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TECHNICAL AND ECONOMIC COMPARISON OF DIRECT CONVERTERS OF ELECTRIC ENERGY PARAMETERS

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Abstrakt. *The comparison of the energy performance of the main schemes of valve converters of electric energy parameters: currents, voltages, installed powers. Recommendations for their optimal use are done.*

Keywords: inverter, parameters of electric energy, the installed power.

Introduction. Formation of the output voltage or current by direct converter is performed by modulating voltage of the power supply network with the phase compensation of harmonics in the load. In the output of the converter individual modulated voltages or currents are summed up in the common node or loop. Converters can be built on single-ended or full-ended, single-phase or multi-phase circuits. Three-pulse, six-pulse, twelve-pulse and multi-pulse circuits find applications in the practical devices.

Formulation of the problem. Now a great variety of circuits converters of the electric energy is not systematized on energy performance, which complicates the choice of optimum variants circuits for specific use. Some publications are local in nature and not directed at a comparative approach [1; 3]. The analysis makes it necessary to systematize circuits known and such, which are developed and designed converters and an evaluation of their energy performance.

Types of schemes of direct converters. The most common converters with summation modulated currents in the common node are in [2]. Figure 1 shows three-pulse circuits with single-phase (1, 2) and three-phase (3) output. Here, the keys 1–3 closed with a shift in the one third period and connected to load z_l turn on to the phases *A*, *B*, *C* of the power supply network. Figure 2 shows the six-pulse circuits (4–10). In the six-pulse circuits of 4, 5 keys 1–6 close in pairs with a shift in the one third period and is connected to load to the line voltages of the power supply network. In the diagram 6 with the help of three-contact keys 1, 2, closing with a shift by the half period, on the load z_l additional antiphase voltage system is formed and number of equivalent phases is redouble. The same is achieved in the circuit of 7 with the help of the secondary windings of the transformer and keys 1–6. In circuit 8 six-pulse system voltage is formed with the help of three-contact keys 1, 2 and one contact keys 3–11. In the circuit 9 six-phase voltage system is formed by six three-contact keys 1–6 on the secondary side of the transformer, and in the circuit 10 – three-contact keys 1, 2 on the primary and 3–5 on the secondary side of the transformer. Figure 3 shows twelve-pulse circuits. In the scheme 11 keys 3–10 served on the load Z_l linear and phase of the voltage of the secondary winding of the transformer T, and the keys 1, 2 on the primary part of the transformer T make even the modules of these voltages. In the scheme 12 twelve-phase voltage system is provided by the switching of the primary windings of the transformer T from the triangle in the star. In the circuit 13 this function is performed by additional set of windings on the primary of the transformer. In the circuit of 14 six-phase voltage system is implemented by the connection of secondary winding to the «zigzag». Diagram 15 is different from the circuit 13 by the fact that the secondary winding of the transformer is made in the form of three sets with three-contact keys. In the circuit 16 the equalization of the phase and linear voltages of output transformer T is made in the form of autotransformer. The shapes of the curves of the output voltage of the circuits 11–16 are shown in fig. 4.

