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A Research Method of IGBT Non-Stationary Mode for Power and Electrical Equipment Control

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Abstract. The non-stationary mode characteristics of the generalized power equipment numerical experiments are analyzed, and the electrophysical dynamic characteristics and reliability of the IGBT in the power conversion process are studied. Based on the results of short-circuit numerical experiments and the steady-state mode of pulse width control, this paper introduces a method for analyzing the nonlinear dynamic process of IGBT drive modules during power conversion. The structure of a software algorithm for conducting numerical experiments to study the non-stationary operation mode of asynchronous electromechanical machines is proposed, and the numerical solution of transient nonlinear differential-algebraic equations of electrical equipment is described by gradient parameter method. The results of this study will help to study the dynamic nonlinear characteristics of the operation process of power and electrical equipment control and automation tools, and have practical significance for evaluating the computational efficiency and reliability of developing mathematical models in the next research work.

Keywords: IGBT, non-stationary, dynamic, reliability, nonlinearity, power conversion, emergency, nonlinear differential equations, power electrical equipment

1. Introduction

In the actual industry, because the power and capacity of power equipment are getting larger and larger, IGBTs have less harmonic components, and the multi-level voltage waveforms formed by IGBTs require fewer switching devices, simple topology and PWM modulation is relatively easy. In recent years, it is widely used in large-capacity high-voltage inverters and low-voltage high-performance inverters [1]. In this paper, an analysis method for nonlinear dynamic process of IGBT driver module in power conversion process will be described.

When creating a mathematical description of the transient processes of power electrical equipment, the main provisions of the theory of stationary, non-stationary and non-linear filtering of signals, methods of the theory of analysis and synthesis of linear

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and nonlinear electrical circuits, as well as methods of the theory of electromagnetic, electromechanical transient processes and the stability of electric power systems are used. The methodology consists in conducting numerical experiments to study the dynamic nonlinear characteristics of power electrical equipment and its control and automation tools， Studies to identify the features of the dynamic properties and electrophysical characteristics of IGBT modules that are part of the power converter devices are carried out in non- stationary (including emergency) modes of electromagnetic and electromechanical frequency and power conversion [2-6].

2. Research Methodology for Non-stationary Modes of Power Electrical Equipment, Taking into Account the Electrophysical Characteristics of IGBT

When carrying out numerical experiments, In the non-stationary modal and nonlinear operation process of power equipment, differential equations are solved numerical solution method. In all investigated modes of operation of the power equipment, the value of the integration step is automatically selected based on the criteria for changing the rigidity of the nonlinear DAE system and ensuring the stability of the numerical method. The stable numerical solution was carried out when estimating the value of the methodical error determined by (1) and (2) [7].

$$[F_{11}^{-1}]\times dy'_{D_k} - [F_{11}^{-1}\times F_{12}]\times dy_{A_k} = dy_{D_k} \le \varepsilon \; ; \tag{1}$$

$$[F_{21}\times F_{11}^{-1}]\times dy'_{D_k} + [F_{22} - F_{21}\times F_{11}^{-1}\times F_{12}]\times dy_{A_k} = -f_{A_{k-1}} \le \varepsilon \; , \tag{2}$$

ε – The specified value of the maximum permissible error of the iterative solution;
dy_{D_k} – Increment of variables of the subsystem of differential equations determined according to the formula of the numerical integration method.

Numerical models are investigated using the fourth-order Runge-Kutta numerical method. In this case, the stability evaluation of the numerical integration method is carried out while controlling the remainder $O(h^5)$ of the Taylor series in the stability region shown in figure 1.

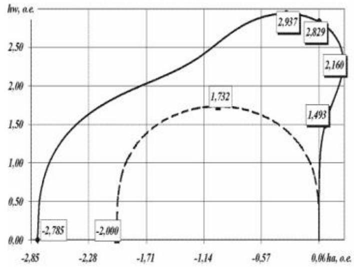

Figure 1. The area of stability of numerical methods of the 2nd and 4th order.

