conductors due to an increase in the RMS current.

A method for determining additional heat losses from higher harmonics in the windings of electric motors of alternating current, which are uniquely determined based on the resulting value of the coefficient of harmonic distortion of the motor current. This method can be used in the case when the effect of the skin effect on the resistance of the windings of motors with a limited range of higher harmonics of the current is insignificant. In this case, the additional losses in the windings from the higher harmonics can be calculated based on the value of the root mean square value of the current, and, consequently, the increase in losses in the square depending on the value of the RMS value of the current.

These ratios allow to determine the additional losses in the power supply system from the value of the harmonic distortion coefficient (THD) of the load current. Distortion of mains current with a harmonic distortion coefficient of 50 % causes an increase in power losses in the electrical network by approximately 25 %. In the case when the spectrum of higher harmonics is limited and the increase in the active resistance of the network in this frequency range increases insignificantly, the effect of the skin effect can be neglected. In this case, the influence of higher harmonics of the load current on the power loss in the resistance of the windings can be determined based on the root mean square value of the load current.

The dependence of additional power losses in the active resistance of windings on higher harmonics as a function of the coefficient of harmonic distortions of the load current is established. It is shown that in the range of THD values of the input current from 0 % to 30 %, the additional losses in the electrical network will increase from 10 % to 48 % relative to the electrical resistance of the DC conductor.

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DETERMINATION OF POWER LOSSES IN SEMICONDUCTOR CONVERTERS BY COMPUTER SIMULATION

Power losses and efficiency are one of the most important indicators in semiconductor power converters [1]. "Manual" calculation of power losses in semiconductor converters with different types of modulation is a rather difficult task and requires the search for a new technique.

Programs for automatic calculation of power losses in power IGBT-transistors, such as MelcoSim, Semisel, Iposim, etc. are quite common [2]. These programs are a very convenient tool, but they allow you to perform automatic calculation of power losses only for "standard" topologies (up and down DC converter, three-phase stand-alone voltage inverter) with "standard" control algorithms (pulse-width modulation) (PWM) with DC fill factor, sinusoidal PWM, spatial-vector PWM) [3]. The disadvantages of existing programs are the inability to model "non-standard" topologies, such as power active filters, active rectifiers with power factor correction, multilevel converters and many other topologies, or standard topologies with non-standard control algorithms.

Matlab / Simulink is one of the most popular programs for the study of semiconductor converters, which allows you to simulate almost any converter topology with any control system. However, the disadvantage of this program is the lack of consideration of dynamic power losses in IGBT transistors. In addition, the volt-ampere characteristic of IGBT-transistors is presented as a linear function (Fig. 1).

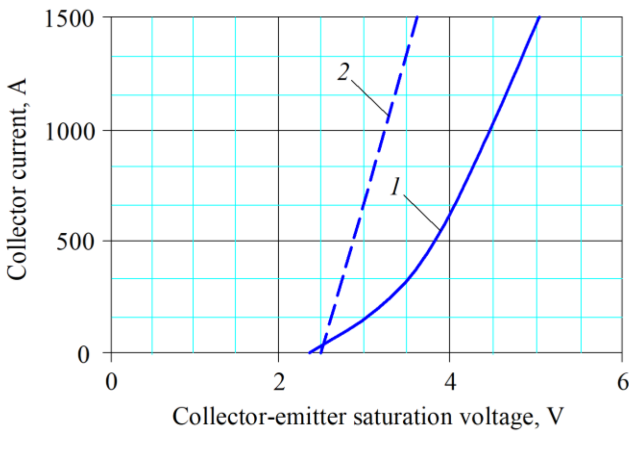

Fig. 1. Volt-ampere characteristic:
1 – real transistor; *2* – transistor in the Matlab/Simulink program

In programs of the scheme of technical modeling of SPICE type, such as Multisim, LT-spice, TINA, MicroCap, modeling of volt-ampere processes is more exact. Transistor models in SPICE simulation take into account the on and off time of transistors and take into account the dynamic losses in transistors. However, the above programs allow you to simulate only low-power transistors, as models of high-voltage power IGBT-transistors in these programs simply do not exist. When determining the power loss of IGBT-transistors, the following dependences are basic:

– the dependence of the voltage between the collector and the emitter on the collector current (volt-ampere characteristic (VAC) of the transistor);

– VAC of the reverse diode;

– the dependence of the power of the transistor, the power of the transistor, as well as the recovery energy of the reverse diode from the current of the emitter of the transistor.

The process of current and voltage switching in the IGBT-transistor and the graphical distribution of static and dynamic losses is shown in Fig. 2.

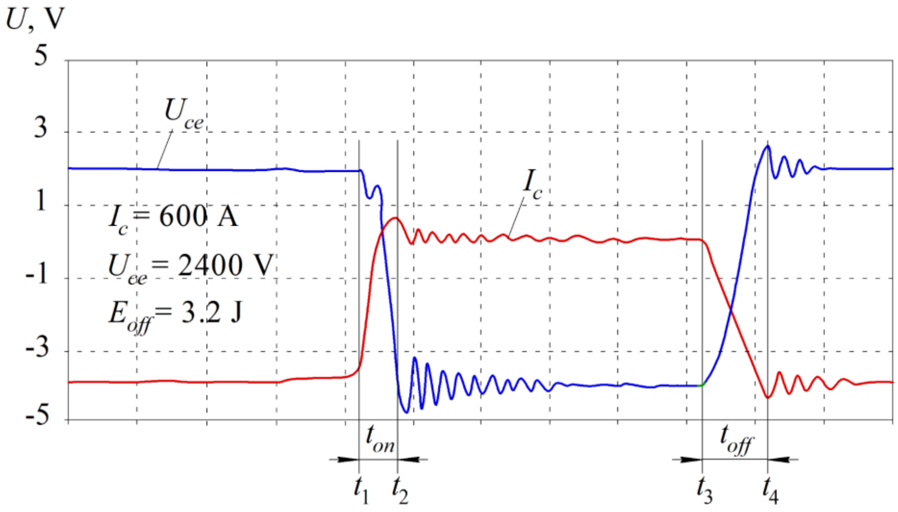

Fig. 2. The process of switching current and voltage in the IGBT-transistor

It should be noted that the energy characteristics of the transistor at a temperature of 25 °C and 125 °C are quite different and with increasing temperature, the losses in the transistor increase.

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ЕНЕРГОРЕСУРСОЗБЕРЕЖЕННЯ У СИСТЕМАХ ЕЛЕКТРИЧНОЇ ТЯГИ

Для систем електричної тяги можна виділити такі ключові тенденції у енергоресурсозбереженні: використання на рухомому складі сучасного тягового електропривод, застосування комбінованих енергетичних установок, удосконалення систем тягового електропостачання шляхом застосування накопичувачів енергії. Важливим також є забезпечення оптимального управління енергетичними потоками як між тяговим електроприводом та силовою установою на рухомому складі, так і між рухомим складом і системою тягового електропостачання в цілому.