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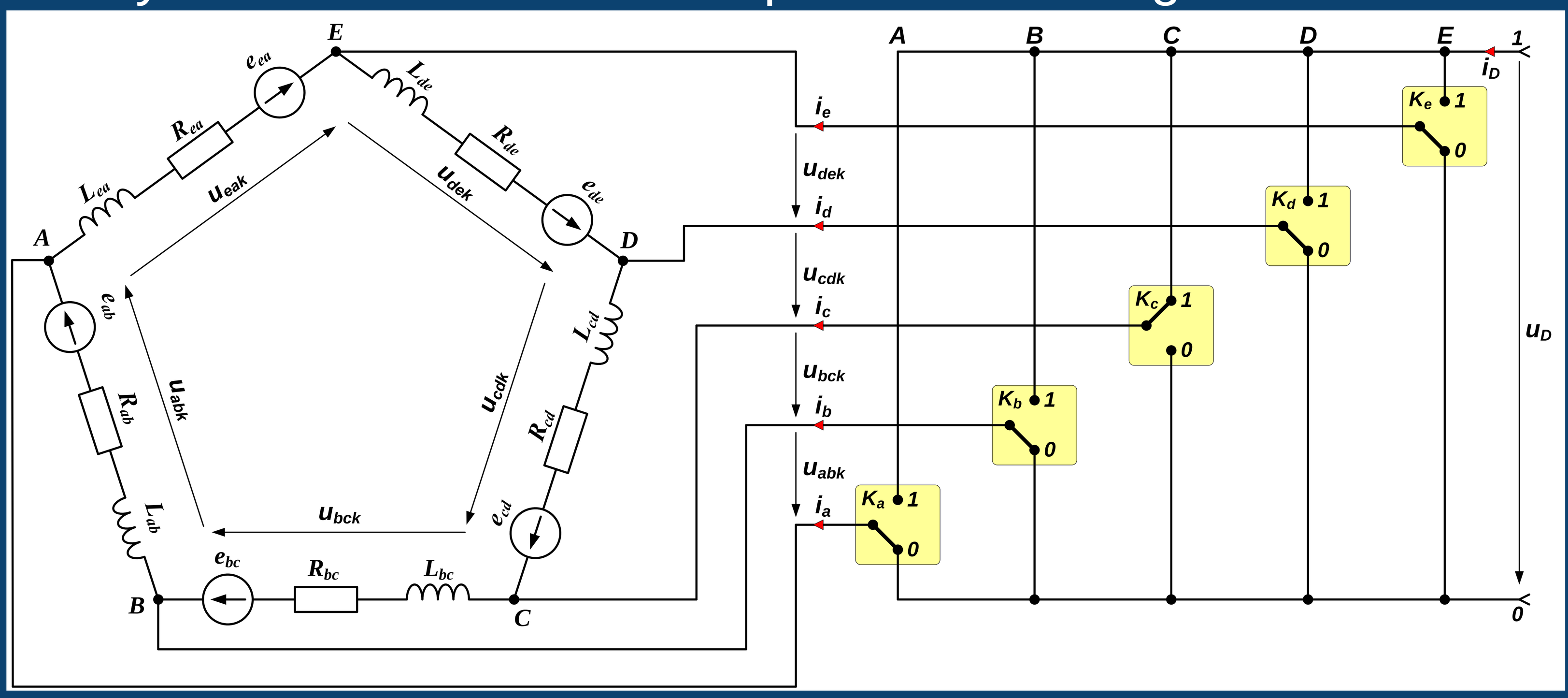