The initial value of the integration step h (or dt) during the calculations was chosen equal to dt = 50 μs based on the acceptable error value (no more than 10^{-6} relative units) for calculating the desired variables (phase currents) According to the flowchart of figure2, at each k-th integration cycle with a step h_k, the procedure for finding are performed the values of the derivatives of currents of equivalent generators $di(t_k)/dt$ loads (figure 2), derivatives of currents flowing in the circuits of frequency and power converters with IGBT modules and flux linkages of asynchronized electrical machines $d\Psi(t_k)/dt$ power and measuring transformers, and calculating their integral values.

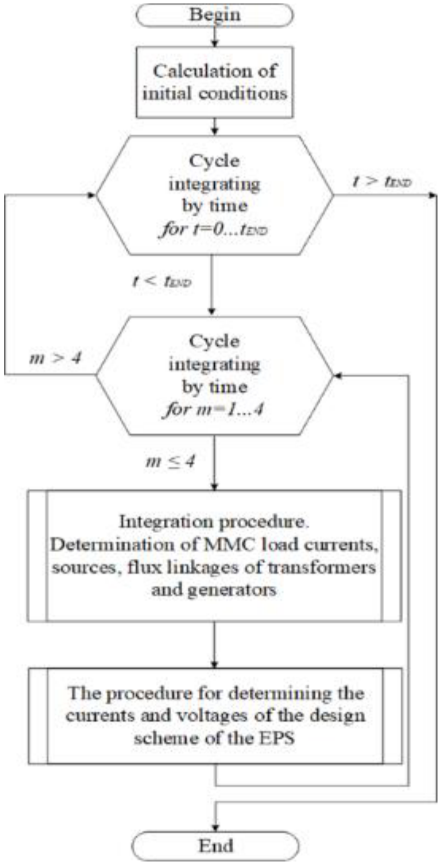

Figure 2. Generalized algorithm for calculating non-stationary modes.

3. Solving Nonlinear System of Non-stationary Modes of Power Converter with IGBT Modules

The gradient parametric method for the numerical solution of rigid systems of nonlinear differential-algebraic equations with error control. Its distinctive feature is that in the process of iterative solution, the previously found predicted integral values of the functions of variables are corrected with the parametric coefficients of the equations (Jacobi submatrices) [8,9].

The study of transient processes in the electric power system is carried out using the equations of the balance of electrical and mechanical moments (or powers). The system of equations under study is reduced to relative units by introducing the basic values of the frequency ω_{base}, voltage U_{base}, current I_{base}, power S_{base}, and resistance Z_{base}. This approach is necessary for a correct and proportionate assessment of the conditions for the iterative solution (convergence) of nonlinear differential and algebraic equations with a given relative error ε. Thus, we will assume that equations (3) and (4) and all the following expressions for the unknown variables y_D and y_A are reduced to a single system of quantities using some basic parameter Y_{base}. This approach simplifies the interpretation of the mathematical description of the numerical method developed, provided that all physical parameters and quantities, except for time, are measured in relative (reduced) units. The step, the integration interval, as well as the physical function of time itself, are measured traditionally (according to the SI system) in seconds.

$$M_D(t, y_D, y_A) \times y_D' = f_D(t, y_D, y_A); \tag{3}$$

$$0 = f_A(t, y_D, y_A), \tag{4}$$

4. Approbation in Conducting Numerical Experiments of a Digital Nonlinear Model with IGBT Modules

Studies of the developed mathematical models of power electrical equipment of the design electric power system with asynchronous machines (figure 3) were carried out under the following design conditions (non-stationary modes) of operation:

