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A STUDY OF ELECTROMAGNETIC PROCESSES IN THE CONVERTER WITH THREE-ZONE VOLTAGE CONTROL

Abstract: The article focuses on electromagnetic processes in electric circuits with semiconductor switches. A mathematical model of a semiconductor converter with three-zone output voltage control has been created so as to analyse electromagnetic processes in semiconductor converters with pulse-width control. The graphs showing electromagnetic processes in electric circuits are given.

Key words: electromagnetic processes, output voltage and current.

Introduction

The use of switches in the electric circuits of modern converters of electricity parameters significantly complicates the analysis of electromagnetic processes. Complications arise when it is necessary to model steady processes in branchy circuits of the variable structure, where in the sections with reactive elements there appear sinusoidal, impulse and DC voltages. Studies [1-4] point out the importance of using single-modulation semiconductor converters in the construction of secondary power supply systems for diagnostic complexes of electromechanical devices with various types of input energy. This paper considers the usage of semiconductor converters as a high-frequency link in a three-zone control.

The purpose of this study is to create a mathematical model of a semiconductor converter with a three-zone control of output voltage.

Analysis of electromagnetic processes

In the construction of a mathematical model of the converter, we used the method of multiparameter modulating functions [2] which provides a preliminary representation of the algorithmic equation of the converter. The following assumptions were made: the input power grid is symmetric, and its internal resistance is zero; transistors and diodes of the rectified voltage inverter are ideal switches; matching transformers in every regulating zone of output voltage have no losses, and the load of the converter has an equivalent active inductive character.

The complete structural diagram of the converter is shown in fig. 1, where PM*A*, PM*B*, PM*C* are power modulators (PM) of phase voltages A, B and C respectively; HR – high-frequency rectifier, L – load. The set of PMs, connected to the power grid in parallel and connected at the terminal in series, is the high frequency link of the converter. The PM consists of rectified voltage invertors and matching transformers (T).

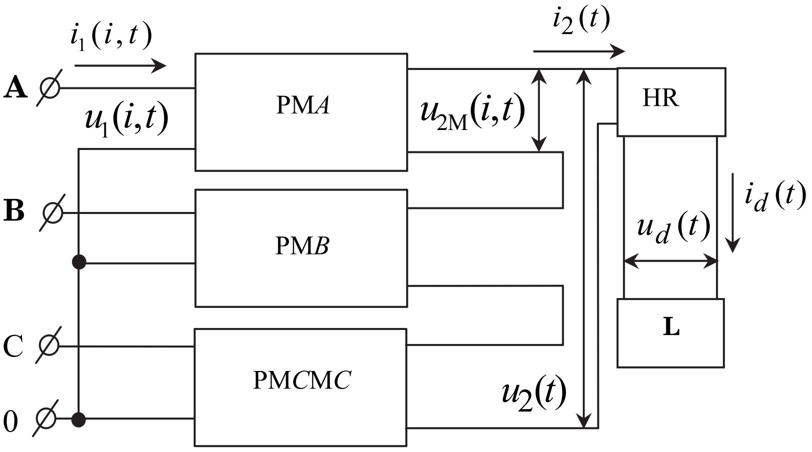

Figure 1. Structural diagram of the converter

Thus, each PM includes *N* (the number) of rectified voltage invertors.

Creating a mathematical model of the converter involves the development of mathematical support capable of analysing its electromagnetic processes with respect to the generated energy, taking into account the nature of the load, the energy consumed, as well as the energy which is transformed in specific sections and elements of the converter.

When building the mathematical model of a converter with its computer application, we use the method of multiparameter modulating functions [1-3], which provides a preliminary representation of the algorithmic equation of the converter. The following assumptions were made: the input power grid is symmetric, and its internal resistance is zero; transistors and diodes of the rectified voltage inverter are ideal switches; matching transformers in every regulating zone of output voltage have no losses, and the load of the converter has an equivalent active inductive character.