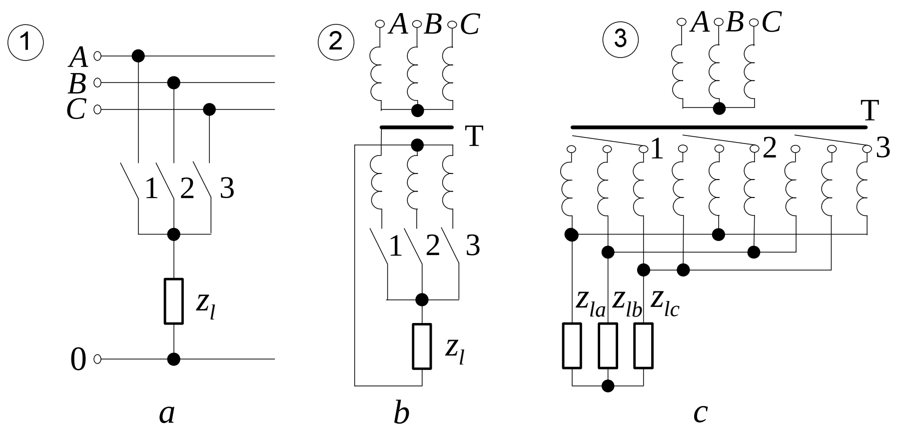

Fig. 1. Three-pulse circuits

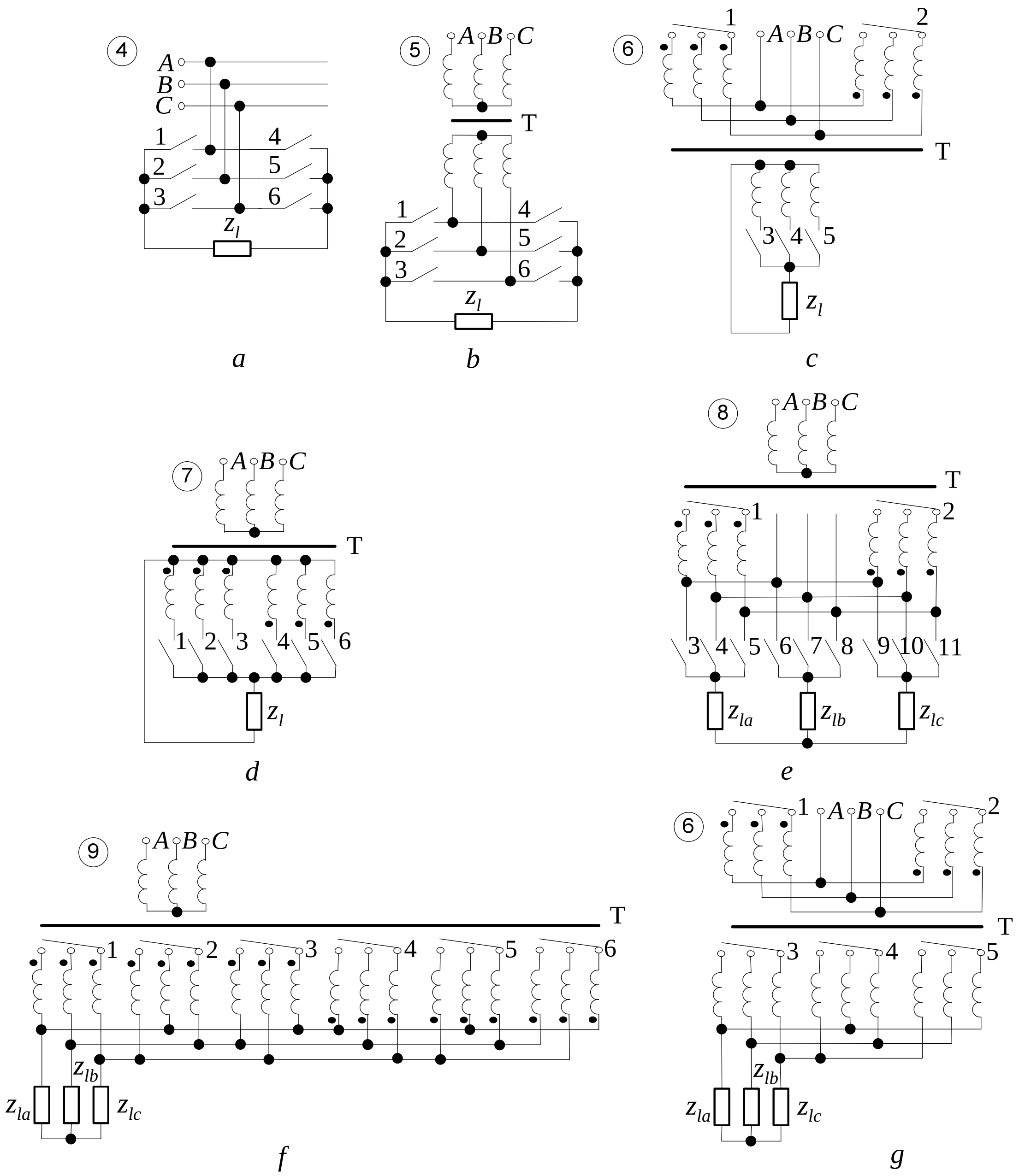

Fig. 2. Six-pulse circuits

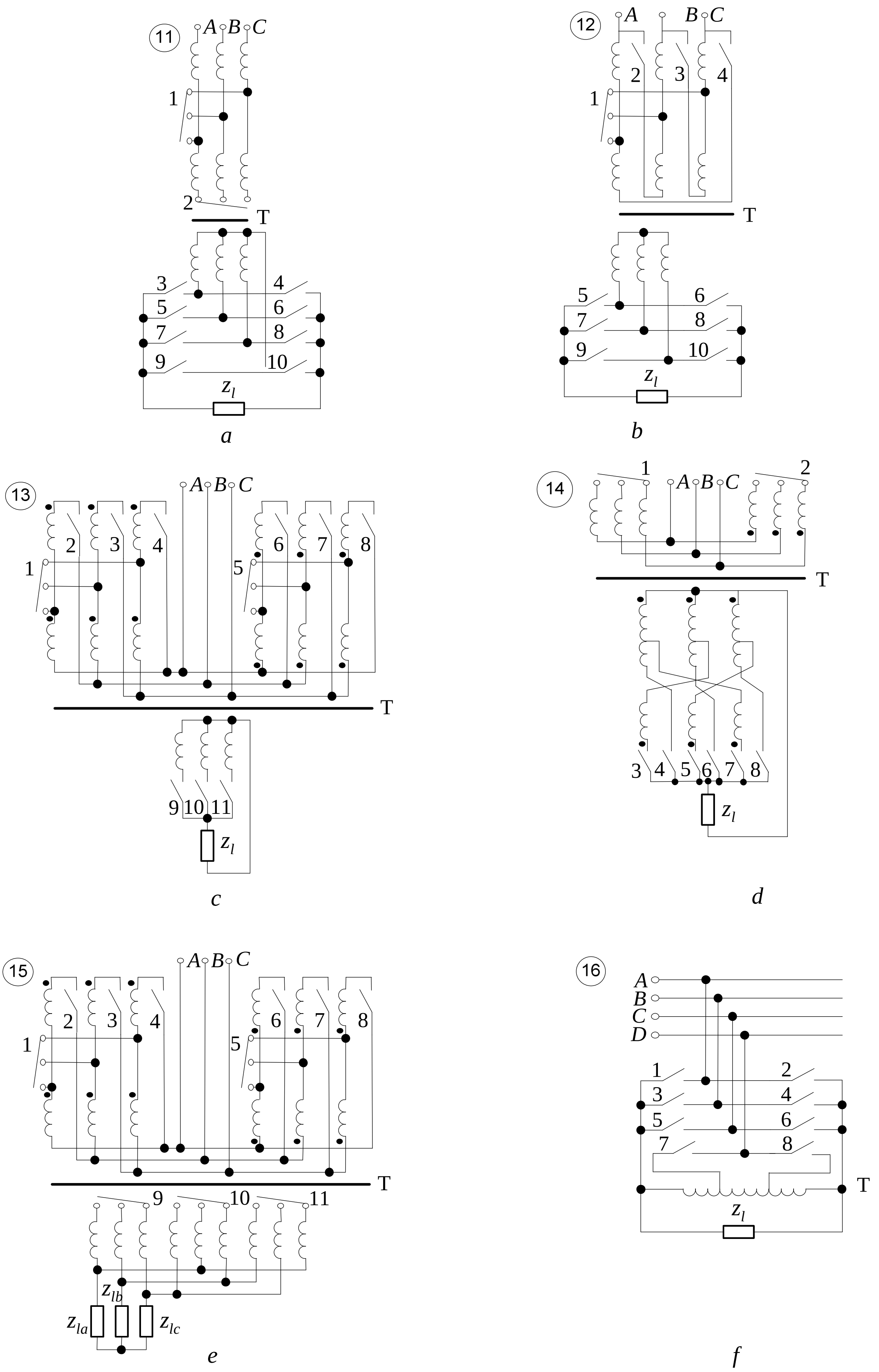

Fig. 3. Twelve-pulse circuits

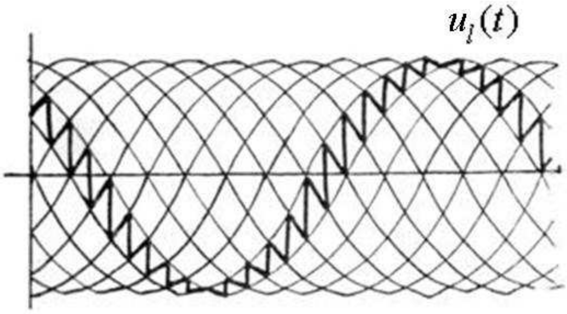

Fig. 4. The shape of the curves of output voltage in twelve-pulse ciruits

The evaluation and comparison of converter circuits. Define the installed powers of the elements. For the transistors, diodes and transformers the installed powers are defined by the expressions

$$P_{st\ \mathrm{VT}} = I_{\mathrm{VT\,max}} U_{\mathrm{VT\,max}}, \qquad P_{st\ \mathrm{VD}} = K_{rev} U_{\mathrm{VD\,max}}, I_{\mathrm{VD}},$$
$$P_{st\ \mathrm{T}} = I_{\mathrm{T1}} U_{\mathrm{T1}} + I_{\mathrm{T2}} U_{\mathrm{T2}},$$

where $I_{\mathrm{VT\,max}}, U_{\mathrm{VT\,max}}$ – the maximum values of current and voltage of the transistor, respectively; i K_{rev} = 0,5 is the conversion factor; $I_{\mathrm{VD}}, U_{\mathrm{VD\,max}}$ – effective value of the diode current and maximum value on the diode voltage, respectively, $I_{\mathrm{T1}}, I_{\mathrm{T2}}, U_{\mathrm{T1}}, U_{\mathrm{T2}}$ – effective values of currents and voltages, respectively at the primary and secondary windings of the transformer.

Table shows the relative values of currents, voltages and installed powers of the elements of the circuits 1 – 3 in fig. 1. The current, voltage and power in the load taken as the basic values on the main harmonic I_{l1}, U_{l1}, P_{l1}. The basic circuit of the converter adopted circuit 3 in fig. 1, which has the lowest installed power ($P_{st3} = P_{st.\,cir}$). From the table it is visible, that the circuits 1 and 2 for the installed power differ only by a relatively small installed power of transformer T ($P_{st\ \mathrm{T}}$ = 2,92 P_{l1}). Circuit 3 has a lower installed power, the circuits 1 and 2 (P_{st1} = 1,19 P_{st3}, P_{st2} = 1,33 P_{st3}). That is explained by the best use of transistors on current (I_{VT3} = 0,87 I_{l1} compared with I_{VT1} = I_{VT3} = 0,7 I_{l1}), and also a greater efficiency of the three-phase bridge circuit, which built three-contact keys scheme 3, compared with single-phase circuit, which built one contact keys 1, 2. At the same voltage transistors and diodes circuit 3 is worse than in circuits 1, 2 ($U_{\mathrm{VT\,max1}} = U_{\mathrm{VD\,max1}} = U_{\mathrm{VT\,max2}} = U_{\mathrm{VD\,max2}}$ = = 2,95U_{l1} compared with $U_{\mathrm{VT\,max3}} = U_{\mathrm{VD\,max3}}$ = 5,02U_{l1}), but the total installed power of the transistors and diodes in this circuit is below. The installed power of the transformer ($P_{\mathrm{st\,T}}$ = 4,01P_{l1}) is about 25 % of installed power of semiconductor elements (P_{st3} = 16,4P_{l1}). Therefore from the point of view of the minimum installed power is advisable to use the circuit 3, taking into account the considerably higher voltage for transistors and diodes.

