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Research of the Speed Mode of Power Keys of Matrix and Bilateral Frequency Converters

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Abstract

The article is devoted to the investigation of the thermal regime of power switches of a matrix frequency converter (MFC) and a traditional two-link frequency converter (TFC). A comparison of the processes of thermal cycling of MFC and TFC with scalar modulation is made. The carried out researches have shown the difference in the processes of thermocycling of bi-directional keys (BiDK) of MFC and power transistors of TFC. The established fact makes it possible to provide a current load on the BiDK MFC on average 15-20% higher than in the TFC under other equal conditions, which should be taken into consideration when designing frequency converters (FC).

Keywords: thermal mode, power switches, matrix frequency converter, two-link frequency converter, bi-directional key

INTRODUCTION

The matrix frequency converter (MFC) [1] belongs to the group of direct frequency converters (DFC), the main feature of which is the absence of the need for a BiDK link [2,3]. The basis of the MFC power part of the MFCis a bi-directional key (BiDK) [4], usually made on the basis of two IGBT-transistors connected by emitters.

The greatest interest in studying the static characteristics of the MFC is their comparison with the analogous characteristics of a traditional TFC. This is a complex problem, since it is necessary to take into consideration the difference in the circuitry, control methods, the difference in the approaches to calculating the parameters of the input filter and the switching frequency of power switches and in the transmission coefficients of the voltage.

The study of thermal processes in the BiDK and the determination of the relationship between the temperature and the parameters of the output voltage of the MFCand the load current will allow to determine both the maximum output power of the MFC and the safe operation area of the converter.

THERMAL MODEL OF FC TRANSISTORS

To perform the task, simulated Simulink-models of the MFC and the TFC have been used. The control of the power keys of the MFC model is carried out according to the algorithm [5] with the observance of the law of scalar modulation U/f^2=const.. The power keys of the TFC model are also governed by the law U/f^2=const..

When modeling, it was assumed that both FC inverters operate on a static RL load with cosφ=0,8. The rest of the initial data for modeling are the parameters of the supply network (inductance L, active resistance R), network filters (inductance L_f, capacity C_f), key switching frequency . The frequency f_s BiDK of the MFC was equal to 8 kHz, which corresponds to a switching period T_s = 125 μs.

In turn, for the TFC, the switching frequency of the transistors of the inverter was assumed to be equal to 16 kHz to achieve an equal number of switching transistors per second with the MFC, and also to provide a non-linear distortion factor of the output voltage corresponding to that in the MFC.

The switching frequency of the transistors of the rectifier TFC was equal to 6 kHz in order to reduce the switching losses in the transistors. The initial data for modeling are summarized in Table 1.

Table 1: Initial data for modeling thermal conditions

	MFC	TFC
PowerVolt,U, V	3x380V 50Hz	3x380V 50Hz
Coil resistance of power mains	0,105	0,105
Inductance of power mains	0,165	0,165
Voltage of DC link filter, V	-	600
Capacity of DC link filter	-	200
Input filter capacity	40	25
Inductance of the input filter	0,35	1
Switching frequency of transistors k Hz	6 (converter) 16 (inverter)	8
Load power factor cosf	0,8	0,8
Management law	if f< 50Hz U/f^2=const if f>50Hz U=330V	if f< 50Hz U/f^2=const if f>50Hz U=380V

The maximum output power transmitted to the load through the converter can be determined as a function of the maximum transition temperature of the IGBT transistors depending on the current load of the IGBT. To determine the transition temperature of transistors in the simulation models of the MFC and TFC, power loss calculation units and calculation of the IGBT transition temperature have been added (Fig. 1).

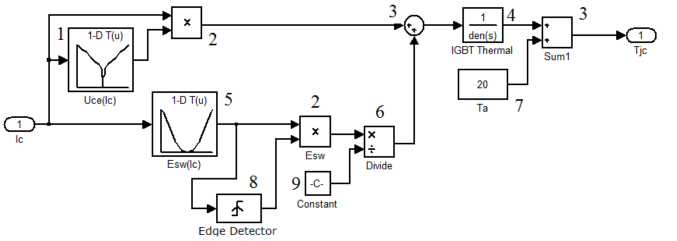


Figure 1: Model of loss calculation and calculation of the transition temperature of an IGBT- transistor: 1- block for calculating the forward voltage drop "collector-emitter" U_{ce} (I_s); 2- multiplier, 3- adder, 4- thermal model IGBT, 5- switching power calculation unit IGBTEsw (I_s); 6- division unit, 7 - Ambient temperature setting unit, 8- Front detector, 9 - IGBT switching time setting block

The model presented in Fig. 1 is simplified, and does not take into account the uneven temperature distribution inside the device. The input signal of the model is the signal I_s, proportional to the current through the transistor of the IF. Based on the magnitude of this signal, the loss of conductivity and the switching losses of the transistor are calculated.

The calculation of the instantaneous value of the IGBT conductance loss power with the reverse diode is performed by multiplying (block 2) the instantaneous values of the collector current I_s and the voltage drop at the transition of the transistor U_{ce} (with a positive current direction) or the voltage drop at the transition of the transistor U_{ac} (with negative current direction).