This structure allows implementing a multichannel method for converting the parameters of electromagnetic power of the grid, in which the PM carries out the branchy modulation of instantaneous values of pre-rectified phase voltages $u_1(i,t)$, frequency ω1, and three-phase power supply with corresponding equivalent modulating effects $\phi(\alpha_P,t)$ and frequency ω2. As a result, the modulated voltage is generated at the output of every rectified voltage invertor:

$$u_{2\text{M}}(p,i,t) = \frac{1}{k_\text{T}} u_1(i,t)\phi(i,t)\psi(\alpha_P,t) \quad , \tag{1}$$

where: i = 1, 2, 3 – numbers of the phases of the power supply grid; k_T – transformation coefficient of the matching transformer; p = 1, 2, 3, ⋯, n – numbers of zones of output voltage control; $\phi(i,t)$ – rectangular sine functions coinciding in time with the positions of the respective phase voltages of the grid; $u_1(i,t)$ – instanteneous values of the input voltage of the grid.

The functions of a rectangular sine are given as

$$\phi(i,t) = \text{sign}\left\{\sin\left(\omega_1 t - \frac{(i-1)2\pi}{3}\right)\right\} , \tag{2}$$

and instanteneous values of input voltage of the grid are represented by

$$u_1(i,t) = U_{1m}\sin\left(\omega_1 t - \frac{(i-1)2\pi}{3}\right), \tag{3}$$

U_{1m} – the amplitude value of the phase voltage.

Equivalent modulating effects are given as

$$\psi(\alpha_P,t) = \frac{1}{2}\sum_{2}\text{sign}\left[\sin\left(\omega_2 t \pm \alpha_P(t) - \varphi\right)\right] \; , \tag{4}$$

where $\alpha_P(t)$ – the angles of control whose changes provide the pulse-width regulation of the output voltage of the converter; φ – intial phase of equivalent modulating effects.

The output voltage of the converter $u_d(t)$ is calculated as follows:

$$u_d(t) = \frac{1}{k_\text{T}}\sum_{P=1}^{7}\sum_{i=1}^{3} u_1(i,t)\phi(i,t)\psi(\alpha_P,t)v(t) \; , \tag{5}$$

where $v(t)$ – the rectangular sine function which coincides in time with the position of the output voltage; $u_2(t)$ – the links of the high frequency converter.

$$v(t) = \text{sign}(u_2(t)) \, . \tag{6}$$

The load current is calculated as a response of a single-loop RL-circuit to the action of voltage (7). Here is the differential equation for the output circuit of the converter:

$$D(t,y) = \frac{u_d(t)}{L} - \frac{R}{L}y_0 \, , \tag{7}$$

where y_0 is derived from the initial conditions; R i L – active resistance and inductance of the load respectively.

Solution (7) with respect to the load current is determined numerically by the matrix:

$$i_d(t) = \mathrm{rkfixed}\left(y, 0, k, s, D\right), \tag{8}$$

where y – vector of initial conditions; 0, k – time interval of the solutions; s – the number of points in the time interval of the solutions; D –vector function of differential equations.

In order to calculate the input current of the high-frequency rectifier, it is necessary to divide (7) by (6). If the conversion function has a zero level, the division for the full period of existence (8) cannot be performed. This causes the need to find the current at non-zero intervals forward of the high-frequency rectifier, with subsequent adjustments of the results of separate calculations. However, representation (6) by the function of the single amplitude allows us to determine the current $i_2(t)$ by multiplying (8) by (6) and, thus, to simplify the process of calculations by giving the results for the full interval of existence (6) and (8). Thus, the input current of the high-frequency rectifier is equal to:

$$i_2(t) = i_d(t)v(t) \; . \tag{9}$$

In order to calculate the input currents of the inverters of *i*-phases for each *p*-zone of control, we accept that $i_2(t)$ flows in the general circuit of all PMs, which is formed by the series-connected secondary windings of the matching transformers, and also take into account algorithmic equation (9) as well as the fact that (2) and (4) are the functions of a single amplitude. Thus,

$$i_1(n,i,t) = \frac{i_2(t)\psi(\alpha_P,t)\phi(i,t)}{k_{\mathrm{T}}} \, . \tag{10}$$

The time charts of the load current in the coordinates of the output voltage of the converter built according to (5)-(8) for three-zone control are shown in Fig. 2.