Table shows the relative values of currents, voltages and installed powers of elements for circuits 4 – 10 according to fig. 2. Without transformer circuit 4 adopted as basic, which has the lowest installed power. The table shows that the loading of transistors operating in the diagonal of three-phase diode three-contact keys l, by one-third exceeds loading of the rest transistors. The same ratio for the current of the diodes. The maximum values of currents for all circuits are identical. Significantly different maximum values of transistors voltages. The least they have circuits 4, 5 the fact that they are defined by a linear voltages of network and the secondary winding of the transformer. Voltages to the transformer circuits 6 – 10 is almost three times higher than those previously mentioned, because they are determined by the autotransformer action of the windings of the various groups both on the primary and secondary sides of the transformers. In addition, the voltage transmission coefficient of the main harmonics for the circuits 4, 5 is three times higher than that of other circuits. Due to the growing installed transistors and diodes powers for these circuits. In connection with the fact that the total installed power of active elements is also

Relative values of currents, voltages and in stalled powers for the circuits of fig. 1 –3

Parametres	No. of the circuits															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$I_{Т}/I_{н1}$	0,7	0,7	0,87	0,61	0,61	0,92 0,61	0,43	0,92 0,61	0,52	0,92 0,74	1,51, 0,87 0,51, 0,51	1,24, 1,52 0,58	0,51, 0,51 0,41	0,8, 0,41	0,51, 0,62 0,71	0,66 0,87
$I_{Тm}/I_{н1}$	1,71	1,71	1,71	1,48	1,48	1,48	1,48	1,48	1,48	1,48	2,46, 1,42 1,42, 1,42	2,47, 2,47 1,42	1,42, 1,42 1,42	1,42, 1,42	1,42, 1,42 1,42	2,46 2,46
$I_{Д}/I_{н1}$	0,5	0,5	0,5	0,43	0,43	0,53 0,43	0,31	0,53 0,43	0,3	0,53 0,43	0,87, 0,5 0,36, 0,36	0,88, 0,88 0,41	0,36, 0,36 0,41	0,46, 0,29	0,36, 0,36 0,41	0,47 0,62
$U_{Тm}/U_{н1}$	2,95	2,95	5,02	1,48	1,48	5,12 2,56	2,56	5,12 2,56	5,12	5,12 4,44	1,04, 1,04 2,46, 1,42	0,43, 0,74 1,42	3,49, 2,2 2,46	4,93, 2,75	3,49, 2,2 4,27	1,42 0,82
$U_{Дm}/U_{н1}$	2,95	2,95	5,02	1,48	1,48	5,12 2,56	2,56	5,12 2,56	5,12	5,12 4,44	1,04, 1,04 2,46, 1,42	0,74, 0,74 1,42	3,49, 2,2 2,46	4,93, 2,75	3,49, 2,2 4,27	1,42 0,82
$P_{вт}/P_{н1}$	5,04	5,04	8,58	2,19	2,19	7,58 3,79	3,79	7,58 3,79	7,58	7,58 6,56	2,56, 1,48 3,49, 2,02	1,04, 1,83 2,04	4,96, 3,12 3,49	7,0, 3,9	4,96, 3,12 6,06	3,49 2,02
$P_{вт.\ зв}/P_{н1}$	15,12	15,12	8,58	13,14	13,14	16,42	22,74	16,42	15,16	11,61	26,33	14,42	20,02	2,81	15,61	24,96
$P_{вд}/P_{н1}$	0,3	0,73	0,26	0,31	0,31	1,36 0,55	0,4	1,36 0,55	0,77	1,36 0,95	0,45, 0,26 0,44, 0,26	0,18, 0,33 0,29	0,63, 0,4 0,5	1,13, 0,4	0,63, 0,4 0,88	0,33 0,25
$P_{вд.\ зв}/P_{н1}$	8,76	8,76	7,56	7,44	7,44	12,04	9,6	12,04	9,24	11,06	12,52	8,64	11,72	13,84	11,00	9,92
$P_{в.\ пер}/P_{н1}$	23,88	23,88	16,14	20,58	20,58	28,46	32,34	28,46	24,4	22,75	38,85	23,06	31,74	42,19	26,61	34,9
$P_{в.\ тр}/P_{н1}$	–	2,92	4,01	–	2,22	2,59	2,66	2,62	3,51	3,47	2,14	2,55	3,23	2,63	3,96	0,92
$P_{в.\ зв}/P_{н1}$	23,88	26,8	20,15	20,58	22,8	31,05	35,0	31,08	27,91	26,22	40,99	25,61	34,97	44,82	30,57	35,82
$P_{в.\ сх}/P_{в3}$	1,19	1,33	1,0	1,0	1,11	1,51	1,7	1,51	1,36	1,27	1,6	1,0	1,37	1,75	1,19	1,4