In its turn, the instantaneous value of U_{ce} is calculated by the unit (1) based on the U_{ce} (I_s) and U_{ac} values given in the instrument passport and entered in block 1 in the form of an approximated dependence. The instantaneous conductivity loss signal is transmitted to the adder 3.

The switching loss power value is calculated as follows: the switching energy E_{sw} (which is the sum of the IGBT on and off energies) is calculated in block 5 based on the approximated $E_{sw}(I_c)$.

The calculation of the value of E_{sw} occurs at the moment of IGBT switching from the closed state to the open state at the signal from the front detector 8. The calculation of the switching loss power is performed by the division unit 6 based on the set switching time (block 9), after which the corresponding signal is transmitted to the adder 3.

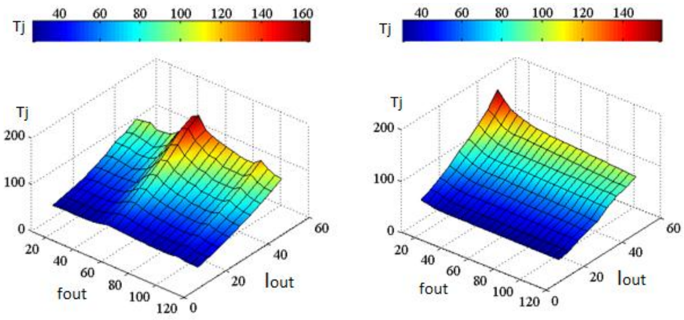
The signal of the total loss power is transferred to the thermal model IGBT (4), constructed according to the principle described in [6].

In this case, the values of the thermal resistances and the heat capacity of the crystal-casing transitions IGBT are taken from the data for the IRG4PN50UD device manufactured by the International Rectifier corporation.At the output of block 4, a transition temperature signal IGBTTj is generated, which is summed with the ambient temperature T_a set in block 7.

The values of the transition temperature $T_J$in both the MFC and the TFC are a function of the output frequency and the output current of the converter. Based on the values of obtained Tj it is possible to construct temperature maps T_J =f (I_{exit}, f_{exit}).

Temperature maps of transistors for the MFC and the TFC atT_a= 20 ° C are presented in Fig. 2.

For the MFC, a map of the most transistors DK (S1, S5, S9) loaded at a frequency f_{exit} = 50 Hz is given. On these maps, the temperature values are limited to T_J = 200 °C; the excess of T_J= 100 ° C will be considered as a condition for the output of IGBT from the system (taking into account the modeling error in this way).



a) b)

Figure 2: Temperature maps of MFC transistors (a) and TFC (b) TJ = f (I_{exit}, f_{exit})

The temperature maps in Fig. 2 show the difference in the thermal load on the MFC and TFC transistors as a function of the output frequency and current: in the case with the TFC at low output frequencies (f_{exit}<30 Hz), the duration of the current load on individual transistors increases, which causes their intense heating .

The MFC does not have such a disadvantage, because even as the output voltage is close to zero, the load phase current is distributed between transistors connected to different phases of the supply network, which reduces the load on individual keys and allows increasing the output power of the converter.

When analyzing the instantaneous values of the output signal of the model in Fig. 1, the difference in the processes of thermal cycling of the keys of two types of inverter is seen (Fig. 3).

As can be seen from Fig. 3, a, c, d, with $f_{exit} \neq$ 50Hz, a cyclic uniform heating of the MFC DC takes place. A similar effect is observed for all $f_{exit} \neq n \cdot f_{вх}$, where n- is an integer.

Atf_{exit}= 50 Hz, on the contrary, there is uneven heating of the DC (Fig. 4). In fact, when the frequency of the MFC output voltage is equal to the frequency of the supply voltage, the output current is not evenly distributed between the BiDK. The way in which the output current of the MFC will be distributed between different BiDK s depends on the angle of displacement between the input and output voltage vectors and the load power factor. [7]. This mode from the viewpoint of heating the MFC BiDK is the worst.

In the case of the TFC, the cooling conditions of the transistors improve with increasing output frequency f_{exit}, (Fig. 3, b, d, e), while the thermal load on the rectifier keys is less than in the inverter. This property is typical for the operation mode of the TFC, in which the energy flow is directed from the network to the load. In the recuperation mode, the reverse phenomenon is observed.