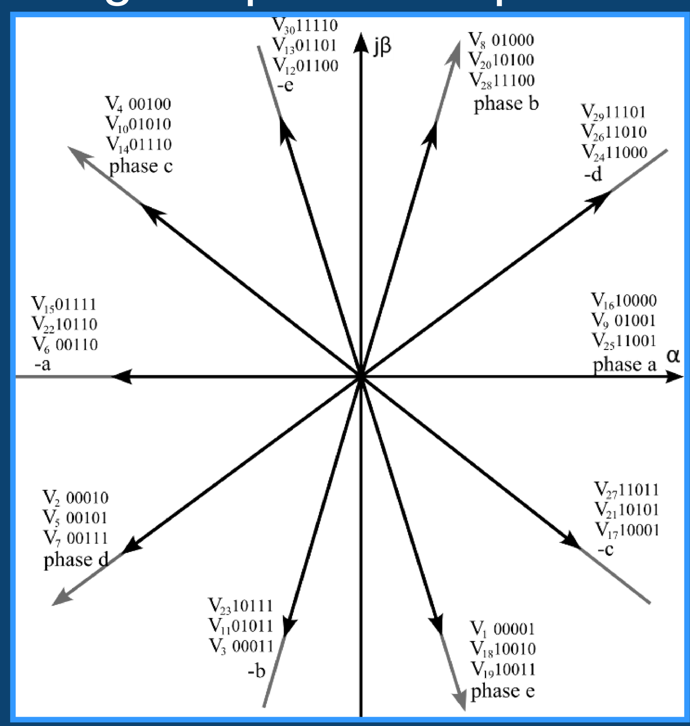
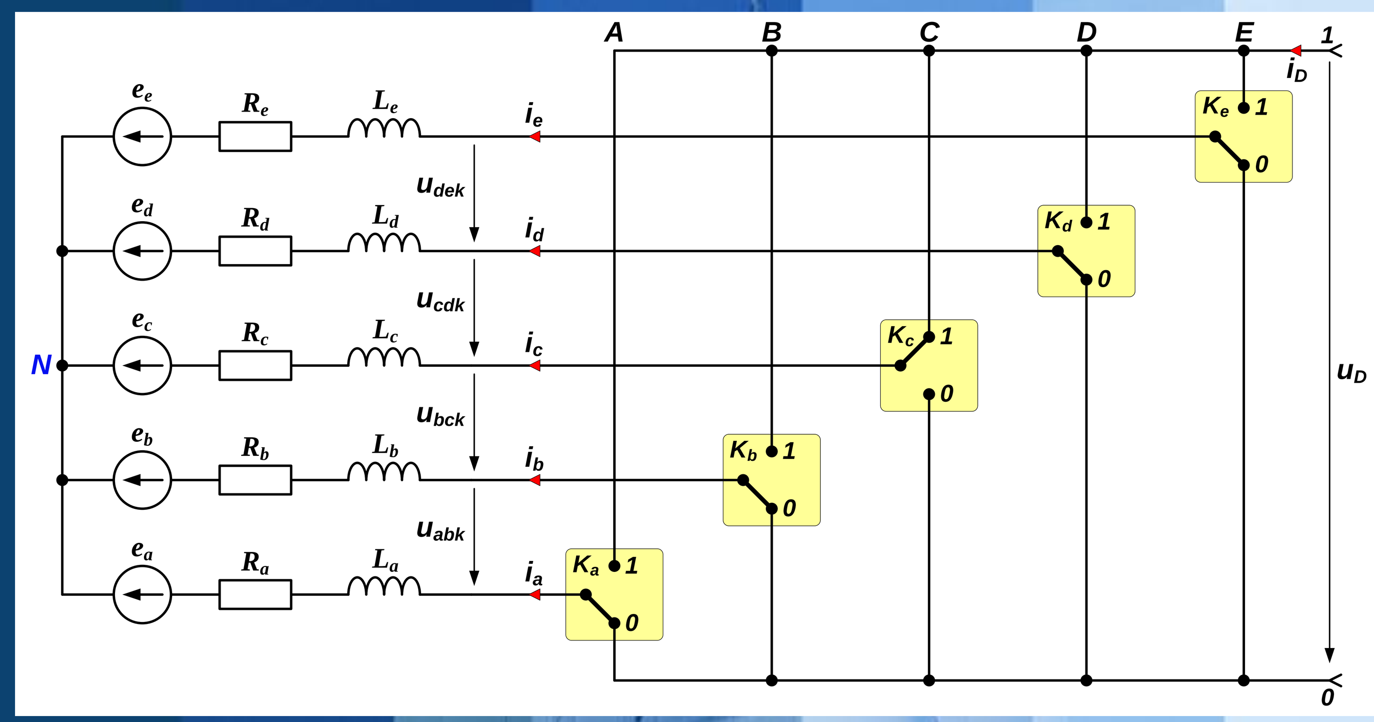
Vector control strategy of the 5-Phase 2-Level VSI

