

According to the above of the problem of identifying the electrical parameters of an equivalent passive load, we will initially assume that there are no interconnected electromagnetic circuits. In this case, in order to reduce the volume, it is permissible to present a mathematical description of the identification problem in relation to one of the phases. Naturally, in order to identify the electrical parameters of an equivalent electric three-phase load, it is necessary to supplement the equations of the residual and sensitivity functions presented below with similar expressions for the other two phases.

Taking into account this observation, the system of transient equations of the computational model of one of the load phases has the form:

\[
\begin{align*}
    i_{\text{mes}} & = i_{R\text{mod}} + i_{L\text{mod}} + i_{C\text{mod}} \\
    u_{\text{mes}} & = i_{R\text{mod}} \cdot R_{\text{mod}} \\
    u_{\text{mes}} & = i'_{L\text{mod}} \cdot L_{\text{mod}} \\
    u_{\text{mes}} & = \frac{1}{C_{\text{mod}}} \int i_{C\text{mod}} dt
\end{align*}
\]

where \(i_{R\text{mod}}, i_{L\text{mod}}, i_{C\text{mod}}\) – active, inductive and capacitive components of the phase current of the equivalent load model, A;

\(R_{\text{mod}}, L_{\text{mod}}, C_{\text{mod}}\) – active resistance, inductance and capacitance of the equivalent load model, measured in [Ohm], [Hn] и [F].

The complete system of equations for identifying the RLC parameters of the equivalent of an electric network relative to its switching buses is formed on the basis of differential and integral expressions of equations (1). This approach is well-known and, in particular, is described in sufficient detail in research [1-8].

Through the joint equation solution, the internal current signal is discharged at the same time, and the initial balance equation of the phase current is obtained. In the solved equations, take the basic root mean square (effective) value: voltage and current, and need to introduce the basic frequency and integration step length. This is necessary, as it was shown in [1-10], to bring the residual equations to a unified system of calculus.

The calculation (identification) of the electrical parameters \(X = (R_{\text{mod}}, X_{L\text{mod}}, X_{C\text{mod}})\) of the considered model of active-reactive load is carried out as a result of the numerical solution of the nonlinear system of equations in matrix form.

\[
\left[ \frac{\partial E(t,X)}{\partial X} \right] \times [\Delta X] = -[E(t,X)]
\]
where \( \frac{\partial E(t,X)}{\partial X} \) - the matrix of sensitivity coefficients, p.u.;
\( \Delta X \) - vector-column of increments of the desired parameters, p.u.;
\( E(t,X) \) - vector-column of integral values of the objective function defined by the expression, p.u.

Based on Kontorovich's theorem, the numerical solution of Equation 2 is convergent and approaches the approximate value \( X_0 \). The speed of the calculation process is based on the extreme value and the nature of the error according to problem [7]. At the same time, a method to improve the accuracy of reading the identification parameters \( R, XL \) and \( XC \) is proposed. For the possibility of carrying out a functional analysis using the above expressions, we assume the sinusoidal nature of the change in the input phase voltages and currents. We will also consider the equivalent electrical parameters \( R, XL \), and \( XC \) of the load of the electrical network to be linear. As a result of connecting the microprocessor identification system to the current and voltage measuring transformers, according to the scheme of figure 1, digital oscillograms of phase voltages and currents were recorded in the steady-state consumption mode with a bus equivalent power load \( P_{nom} = 40 \text{ MW}, Q_L \text{nom} = 30 \text{ Mvar} \) and \( QC \text{nom} = 15 \text{ Mvar} \). A detailed description of e.

For identification of electrical parameters of an equivalent simplified model of an electromechanical system with active sources, one of the well-known ways of simplification is the representation of the AC power grid by some electromagnetic equivalent generators. In accordance with the previously performed formulation of the problem of research methods for parametric recognition of dynamic systems, the electrical signals of phase voltages \( u_{GS}(t) \), phase currents \( i_{GS}(t) \) and their derivatives \( i'_{GS}(t) \) are measured in a microprocessor system with the necessary and sufficient sampling and speed.

The mathematical description of transients of electromechanically equivalent models of alternators is made taking into account their low-frequency electromechanical properties, since the envelope (magnitude) EMF and angular frequency are functions of time. The peculiarity of these digital models is
that they do not take into account the real volt-ampere characteristics of IGBT power modules in the excitation circuits of generators and the pulse-width principle of controlling their switching. Since the main object of research is pulse converters, the mathematical description of which is made at the first stage taking into account their real volt-ampere characteristics, this approach of simplified representation of models of equivalent generators is acceptable. It should also be noted that such simplified models are characterized by the absence of electromagnetic, pulse interference in electrical signals and introduce minor distortions when reproducing the main electromechanical characteristics of hybrid electrical circuits of a three-level cascade circuit of a frequency and power converter with IGBT modules.

\[ u_{gs}(t) - E_m(t) \cdot \sin(\omega(t) \cdot t) + i_{gs}(t)R + i_{gs}'(t)X_L/\omega_{bas} = 0 \]  

(3)

It should also be understood that the desired identifiable parameters \( E_m, \omega, R, \) and \( L \) the equivalent model of generators are also time-dependent functions. However, due to the uncertainty of the law of their change, the assumption is made in this study that they are constant over a time interval determined by the sampling frequency of the cyclic survey of analog-digital conversion modules (ADC). In the problems studied in this paper, the sampling frequency is from 10 to 100 kHz (the integration step is from 10 to 100 microseconds).

