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# THE ALGORITHMS OF HIGH-VOLTAGE FREQUENCY CONVERTERS CONTROL AND ASSESSMENT OF THEIR INFLUENCE ON PARAMETERS OF FILTER-COMPENSATING DEVICES

**O. Sinchuk, D. Mykhailichenko**
Kremenchuk Mykhailo Ostrohradskyi National University
vul. Pershotravneva, 20, Kremenchuk, 39600, Ukraine. E-mail: seem@kdu.edu.ua

In the article the actuality of the field of study has been presented – the realization of requirements of minimum possible distortion of current and voltage curves and the design of effective structure of high-voltage electric drive. The suggestions concerning the structure of block IGBT- frequency converter have been grounded and given. The algorithm of formation of the trapezoidal integral curve of output voltage and algorithm of the cyclic by-turn switching of blocks of converter has been studied providing the decline of the dynamic losses in transistors and the increase of efficiency factor of the whole electrotechnical complex. The method of calculation of the L-type filter has been suggested.

**Key words:** IGBT-frequency converter, L-type filter.

# АЛГОРИТМИ КЕРУВАННЯ ВИСОКОВОЛЬТНОГО ПЕРЕТВОРЮВАЧА ЧАСТОТИ ТА ОЦІНКА ЇХ ВПЛИВУ НА ПАРАМЕТРИ ФІЛЬТРОКОМПЕНСУЮЧИХ ПРИСТРОЇВ

**О. М. Сінчук, Д. А. Михайличенко**
Кременчуцький національний університет імені Михайла Остроградського
вул. Першотравнева, 20, м. Кременчук, 39600, Україна. E-mail: seem@kdu.edu.ua

Визначено актуальність напряму дослідження – реалізація потреби мінімально можливого спотворення форм кривих струму та напруги і створення ефективної структури високовольтного електроприводу. Обгрунтовано та приведено пропозиції щодо структури блочного IGBT-перетворювача частоти. Представлено алгоритм формування трапецеїдальної інтегральної кривої вихідної напруги й алгоритм циклічного почергового переключення блоків перетворювача, що забезпечить зниження динамічних втрат у транзисторах і дозволить зменшити параметри складових системоутворюючих елементів. Як наслідок, підвищується коефіцієнт корисної дії всього електротехнічного комплексу. Запропоновано метод розрахунку Г-подібного фільтра.

**Ключові слова:** IGBT-перетворювач частоти, Г-подібний фільтр.

PROBLEM STATEMENT. The high-voltage electric drive (HED) is the basic consumer of electric energy of industrial and especially mining and metallurgical works of the country.

The problem of obtaining the required level of efficiency of the high-voltage systems is directly related to the task solution of providing of their energy efficiency that is grounded by a choice of their components – control systems [1].

In their turn, the obtainment or non-obtainment of the required level of energy efficiency of all the complex of HED is mostly determined with the type of one or another control system. Modern HEDs in their basis contain impulsive control system (ICS) by the level of voltage on the clamps of electric engines which provide the impulsive converters (IC) of electric energy (EE). It means that impulsive converters, being the effective types of EE conversion, simultaneously are the sources of distortion of forms as input so as the output current and voltage curves, that defines the most significant factor (HED) – the quality of EE that does not always represent the required level [2].

In this connection among the number of the basic requirements to the system of control of HED there is a requirement of minimum possible distortion of current and voltage curves, so it is necessary to solve the twofold problem – the design of effective structure of HED with minimum possible distortion of current and voltage curves. In order to achieve this goal there are two real methods: the algorithm of the IGBT-converter control and the filter-compensating device [3, 4].

EXPERIMENTAL PART AND RESULTS OBTAINED. 1. The structure and algorithm of the high-voltage IGBT-transistor converter control.

The phase of high-voltage transistor frequency converter is shown in Fig. 1.