determined by their quantity, a general increase of the installed power of the converter does not exceed 1,7 times as compared with the circuit 4. The installed power has diagram 7. The smallest difference from the circuit 4 has the circuit 10 – in 1,27 times (without circuit 5, because it practically identical to the scheme 4). It should be noted that six pulsations in this circuit achieved in the most cost-effective way – two of the primary and three secondary side of the transformer. The product of their gives, as a result, six pulsations. Defect of the circuit is the high voltage transistors and diodes. This circuit also has a larger installed of the transformer, which is explained by a large number of its primary and secondary windings.

From the point of view of the installed powers it is expedient to recommend without transformer scheme 4, and with the transformer circuits – circuits 5, 9 and 10.

In the table 2 for the schemes 6, 8, 10 are double values of the parameters. Here the first magnitude are correspond primary and second magnitude – second winding of the isolating transformer. Table shows the relative values of currents, voltages and installed powers for the circuits 11 – 16 (fig. 3) For basic adopted scheme 12 with a minimum installed power. The table shows that the loading of the transistors on the effective value of current is significantly higher in those circuits where the transistors work in the diagonal of a three-phase bridge AC (circuits 11, 12). The rest of the transistors in all circuits for loading differ insignificantly. The same ratio and for the diodes.

The largest maximum current carry out transistors, included on the primary side of the transformer in circuits 11, 12. This is explained by the low relative pulse period of their switching (Q = 2) compared with transistors of other circuits (Q = 4), as well as the bridge circuit of the converter on the secondary side. The same in respect of the current of the diodes. Autotransformera action windings of transformers causes an increase of the maximum value of voltages on the transistors and diodes in circuits 11 – 16. Due to this increases their installed power. According to the scheme 12 with the lowest total installed power of go circuits 15 and 13. It should be noted that the circuit 15 has the highest installed capacity of the transformer, which exceeds, for example, the installed power of the transformer in the circuit 16 more than four times. But the total value of this impact is insignificant. Almost in two times more than for the circuit 12 the installed power of the circuits 11, 14.

So from the point of view of the installed power the biggest advantage has circuit 12. Next come the circuits 15 and 13. In table 3 several values of currents and voltages for each of the circuits correspond to different transistors and diodes, working in a different mode from the primary and secondary windings of an isolating transformer.

Conclusions. A large variety of schemes electronic converters causes of the urgent need to define criteria for their effectiveness on energy performance. The most important such measure is the installed power of the individual components and the circuit as a whole. Thus it is necessary to take into account the quality of the source of energy, which is defined as the requirements of the load, so losses of electric power in the system: converter – users. The comparative analysis allows to reasonably choose the circuit of the converter.

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Техніко-економічне порівняння безпосередніх перетворювачів параметрів електричної енергії

Проведено порівняння за енергетичними показниками основних схем вентильних перетворювачів параметрів електричної енергії: струмам, напругам, встановленим потужностям. Наведено рекомендації по їх оптимальному застосуванню.

Б. Е. Пьяных

Технико- экономическое сравнение непосредственных преобразователей параметров электрической энергии

Проведено сравнение по энергетическим показателям основных схем вентильных преобразователей параметров электрической энергии: токам, напряжениям, установленным мощностям. Даны рекомендации по их оптимальному использованию.