Application of Discrete Macromodels of Nonlinear Dynamic Subsystems for Transient Analysis by Diakoptic Methods

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Abstract - **In this paper the diakoptic approach to the transient analysis in heterogeneous electrical circuits consisting of nonlinear dynamic subcitcuits submitted discrete macromodels and subcircuits with lumped parameters is proposed. This method is implemented in software system, the adequacy of numerical experiments are shown in the test example.**

Keywords - **diakoptic, nonlinear dynamic subsystem, discrete macromodel.**

I. Introduction

Process design and analysis of modern dynamical systems, which contain a large number of components of different physical nature often requires significant computational resources. Using discrete macromodels under such conditions can significantly reduce the computational cost, because you can ignore minor phenomena for a particular type of analysis. This macromodel can be described as separate components of the designed system and subsystem of the size of elements of different physical nature. On the other hand the existence of mathematical models of heterogeneous subsystems requires diakoptic approach for the calculation of dynamic regimes in general. This situation calls for universal and effective approaches for building macromodels of complex nonlinear dynamic objects in a convenient form.

Currently, there are a number of approaches and methods that can be used for building macromodels of nonlinear dynamic systems [1], [2], but the area of application is limited due to the complexity of the task. However diakoptic approach involves the application of nonlinear dynamic macromodel subsystem as part of a complete electric circuit [3]. Then the solution of each subsystem at a certain time interval is appropriate numerical methods. This approach allows integrating new macromodel to existing software systems, which implemented the calculation of dynamic modes by diakoptic methods.

II. The procedure for building macromodels of nonlinear dynamic systems

Consider the construction of macromodels as a “black box”. This approach allows ignoring the internal structure of simulated object and therefore allows you to build the simplest macromodel (Fig. 1).

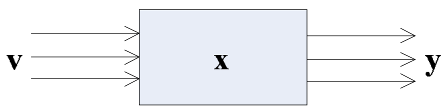

Fig.1 Macromodeling object

Vector $\mathbf{v}$ is labeled input variables, vector $\mathbf{y}$ – output variables, vector $\mathbf{x}$ – values that describe the internal state of simulated object, i.e. state variables that do not have a physical meaning. Macromodeling problem is to find a mathematical operator, which can be based on the known input variables $\mathbf{v}$ and the initial value of vector $\mathbf{x}$ to calculate the response of simulated object $\mathbf{y}$.

One of the most convenient forms of representation macromodel is discrete state equation:

$$\begin{cases} \mathbf{x}^{(k+1)} = \mathbf{F}\mathbf{x}^{(k)} + \mathbf{G}\mathbf{v}^{(k)} + \mathrm{F}\left(\mathbf{x}^{(k)}, \mathbf{v}^{(k)}\right) \\ \mathbf{y}^{(k+1)} = \mathbf{C}\mathbf{x}^{(k+1)} + \mathbf{D}\mathbf{v}^{(k+1)} \end{cases} \quad (1)$$

where $\mathbf{v}$ – vector of input variables; $\mathbf{y}$ – vector of output variables; $\mathbf{x}$ – vector of variables describing the state of the object; $\mathbf{F}$, $\mathbf{G}$, $\mathbf{C}$, $\mathbf{D}$ – matrix of macromodel coefficients; $\mathbf{\Phi}$ – some nonlinear vector-function of several variables; k – step number.

Discrete form is convenient for the calculations on a computer because you can avoid the approximation of output data, and are more practical in the application. The form of equation of state is also due to the convenience of later use macromodel object as components of a complex dynamic system.

Consider some object for which is based macromodel in the form of (1). Let the known number of its transient characteristics $\left\{\mathbf{v}_i^{(k)}; \mathbf{y}_i^{(k)}\right\}$, where k – number of discrete, i – number of characteristics. Introduce the objective function that reflects the precision with which macromodel reproduces the behavior of the simulated object. In the simplest case this may be the standard deviation

$$Q\left(\vec{\lambda}\right) = \sum_i \sum_k \left(\tilde{\mathbf{y}}_i^{(k)} - \mathbf{y}_i^{(k)}\right)^2 \quad (2)$$

where $\tilde{\mathbf{y}}_i^{(k)}$ – the object response, calculated using the macromodel, $\vec{\lambda}$ – number of macromodel parameters.

In constructing the macromodel in the form of (1) vector $\vec{\lambda}$ includes elements of matrices $\mathbf{F}$, $\mathbf{G}$, $\mathbf{C}$, $\mathbf{D}$ and coefficients vector function $\mathbf{\Phi}$.

The optimum number of macromodel coefficients will range $\vec{\lambda}^*$ in which the objective function (2) reaches its minimum. Thus, identification of macromodel coefficients reduces to finding the global minimum point of function (2).