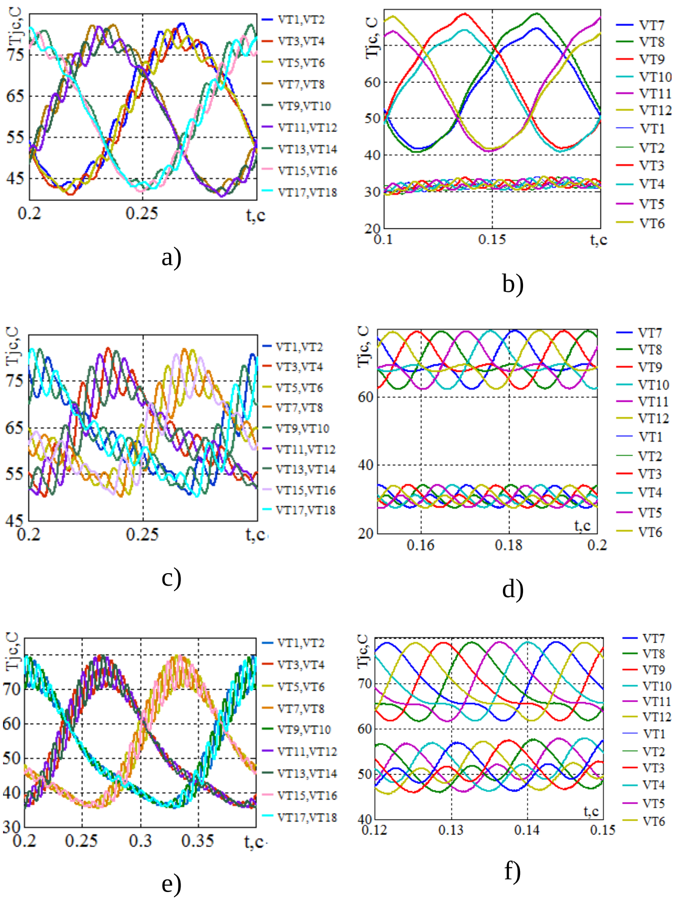


Figure 3: Diagrams of the thermal cycling process of the MKF BiDK: a – MFC f_{output} = 5 Hz; b- TFC f_{output} = 5 Hz; c - MFC f_{output} = 30 Hz; d - TFC f_{output} = 30 Hz; e – MFC f_{output} = 45 Hz; f- TFC f_{output} = 45 Hz;

Using the obtained temperature maps in Fig. 2 and analyzing the diagrams in Fig. 3, it is possible to determine the safe operation area for the two types of inverter based on the maximum permissible value of the transition temperature Tj achieved at the corresponding currents Imax for a given fout. Those. when Imax was determined by simulation, the load power was sequentially increasing to the value at which the temperature Tj became equal to 100 ° C.

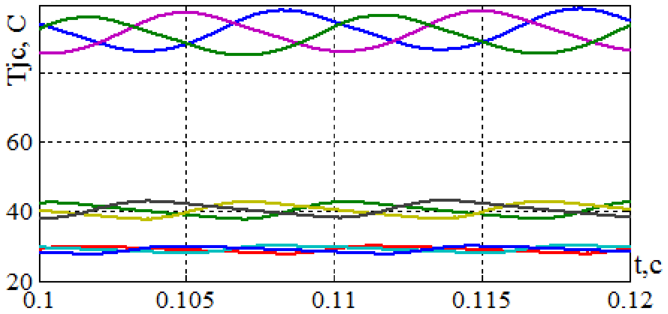


Figure 4: Diagrams of the thermocycling process of the MFC DC at fow = 50 Hz

Areas of safe work Imax (Uout) obtained during the simulation (model for IF output frequencies f from 1 to 50 Hz under the control law U / f2 = const are shown in Fig.5

As can be seen from the simulation results, with output frequencies fout ≠ 50 Hz MFC provides a higher current output compared with the TFC, which is primarily due to the difference in the circuitry of the two transducers.

At the same time, the MFC provides a higher output power only at f <50Hz, which is due to a lower output voltage (330 V at MUF vs. 380 V in TFC).

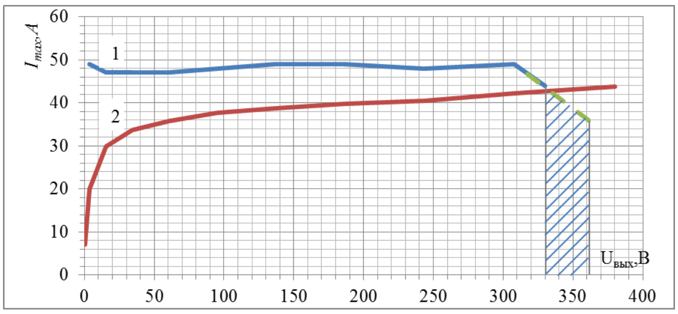


Figure 5: Areas of safe operation of MFC (1) and TFC (2) when implementing IFs on transistors of the type IRG4PH50UD

CONCLUSION

The study of the thermal regime of power keys shows the difference in the thermal cycling processes of the MFC DC and the power transistors of the TFC, that with other things being equal, makes it possible to provide a current load on the MFC DC on average 15-20% higher than in the TFC.

This advantage occurs when the output frequencies of the MFC are not multiples of the power source frequency. In its turn, regimes with fw = n • 50 Hz (n = 1,2,3 ...) are undesirable for MFC, due to uneven distribution of the current load on the DC (and, consequently, uneven heating).

This feature of MFC should be taken into account in the design. It should also be taken into consideration that the use of output voltage modulation slightly widens the area of safe operation of the MFC, in view of the increased thermal load on the DC.

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