The simplified model of the five-phase two-level inverter contains a voltage source and five two-state switches Ka, Kb, Kc, Kd, Ke. Diagrams of a five-phase inverter combined with a star and pentagon load are shown below. The positive pole of the voltage source is denoted as 1 and the negative pole as 0. The switches Ka, Kb, Kc, Kd, Ke are in that order assigned to appropriate phases a, b, c, d, e. Every switch can connect one pole of the voltage source to one assigned phase output.







The consecutive states of the five-phase inverter are denoted by the decimal index k = 0, 1, ... 31. Each selected k-state means that five phase-to-phase output voltages are connected to load. These voltages form a matrix row assembled of five elements as a result defining the state vector of the VSI: $V_k = \left[U_{ab_k}\, U_{bc_k}\, U_{cd_k}\, U_{de_k}\, U_{ea_k}\right]$

Since $u_{abk} + u_{bck} + u_{cdk} + u_{dek} + u_{eak} = 0$, then the state vector V_k is determined by any four successive phase-to-phase voltages under the condition that *x* and *y* denote the neighboring phases that is *x*, *y* are: x – a, b, c, d, e and y = a, b, c, d, e. The binary expansion of the index k permits to determine output polar voltages. They are referenced to the negative pole of the voltage source U_D, for example: $u_{a0k} = a_{kud}$ or $u_{b0k} = b_{kud}$. As a result, the state vector V_k is defined by use of respective binary symbols of the index k. The transpose of the matrix V_k, denoted as the state vector Vk, presents all five phase-to-phase voltages:

$$V_k^T = \begin{bmatrix} u_{ab_k} \\ u_{bc_k} \\ u_{cd_k} \\ u_{de_k} \\ u_{ea_k} \end{bmatrix} = \begin{bmatrix} u_{a0_k} - u_{b0_k} \\ u_{b0_k} - u_{c0_k} \\ u_{c0_k} - u_{d0_k} \\ u_{d0_k} - u_{e0_k} \\ u_{e0_k} - u_{a0_k} \end{bmatrix} = U_D \begin{bmatrix} (a_k - b_k)_2 \\ (b_k - c_k)_2 \\ (c_k - d_k)_2 \\ (d_k - e_k)_2 \\ (e_k - a_k)_2 \end{bmatrix}$$

Since the symbols a_k, b_k, c_k, d_k, e_k can assume only values 0 or 1, then the output phase-to-phase voltage, independently of the phase number, may assume only three values: 0, $+U_D$, $-U_D$.

