Time-domain modeling of large-scale electric circuits by parallel methods

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***Abstract*-- Parallel methods of time-domain simulation of large-scale electrical circuits in local computing network are presented.**

***Index Terms*—Multirate methods, time-domain simulation, local computing network**

I. Introduction

During time–domain simulation of large–scale electrical circuits with different nonlinear and latent properties it is expedient to use relaxation procedure, in which partitioning a large–scale circuit into particular parts and ascertaining of connections between them with the help additional variable is stipulated. Relaxation procedure, namely multirate method, makes it possible to take into account inertial properties by an autodetection of subcircuit step size. The realization of multirate methods on parallel computing systems essentially raises efficiency of their usage [1].

II. The basic theoretical concepts

The mathematical model of a large–scale circuit, decomposed into several parts by multirate method (on k+1 exterior iteration that is an iteration on additional connection variable of subcircuits $\vec{V}$) looks like

$$\begin{cases} \dfrac{d\vec{X}_1^{(k+1)}}{dt} = \vec{F}_1\left(\vec{X}_1^{(k+1)}, \vec{V}^{(k)}\right) \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ \dfrac{d\vec{X}_N^{(k+1)}}{dt} = \vec{F}_N\left(\vec{X}_N^{(k+1)}, \vec{V}^{(k)}\right) \end{cases} \quad (1)$$

where $\left(\vec{X}_1,\ldots,\vec{X}_N\right)^T$ is vector of a subcircuit state variables; N is number of subcircuits. It is necessary to supplement system (1) by topological equations of subcircuit connections

$$\vec{V}^{(k)} = G\left(\vec{X}_1^{(k)},\ldots,\vec{X}_N^{(k)}\right) \quad (2)$$

The advantage of multirate method consists in the account of nonlinear and latent properties of subcircuits, which are evaluated with the step size. During some time, as a rule it is the greatest subcircuit step size, the exterior variables will be corrected by formula (2). If the exterior iterative process is convergent, the transition to the following correction step is carried out. But it is not always possible to obtain final result of such iterative process. Such problem is a drawback of the multirate method. Then it is necessary to use general method, in which the system of the associated discrete linear algebraic equations written in the block–diagonal form should be solved:

$$\begin{pmatrix} \mathbf{A}_1 & \mathbf{0} & \mathbf{0} & \mathbf{C}_1 \\ \mathbf{0} & \ddots & \mathbf{0} & \vdots \\ \mathbf{0} & \mathbf{0} & \mathbf{A}_N & \mathbf{C}_N \\ \mathbf{D}_1 & \cdots & \mathbf{D}_N & \mathbf{D}_0 \end{pmatrix} \begin{pmatrix} \vec{X}_1^{(k+1)} \\ \vdots \\ \vec{X}_N^{(k+1)} \\ \vec{V}^{(k+1)} \end{pmatrix} = \begin{pmatrix} \vec{B}_1 \\ \vdots \\ \vec{B}_N \\ \vec{B}_V \end{pmatrix}. \quad (3)$$

The step size numbers and numbers of subcircuit interior iterations, for example, on a Newton method are not shown here. Let's only indicate that the step sizes of all subcircuits are identical and interior iterations will be carried out simultaneously for all subcircuits. Therefore, it is possible to state, that the properties of this numerical scheme correspond to properties of the whole circuit.

III. Features of realization of parallel algorithms in a local computing network

Because of a wide circulation of local computing networks it is naturally to use them for synchronic parallel matrix operations, for example to solve some subcircuits on workstations and couple these solutions.

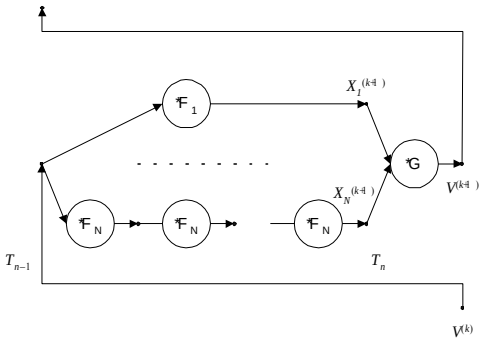

Fig. 1. The information graph of multirate method.