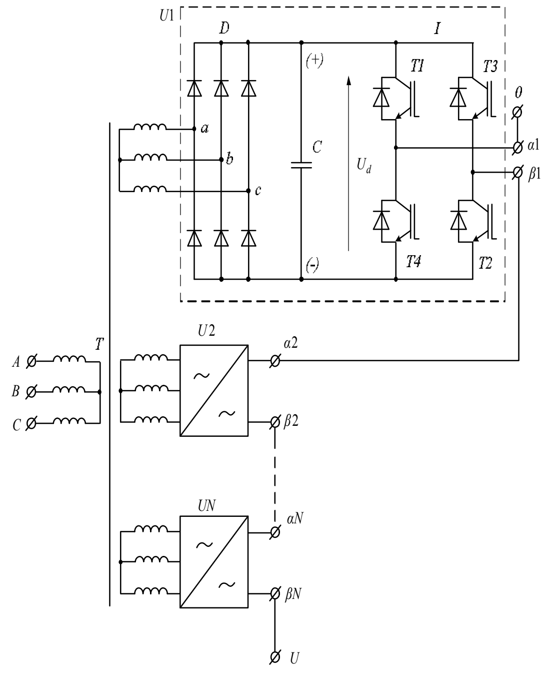


Figure 1 – The schematic circuit of phase of high-voltage IGB-transistor frequency converter

In the Fig. 1 the following notation: *A, B, C* – phases of high-voltage power supply network; *T* – transformer; *a, в, c* – phases of groups of secondary winding supplying the blocks; *U* – converter blocks (N – number of blocks); *D* – diode rectifier; *I* – IGB-transistor inverter; *C* – capacitor-accumulator; $\alpha,\beta$ – output phases of block.

The auxiliary and protective elements are omitted with the aim not to lose the essence. The formation of output curve is carried out in the following way.

The positive half-wave $U_\alpha$ of output voltage is formed by IGB transistors of *T1* and *T2*. The negative half-wave $U_\beta$ is formed by the pair of *T3, T4*. At PWM of voltage, the positive impulse of output voltage is formed by turning on of T1 and T2.

The current flows in the circuit $(+)\to T1\to\alpha1\to 0\to\ldots\to\beta1\to T2\to(-)$. A zero pause (position) appears in case of setting off the one of T1 or T2, for example, T1 is turned off, and T2 remains turned on. The external current flows in a circuit $\beta1\to T2\to(-)\to diode\ T4\to\alpha1$. Therefore, during one half-wave only one transistor T1 PWM modulates, and the other *T2* is constantly turned on. For the even load of the IGB transistors of *T1* and *T2* they are PWM-modulated by-turn through a half-wave.

By means of PWM voltage the optimum integral curve of output voltage is formed as a trapezoid with the duration of horizontal section $\pi/3$ [1, 2].

It is accepted, that PWM of voltage constantly carries out the only one block of converter, for example, always block $U1$ . Other blocks form either voltage of rectangular configuration with permanent amplitude $U_d$, or are in a zero position (through conductivity). The first block $U1$ is regulated with the value of voltage from 0 to $U_d$ and forms the integral curve of output voltage the phase by it, complementing the rectangular voltage of other blocks to the trapezium. The illustrating example is in Fig. 2, 3 for the case of the converter operation on the second stage of voltage. On the first stage (level) of the voltage only $U1$ was functioning.

On the second stage it was the second block $U2$, forming the rectangular voltage with the permanent amplitude and variable duration without PWM, and first block $U1$, forming PWM of voltage, which is complementary rectangular to the trapezoidal total output voltage of the phase with amplitude from $U_d$ to $2U_d$. The rest of the blocks were in a zero position.

In fig. 2 for the simplicity, the modulating impulses were not shown, but only integral curves were given.

The further increase of the voltage value is carried out by means of connection of the next blocks.

For the even load of blocks they are put into operation cyclically, in turn of half-wave formations of an output voltage of phase.

The cycle on the second stage:

– the first half-wave – $U1$ . $U2$ ;

– the second half-wave – $U1$ . $U3$ ; etc.

It is obviously that the cycle is in maximum (all blocks are involved):

– the first half-wave – $U1$ . $U2$ . $U3 \ldots U_N$ ;

– the second half-wave – $U1$. $U3$. $U4 \ldots U_N \,..U2$ ;

– the last half-wave – $U1 . U_N$ . $U2 \ldots U_{(N-1)}$.

The algorithms of formation of the trapezoidal integral curve of output voltage of the cyclic by-turn control of the converter blocks provide the substantial decrease in the dynamic losses in the IGB transistors. In spite of considerable improvement of the output voltage curve form of the IGBT-converter, the offered algorithm of its formation does not show the expected approximation to the sinusoidal. The natural step of the further approximation to this form will be connected with application of the filter-compensating devices-filters [4]. However, this problem also requires its foundations for the convincing arguments.