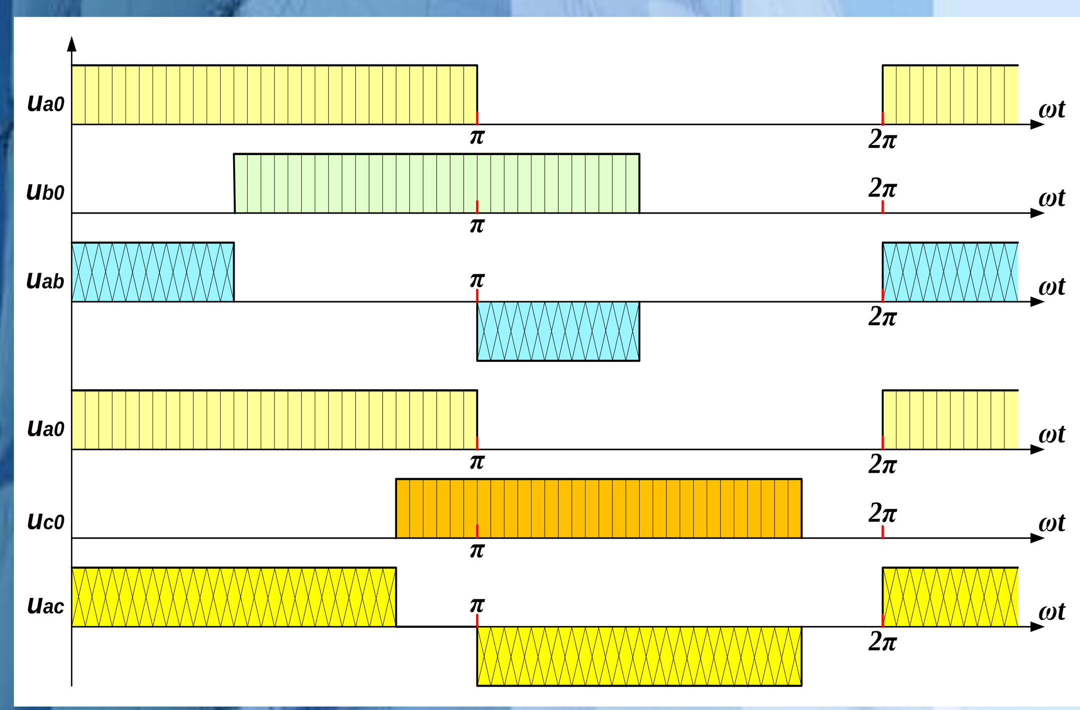


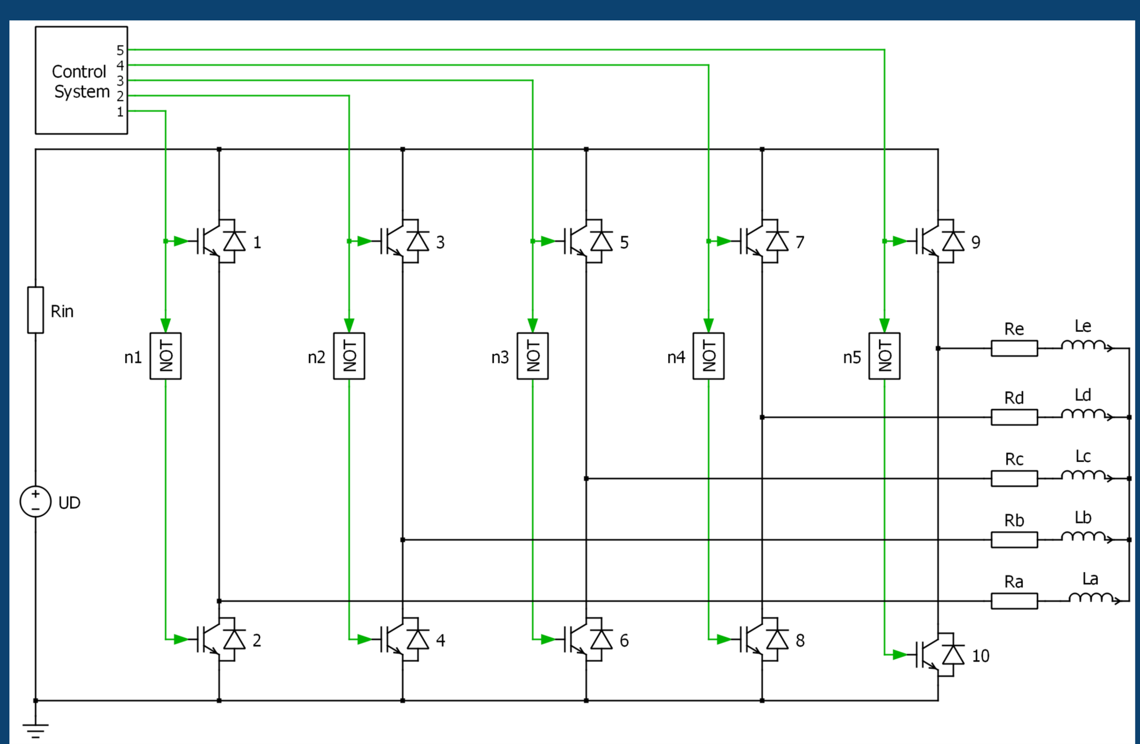
Figure presents a few selected voltage waveforms: three polar and consequential two phase-to-phase voltage waveforms: u_{a0}, u_{b0}, u_{c0}, u_{ab}, u_{ac}. In order to receive such voltage waves, it was assumed that all phase outputs are connected consecutively, every single 72º, for half a period to the positive pole of the voltage source U_D. The phase-to-phase voltage U_{ac} has been determined according to the rule $U_{x(x+2)k}$. So, the state vector is defining as a matrix composed of one row including five elements.