The common structure of a program object, in which multirate method is implemented, consists of two parts: basic (which controls information flows between workstations) and additional (which solves the particular subcircuit). The control part corrects subcircuit variable couplings and watches convergence of exterior iteration also.

On modern classification of parallel methods [2] multirate method agrees very well with parallelization of processes in space as some relaxation method. In other words each processor serves particular group of subcircuit state variables. The information graph of such process is shown in a fig. 1. Here each processor executes the procedure *F or *G. The amount of the executive procedures *F depends on the subcircuit

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step size and its commensurability with a correction step $H_{n+1}=T_{n+1}-T_n$.

IV. Results of Numerical Simulation

The procedure of the coordination of subcircuits is visually demonstrated on an example by coupled oscillator circuit (fig. 2). The peculiarity of this subcircuit is presence of nonlinear conductances with ampere–voltage function characterized by *N*-type curve. In the particular operation modes in branches that belong to primary and secondary transformer windings there are oscillations of different frequencies, which influence one another. The voltage source E_1 imitates supply voltage switching for short time from 0 up to 1 V.

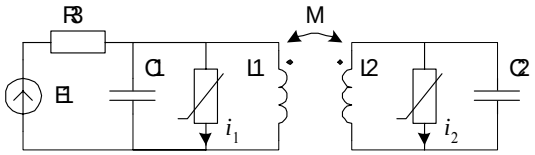

Fig. 2. Coupled oscillator circuit.

Parameters of elements are the following: $R_3 = 1\ \Omega$, $C_1 = 1\ \mu F$, $L_1 = 1$ H, M = 1 H, $L_2 = 8$ H, $C_2 = 8\ \mu F$. For both nonlinear elements their ampere–voltage characteristics are determined by expression $i = -1.5u + u^3$.

During simulation of the whole circuit (fig. 3) the step size was defined by the fastest state variable in a primary branch of the transformer. After circuit decomposition into two parts (the primary branch and secondary branch of the transformer) it has appeared, that the first subcircuit is simulated almost with the same step size, and the second branch – with considerably smaller step, which sets a correction step of coupled variables (fig. 4). It has caused diminution of execution time almost twice even for such small circuit (tab. 1).

TABLE I

Time–domain Simulation of Whole and Partitioning Circuits

	Amount of step sizes	Execution time, s
Whole circuit	8754	5.33
Two subcircuits	1: 8821 2: 1955	2.96

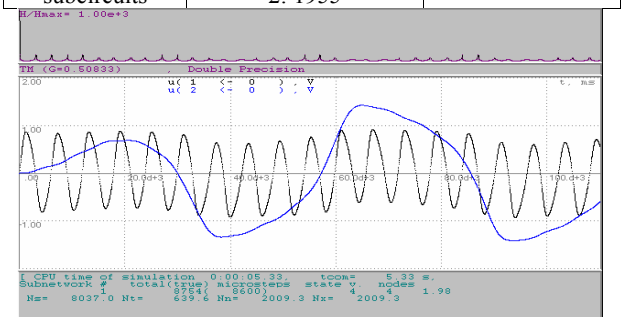

Fig. 3. Time–domain simulation of whole circuit.

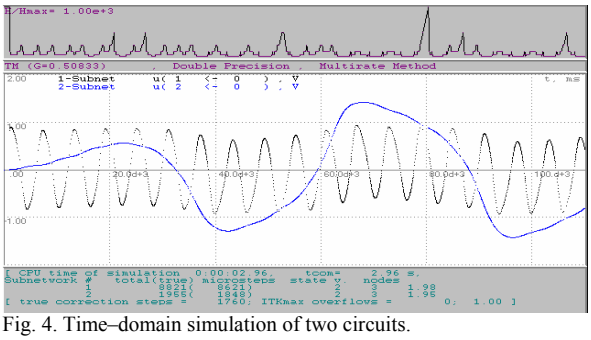

Fig. 4. Time–domain simulation of two circuits.

V. Conclusions

1. Designed multirate method, as one of relaxation methods, confirms the efficiency of time–domain simulation of large–scale electrical circuits.
2. The influence between latent properties of subcircuits and their step size is determined. The greatest step size is selected by a correction step of coupled variables.
3. Usage of local computing networks allows us to debug parallel computing procedures and define their efficiency and exploitation conditions.

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