To determine the currents of *i*-phases of the power grid in the whole range of output voltage control, we add the input currents of the inverters of all control zones in each *i*-phase. Using equation (10), the currents of *i*-phases of the power grid are calculated as:

$$i_1(i,t) = i_1(1,i,t) + i_1(2,i,t) + i_1(3,i,t) \, , \tag{11}$$

where $i_1(1,i,t)$, $i_1(2,i,t)$ and $i_1(3,i,t)$ – input currents of inverters *i*-phases for the first, second and third zones of control.

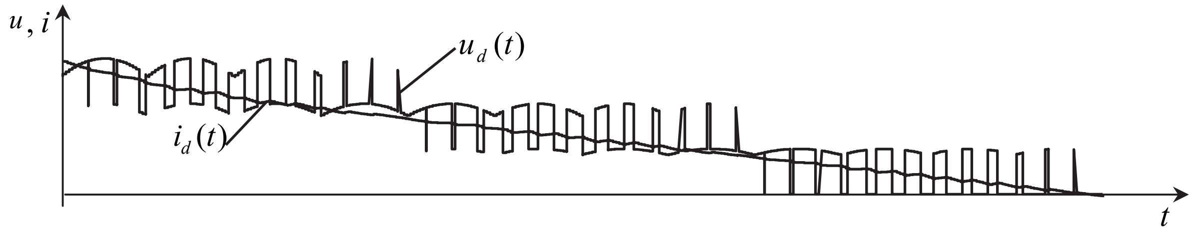

Figure 2. Time charts of the load current and voltage and input currents of inverters in the coordinates of phase voltages of the power grid

The time charts of the input currents of *i*-phases of the power grid in the phase voltage coordinates built by (11) for three-zone control are shown in Fig. 3.

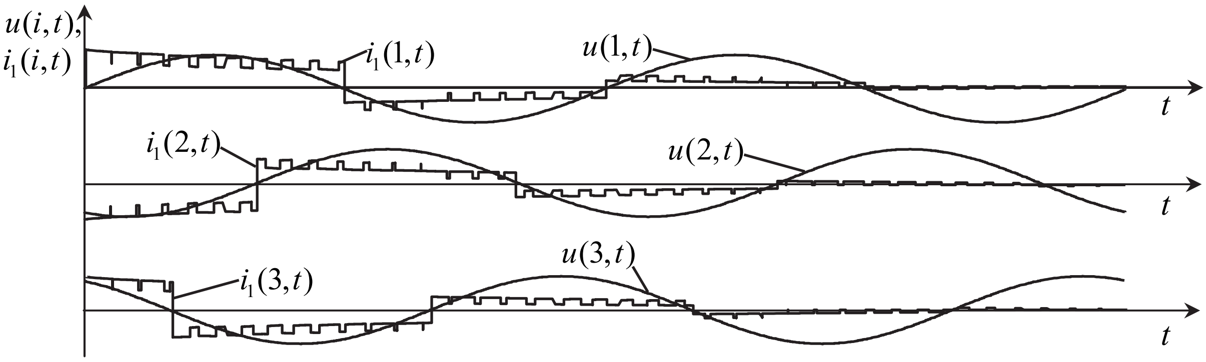

Figure 3. Time charts of the input currents of *i*–phases of the power grid in the coordinates of phase voltages

In order to find the amplitude of the currents through the power transistors of rectified voltage invertors, it is enough to analyse the currents $i_{1T}(n,i,t)$ of the primary windings of the matching transformers, which are present in the circuits where currents flow through power transistors.

Conclusions

In this study, we have analysed the electromagnetic processes in electric circuits with semiconductor switches. By means of the method of multiparameter modulating functions, the current and voltage of the load and the input currents of the converter have been calculated. We have improved this method by developing a new mathematical model with multi-zone control of output voltage and determining modulating functions to analyse subsystem components of the structure of electrical circuits with semiconductor converters.

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