Analog Simulation of Transient Behavior of Converters with the Application of Dynamic Thyristor Models

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INTRODUCTION

Simulation of transients in converters of electrical energy is useful when designing and examining systems operating at a high frequency, especially those with internal commutation. Transients can be simulated by different methods - dynamic models of semi-conductor valves can be used for this purpose. In analog modelling, parametric models are especially promising. A synthesis of the model can be made by the branch method, adapted to analog technology by J. Deskur [2]. The method, based on topological analysis, permits an easy arrangement of an analog model of any branched electric circuit with diodes and thyristors.

PRINCIPLES OF BRANCH MODELLING

A full description of the electric circuit is contained in Kirchoff's laws and the characteristics of its particular elements. Kirchoff's laws are topological in character. They are conveniently formulated on the basis of an oriented graph, for which a matrix of cycles $B = [B_T 1]$ and a matrix of cutsets $D = [1_D D_L]$ are determined [1]. Using the relation between the matrix of cutsets for the chords and the matrix of cycles for the tree $B_T = - D_L^t$, we get a description of the electric circuit model by means of one matrix only, e.g. the matrix of cutsets $D_L$ which pertains to the chords. A structure of a branch model corresponding to the above notation is shown in Fig. 1. It was applied to analog modelling following the development of unified models of elementary branches present in electric circuits, including branches containing diodes and thyristors [2].

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Models of tree branches have a causality of the $i \leftrightarrow u$ type; models of cords have a causality of the $u \leftrightarrow i$ type. Considering the amplification value for high frequencies, the elementary models can be arranged into a series [2]: E-C-G-G$_o$-modulated for $i \leftrightarrow u$, and then elements R$_o$-R-L-I-modulated for $u \leftrightarrow i$. Models of semiconductor devices belong to the groups of "peculiar" elements G$_o$R$_o$.

\[
\begin{align*}
U_L &= D_t U_T \\
\text{chord models} & \quad \text{branch models} \\

D_L i_L &= -I_T
\end{align*}
\]

Fig. 1. A general structure of a branched electric circuit

THYRISTOR MODELS

In view of a limited number of the operational elements of an analog device, it is recommended that the simplest thyristor models be used. In order to simulate transients of a converter of electrical current, it is necessary that models of the devices reflect their dynamic properties, at least for the forward direct off-state voltage. A number of thyristor dynamic models, derived from Linvill's physical model of a semiconductor, are discussed in [3]. The models are different with regard to complexity and $i \leftrightarrow u$ causality. In the synthesis of the circuit model it appeared necessary to define the graph tree in such a way that it contain devices used for dynamic simulation. The other devices, commutated naturally, could be simulated as static. Fig. 2 a, b shows analog diagrams for the two cases of a dynamic thyristor model. They were formed by combining respective circuits of static models [2] with a circuit which represents the recombination of carriers in the device (Fig. 2c). The thyristor model does not take into account the turn-on process and the junctions were adopted to be ideal. Despite considerable simplifications, the model can be applied to the simulation of the thyristor turn-off process, thus representing the recovery time of the blocking properties of the reverse voltage and