This approach is suitable for the identification of macromodels in any form and at present any method of approximation of nonlinearity. Moreover it does not impose specific requirements for information on which the identification is performed macromodel. This allows efficient use of optimization approach as a universal algorithm for identification of parameters of dynamic macromodels.

Given the complexity of the optimization problem, which in this case is essentially nonlinear with a large number of unknown coefficients and large variations in the level of dependency of the optimized function $Q(*)$ on various parameters, one should draw attention to the choice of optimization algorithm. Practice shows that such problems are best used stochastic optimization algorithms, in particular is much less sensitive to a large number of local minima that grow from rounding errors and a large number of calculations. The authors used an algorithm of Rastryhin's directing cone [4] with adaptation of the search step length and opening angle of the cone.

III. An Example of Transient Analysis

During the numerical experiment investigated the transition process of electric circuit with transformer, loaded on half-wave rectifier with C-filter. Sinusoidal voltage source is connected to the primary winding. Discrete nonlinear macromodels of single-phase transformer [5] describes a system of equations

$$\begin{pmatrix} x_1^{(k+1)} \\ x_2^{(k+1)} \end{pmatrix} = \begin{pmatrix} 0.992 & 0 \\ 0 & 0.996 \end{pmatrix} \begin{pmatrix} x_1^{(k)} \\ x_2^{(k)} \end{pmatrix} + \begin{pmatrix} 0.05 & 0 \\ 0 & 0.05 \end{pmatrix} \begin{pmatrix} u_1^{(k)} \\ u_2^{(k)} \end{pmatrix} + \begin{pmatrix} 0.048u_1^{(k)} - 0.00048x_1^{(k)} \\ 0 \end{pmatrix} \left(x_1^{(k)}\right)^2;$$

$$\begin{pmatrix} i_1^{(k+1)} \\ i_2^{(k+1)} \end{pmatrix} = \begin{pmatrix} 0.001 & 0.0283 \\ 0.0153 & -0.00013 \end{pmatrix} \begin{pmatrix} x_1^{(k+1)} \\ x_2^{(k+1)} \end{pmatrix} + \begin{pmatrix} 0.0947 & -0.332 \\ 0.151 & 0.193 \end{pmatrix} \begin{pmatrix} u_1^{(k+1)} \\ u_2^{(k+1)} \end{pmatrix},$$

where x_1, x_2 – some internal state variables that do not have a physical meaning, u_1, u_2 – instantaneous values of voltage primary and secondary windings, i_1, i_2 – instantaneous values of current primary and secondary windings, k – number of discrete. Discretization step determines the numerical value of discrete macromodel parameters and depends on the range of operating components.

Calculation of the transition process was conducted in two modes transformer: nominal mode (Fig. 2) and saturation mode (Fig. 3), where the voltage amplitude of the transformer primary winding increased double. Calculation results of the transient test circuit known and adequate.

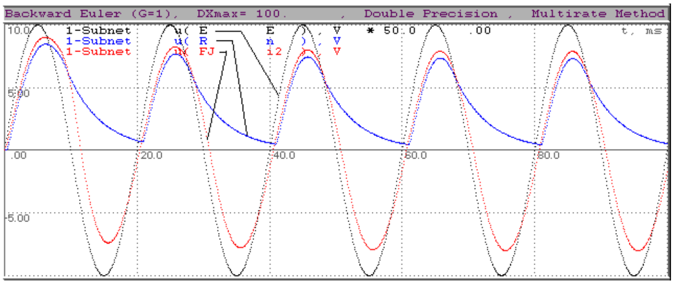

Fig.2 Graphs of the instantaneous values of voltage primary u(EE) and secondary u(FJ i2) windings of the transformer and voltage at load resistance u(R n) in the nominal mode

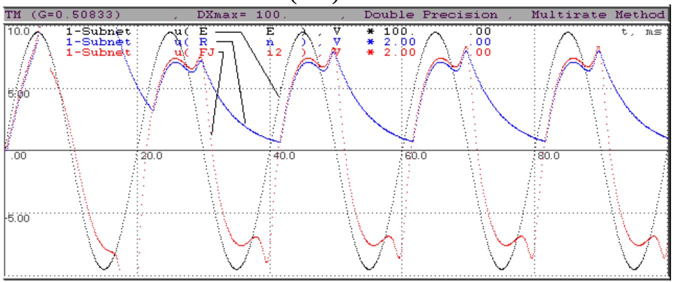

Fig.3 Graphs of the instantaneous values of voltage primary u(EE) and secondary u(FJ i2) windings of the transformer and voltage at load resistance u(R n) in the saturation mode

IV. Conclusion

The potential diakoptic approach to the calculation of dynamic regimes of nonlinear systems composed of heterogeneous parts, in our time is not exhausted. Effective implementation of new mathematical object to the software of electrical circuits simulation by diakoptic methods, namely discrete macromodel of components of nonlinear dynamic system confirms the correctness of the chosen way to improve current methods of analysis of heterogeneous systems.

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