Simulation Tests

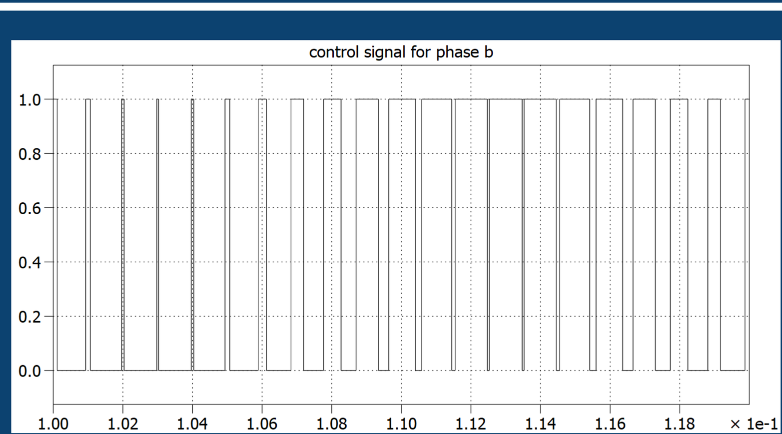
PWM contol

Vector control

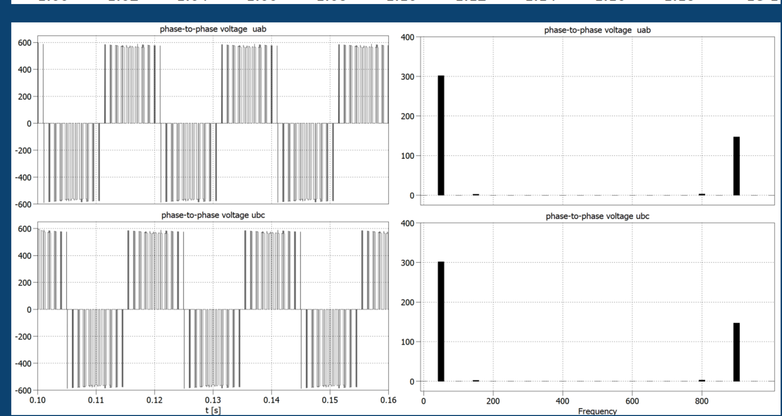
The following parameters were assumed for the purposes of simulation tests: voltage UD=600 V, frequency f=50 Hz and load: R=10 Ω and L=15 mH. In the simulation studies, two control strategies were compared with the same parameters of the load circuit, i.e. the strategy described in the article (which was named of vector studies) and PWM (Pulse-Width Modulation).



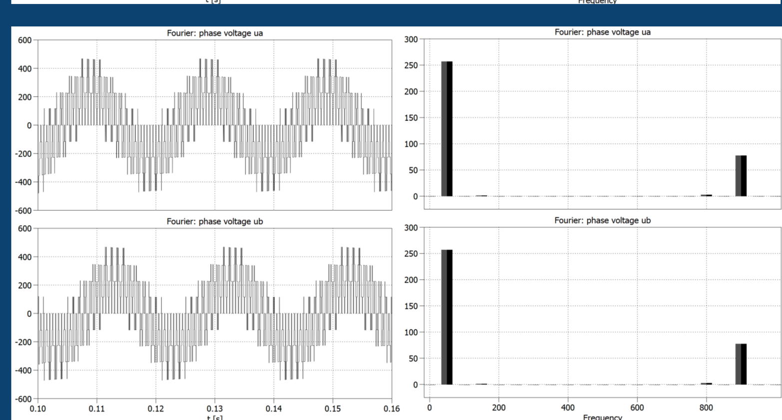
The model of the five-phase two-level inverter made in the PLECS program