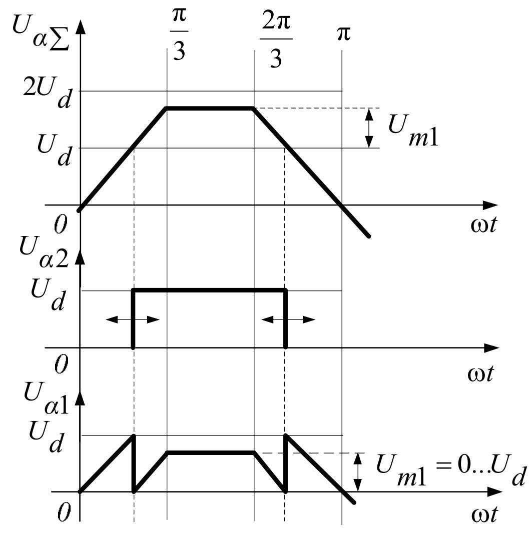


Figure 2 – The integral curves of the intermediate voltage in the second stage

2. The filtration of the modulated voltage impulses of high-voltage frequency converter. In order to carry out the filtration of the modulated voltage impulses of the IGB transistor frequency converter it is necessary to set L-type LC-filter in their output, fig. 4 [4].

The following notation was considered: $U_1$ – input voltage of high frequency; $U_2$ – output filtered voltage; $K=\frac{U_2}{U_1}$ – transmission coefficient; $b=\ln K$ – damping of overwhelming high-frequency component; $\omega_b$ – frequency at which the required damping is provided; $\omega_c=\frac{2}{\sqrt{LC}}$ – cutoff frequency.

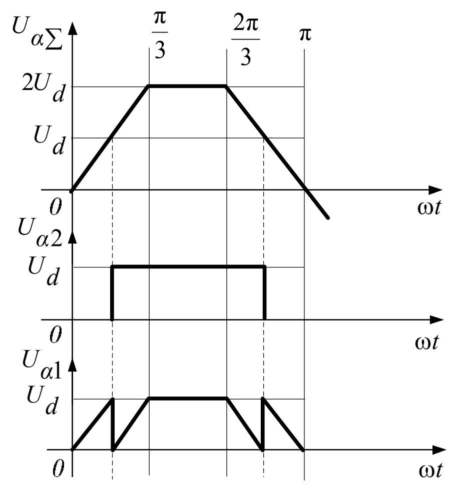


Figure 3 – The integral curves of the maximum voltage in the second stage

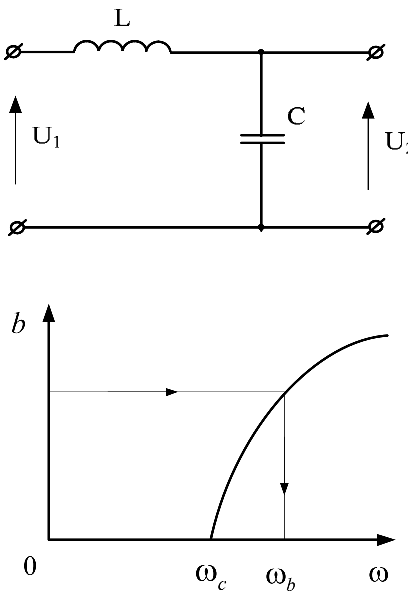


Figure 4 – The circuit and characteristics of L-type filter

According to the theory of quadripoles, the filter elements parameters are connected by the correlation [4]:

$$\omega_b = \omega_c \sqrt{1 + \frac{1}{K}} \,. \qquad (1)$$

It is supposed that the frequency of modulation is $\omega_M = \omega_b$, and according to (1) $\omega_c$ can be found. By means of selecting the condenser, its capacity $C$ is determined, and the inductance of choke $L$ is defined.

So long as in the formation of output voltage of converter by means of PWM the all blocks are involved, than the amplitude of impulses, put to the filter, is $NU_d$, where $N$ is a number of serially united blocks in a phase, $U_d$ is the maximum amplitude of the voltage impulse on the output of every block.

The maximum amplitude of variable high-frequency component of voltage on the output of converter (at space factor of period of modulation is $q = 0{,}5$):

$$U_1 = \frac{N}{2} U_d \qquad (2)$$

and

$$K = \frac{2U_2}{NU_d} \,. \qquad (3)$$

The filter will be powerful and bulky because of high voltage and the necessity of deep damping.

It is possible to decrease filter by means of use of the method of cyclic by-turn introduction the blocks into operations in a converter control at which all the blocks, except for the one, either can form voltage of the rectangular configuration with the permanent amplitude $U_d$ or are in a zero position; and only one block carries out PWM complementing the output integral voltage of converter to the optimum level. It should set up a filter, Fig. 5, 6, on the output of this block, for example $U_1$.