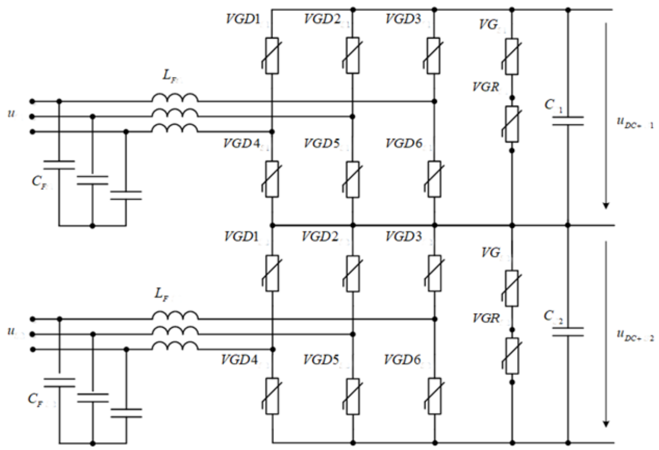

Figure 3. The area of stability of numerical methods of the 2nd and 4th order.

1). Starting and subsequent normal operation of the cascade circuits of the frequency and power converter with IGBT modules;

2).Short-circuit mode (at time t = 0 second) in a DC circuit with full bypass of the cascade rectification circuit;

3).External three-phase short circuit mode (at time t = 0 second) in the AC power supply network of industrial frequency (50 Hz);

To conduct numerical experiments, the developed model of hybrid power transmission (with the equivalent of an AC network) is used, in which two frequency and power converters operate in parallel (figures 3). Also, when performing calculations, it is assumed that the load nodes have autonomous power sources capable of feeding the short-circuit point.

By analyzing perform an analysis of non-stationary processes caused by short circuits. It follows from the figure that before the occurrence of a short circuit (at time t = 0 s), the required electrophysical characteristics of a hybrid AC and DC power transmission system with two frequency converters are provided for the specified model parameters. It should be noted that under normal conditions, the power transmission system is electromagnetically compatible, since the power quality indicators for monitoring the voltages and currents at the input and output of the system meet the regulatory requirements. At the same time, each transistor rectifier stabilizes the rectified voltage at a given level with relatively small ripples (figure 4).

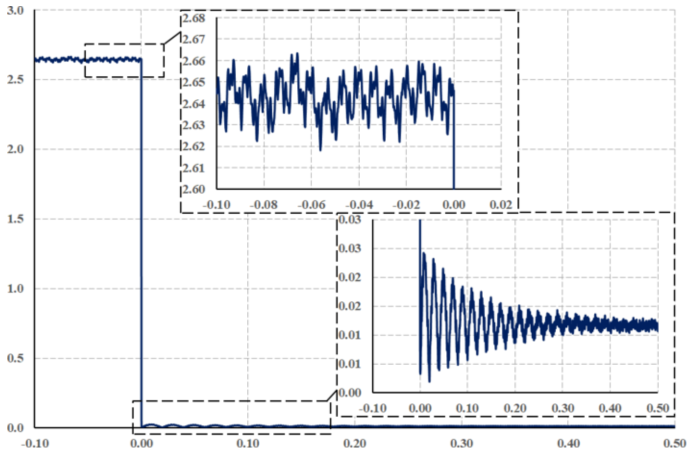

Figure 4. Voltage at the terminals of the transistor.

The presence of distributed generation in the load nodes and active frequency and power converters determines a multiple increase in phase currents during external short circuits in AC circuits. In this case, the IGBT modules that are used in the converters may fail due to their breakdown due to their overload by short-circuit currents. To prevent this from happening, it is necessary to provide a protective device in case of an emergency increase in currents. In this case, the transistors in the frequency and power converters must be disconnected via the control circuits, after which, in the absence of currents, they must be disconnected by protective switching devices.

5. Conclusions

A gradient parametric method for the numerical solution of nonlinear differential-algebraic equations of non-stationary modes has been developed and tested. A distinctive feature of the developed numerical method is the control of its stability range and adaptive correction of the integration step.

The tested shown that in the studied non-stationary modes of power electrical equipment and in short-circuit mode, the developed digital models are adequate and reliably reproduce the dynamic properties and electrophysical characteristics of IGBT modules. The results are of practical significance for the preliminary assessment of the efficiency and adequacy of the developed digital model and the reliability of the proposed modeling methodology.

In the follow-up research, considering the control of computing resources by existing methods, the computing time and cost should be minimized.

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