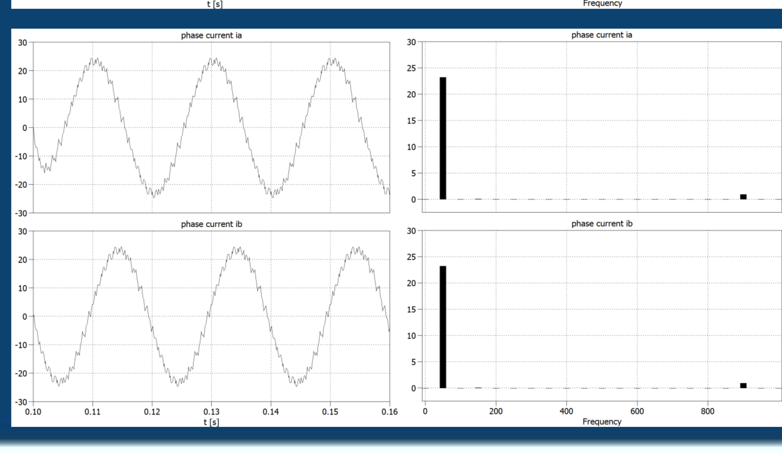
PWM control signals of phase b



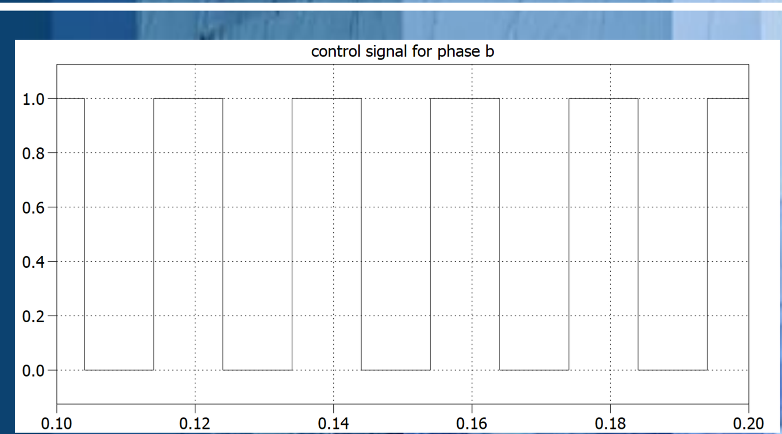
PWM signals - phase-to-phase voltages of phase ab and bc on the left and their Fourier spectrum on the right, RMS = 257V, THD = 119%.



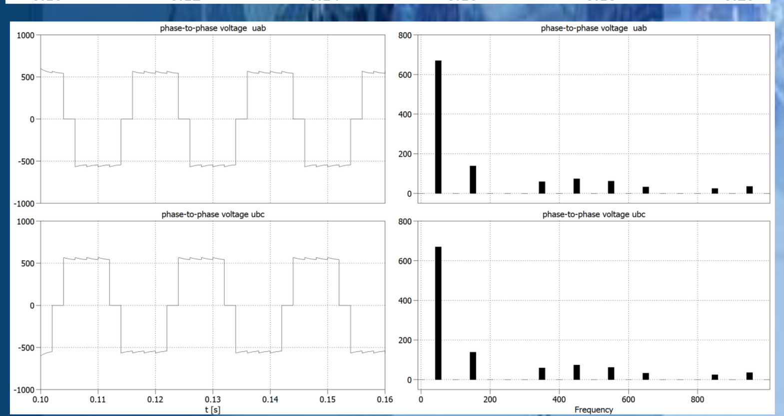
PWM signals - phase voltages of phase a and b on the left and their Fourier spectrum on the right, RMS = 186 V, THD = 86.2%.