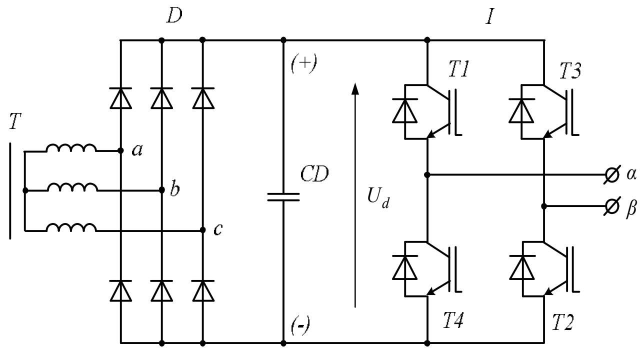


Figure 5 – The circuit of the rectifying IGBT-inverter block of high-voltage frequency converter

In addition, in comparison with the standard decision, voltage is declined in $N$ times that put into the choke and condenser of the filter that substantially affected on the decline in its mass and volume. Moreover, in the suggested circuit of the filter connection only to the PWM block, the transmittance coefficient will be as follows:

$$K' = \frac{2U_2}{U_d} \,. \qquad (4)$$

According to (3) and (4),

$$\frac{K'}{K} = N \,. \qquad (5)$$

Therefore,

$$\sqrt{1 + \frac{1}{K'}} << \sqrt{1 + \frac{1}{K}} \,, \text{ и } \omega'_c << \omega_c . \qquad (6)$$

$L'$ and $C'$ will be less than $L$ and $C$, respectively.

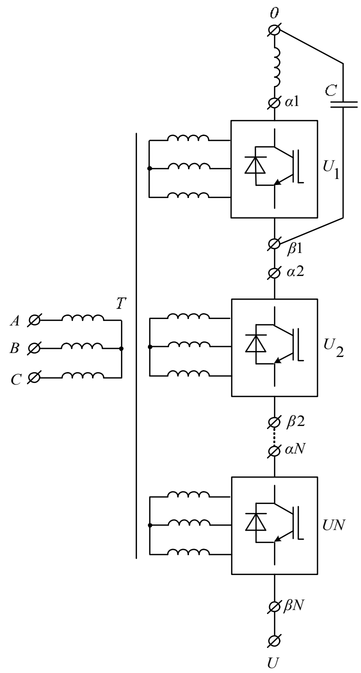


Figure 6 – The structure of block high-voltage frequency converter

CONCLUSIONS. 1. The algorithm of trapezoidal integral curve of output voltage of the IGBT-converter formation and algorithm of the cyclic by-turn control of its blocks has been provided with the substantial decline of the dynamic losses in transistors and in efficiency factor of the whole electrotechnical complex.

2. The application of the method of cyclically by-turn introduction into operations the blocks of multimodule high-voltage IGBT-converter makes it possible to diminish the parameters of components of the system-forming elements of L-type filter.

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## АЛГОРИТМЫ УПРАВЛЕНИЯ ВЫСОКОВОЛЬТНЫМИ ПРЕОБРАЗОВАТЕЛЯМИ ЧАСТОТЫ И ОЦЕНКА ИХ ВЛИЯНИЯ НА ПАРАМЕТРЫ ФИЛЬТРОКОМПЕНСИРУЮЩИХ УСТРОЙСТВ

**О. Н. Синчук, Д. А. Михайличенко**

Кременчугский национальный университет имени Михаила Остроградского

ул. Первомайская , 20, г. Кременчуг, 39600, Украина. E-mail: seem@kdu.edu.ua

Обозначена актуальность направления исследования – реализация требования минимально возможного искажения форм кривых тока и напряжения и построение эффективной структуры высоковольтного электропривода. Обоснованы и приведены предложения по структуре блочного IGBT-преобразователя частоты. Представлены алгоритм формирования трапецеидальной интегральной кривой выходного напряжения и алгоритм цикличного поочередного переключения блоков преобразователя, обеспечивающие снижение динамических потерь в транзисторах и позволяющие уменьшить параметры слагаемых системообразующих элементов, что способствует повышению коэффициента полезного действия всего электротехнического комплекса. Предложен метод расчёта Г-образного фильтра.

**Ключевые слова:** IGBT-преобразователь частоты, Г-образный фильтр.

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