Obtain a matrix with sensitivity coefficients (4), used in the numerical solution of the identification problem (3):

\[
\frac{\partial E(t,X)}{\partial X} = \begin{bmatrix}
\frac{\partial E_1}{\partial R} & \frac{\partial E_1}{\partial X_L} & \frac{\partial E_1}{\partial E_m} & \frac{\partial E_1}{\partial \omega} \\
\frac{\partial E_2}{\partial R} & \frac{\partial E_2}{\partial X_L} & \frac{\partial E_2}{\partial E_m} & \frac{\partial E_2}{\partial \omega} \\
\frac{\partial E_3}{\partial R} & \frac{\partial E_3}{\partial X_L} & \frac{\partial E_3}{\partial E_m} & \frac{\partial E_3}{\partial \omega} \\
\frac{\partial E_4}{\partial R} & \frac{\partial E_4}{\partial X_L} & \frac{\partial E_4}{\partial E_m} & \frac{\partial E_4}{\partial \omega}
\end{bmatrix} 
\]

(4)

The sensitivity functions to the deviation of the identified parameters \( E_m, \omega, R, L \) of the simplified equivalent model of the power grid containing active elements (power sources) are determined by expressions similar to (4).

The characteristics of the vector function of the smallest and largest root-mean-square error \( |E_1(X), E_2(X), E_3(X), E_4(X)| \) and its precision and speed to the initial values of the identification parameters \( X = [E_m, \omega, R, L] \) in the vicinity of the solution are shown in figure 3.

Figure 3. The nature of the change in the smallest (a) and largest (b) root-mean-square error \( E(X) \) when the initial values of the parameters of an equivalent simplified model of an electromechanical system with active sources.

The zero initial values of the desired parameters correspond to the reduced value of the initial deviation of the identification parameter by a negative value (−100)%. Doubled relative to the true
value, the initial value of the parameter corresponds to its deviation by the reduced value (+ 100) %. The analysis of the presented dependencies of the vector function of the root-mean-square error values revealed a low sensitivity of the identification equations to the setting of zero initial values of the active resistance \( R \), inductance \( L \) and amplitude \( E_m \) and frequency \( \omega \) of the equivalent simplified model of an electromechanical system with active power sources. At the initial setting of zero values for the identification parameters \( R \) and \( L \), the largest value of the standard error is 90–105 %, and at zero starting conditions \( \omega \) and \( E_m \), the largest standard error is 80 % and 140%, respectively.

In all cases, the surface of the vector function \( E(Em, \omega, R, L) \) has a moderate parabolic character with a single minimum that meets the conditions for convergence of nonlinear equations to the desired identification parameters. Just as in the previous section, the described nature of the vector function of the convergence error of a system of nonlinear equations confirms the existence and uniqueness of the solution to the parametric identification problem.

To accelerate the convergence process of the problem of identifying the electrical parameters of power nonlinear electrical equipment, it is recommended to use the second-order sensitivity equations (the "steepest descent" equations), which are used in gradient methods for solving systems of nonlinear equations. The results of evaluating its performance are shown in figure 4.

**Figure 4.** Characteristic of the change in the largest value of the standard error \( E_k(X) \) when identifying the parameters of equivalent simplified models of electric power systems.

### 3. Conclusions

By analyzing the root-mean-square relationship of the vector function error, the initial value of the active power components of the equivalent load in the high-sensitivity recognition equation are obtained. When setting the initial zero values of the identification parameters \( R \), \( L \) and \( C \), a rapid increase in the error is observed up to 250 – 400 %. With a positive error in setting the initial values \( \Delta R > 0 \), \( \Delta L > 0 \) and \( \Delta C > 0 \), the surface of the vector function \( E(R, L, C) \) has a moderate parabolic character with a single minimum that meets the conditions for convergence of nonlinear equations to the desired identification parameters.

Taking into account the identified features, when deciding on the choice of the initial values of the identification parameters \( R \), \( L \) and \( C \) of an equivalent load model with a parallel connection structure of elements, preference should be given to non-zero positive values in the space of which the vector function decreases moderately and monotonically. Otherwise, we should expect a significant increase in the error due to an excessive increase in the sensitivity coefficients of the equations for identifying electrical parameters.

For identification of electrical parameters of an equivalent simplified model of an electromechanical system with active sources, it should be noted that it is highly efficient and fast – the error in identifying electrical parameters through three recursive cycles is 6.25 %. Convergence to the desired solution with
a given error of $10^{-8}$ p.u. is achieved in ten iterations of the approximation. In this case, the asymptotic nature of the approximation (descent) over the hypersurface of the vector function is observed, which characterizes the stability of the gradient numerical solution method.

Acknowledgement
Thanks sponsored by The State Key Laboratory of Smart Grid Protection and Operational Control (Contract Number: SGNR0000KJJS2007616)

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