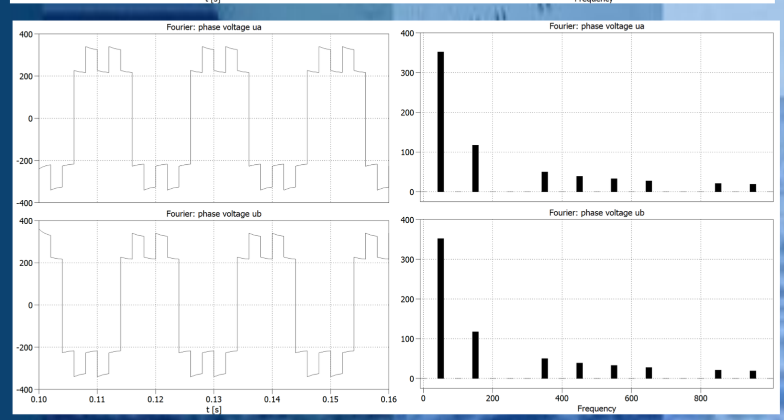
PWM signals - phase currents of phase a and b on the left and their Fourier spectrum on the right, RMS = 12.3 A, THD = 6%.



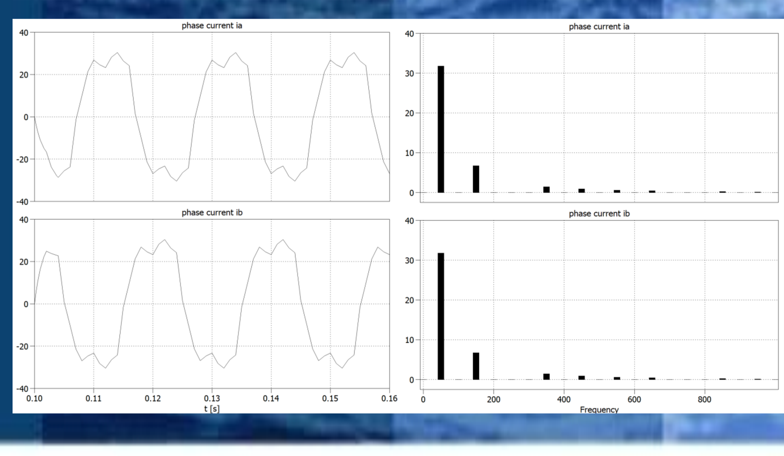
Vector control signals of the phase b



Phase-to-phase voltages of phase ab and bc on the left and their Fourier spectrum on the right, RMS = 382 V, THD = 30%.



Vector signals - phase voltages of phase a and b on the left and their Fourier spectrum on the right, RMS = 209.6V, THD = 43%.



Vector signals - phase currents of phase a and b on the left and their Fourier spectrum on the right, RMS = 17.4A, THD = 22%.

CONCLUSION

The main contribution of this paper was to present a very simple mathematical system of notation and formulas. The inverter may be defined by the use of definite state vectors or standard space vectors obtained with the use of the polar voltage transform. The paper presents a notation system of all five-phase two-level 32 converter states. Every state is defined by two vectors: state vector and polar voltage space vector. Both vectors are specified by the use of the same digits resulting in binary expansion of the decimal vector index. The method could be advanced to other multiphase and multilevel inverters. This construction of the notation system provides an easy-to-use mathematical tool. It enables selection of a suitable vector sequence assuring the desirable voltage or current waveform. The discussed vector sequences were based on the imperative of only one switching in one phase during the whole voltage period. This mathematical tool makes it easier to define state and space vectors as well as to calculate the available phase and phase-to-phase voltages and the resulting load currents.

This mathematical tool was verified during simulation tests using the PLECS program. The results obtained for steering using PWM and then for steering by use of the described method were compared. By comparing the control signals, it can be seen that the described control strategy uses a smaller number of switching's in the same time interval. The inter-phase voltages for the described vector method are characterized by lower RMS and THD values. Similarly, more favorable RMS and THD values can be observed for the phase voltages obtained in the control strategy described in the article. Comparing the phase currents, it was noticed that for the PWM control strategy, the current is characterized by a lower THD, but also a lower RMS value.