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Comparative Study of 2-phase Low Frequency Triac Converter- and High Frequency Two-stage Matrix Converter Systems

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Introduction

The paper deals with comparison of the characteristics between two-phase electronic systems: DC/AC/AC high frequency two-stage converter system made of two single-phase matrix converters with variable orthogonal output and low frequency triac converter with phase-control supplied from AC network. Low frequency triacs or thyristor converters can be innovated using switches of semiconductor devices (IGBT). Design of two-stage DC/AC/AC high frequency converter with two-phase orthogonal output using single-phase matrix converter in half-bridge connection operated with the bipolar PWM is also introduced. The advantage of such system is less number of semiconductor devices. Simulations results are given at the end of the paper.

Two-phase power system

In the very early days of commercial electric power some installations used two-phase four-wire systems for motors [1]. Two-phase systems have been replaced with three-phase systems. Two-phase supply with 90 degrees between phases can be derived from a three-phase system using a Scott-connected transformer. Two-phase circuits typically use two separate pairs of current-carrying conductors, alternatively three wires may be used, but the common conductor carries the vector sum of the phase currents, which requires a larger conductor.

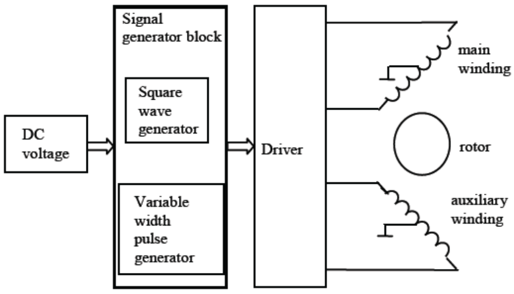


Fig. 1. Block diagram of the supply for two-phase motor

On the other hand, it can be also easily created using power electronic converters e.g. from battery supply, with two-phase transfer of energy for zero distance. DC/2AC, Fig. 1, and DC/HF_AC/2AC, Fig. 2a, b, converter system can generate two-phase orthogonal output with variable voltage and frequency [2, 3], or with using triac- (or thyristor) switches with phase-control, Fig. 3.

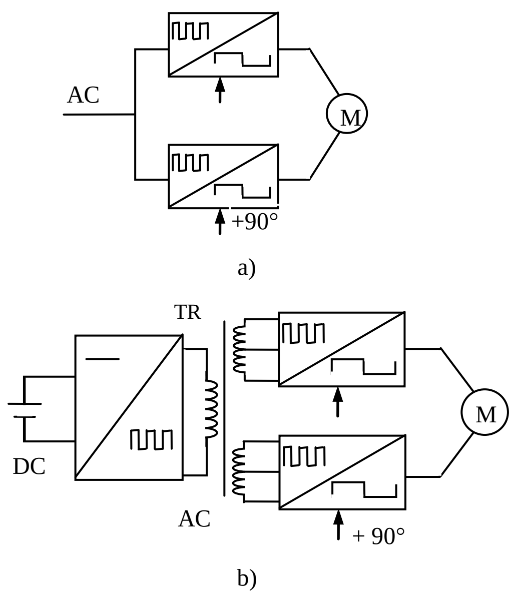


Fig. 2. a – principle diagram of full bridge converter with second phase shifted by 90 degrees; b – block diagram of half bridge converter with HF transformer and central points of the source

Low frequency triac converter

It is known that direct converters can be operated from AC network (or generator) by voltage with relative low frequency of 50-, 60-, 100-, 400 Hz using triac- (or thyristor) switches with phase-control. Their output frequency can only be smaller then input frequency, Fig. 3. Total harmonic distortions of the output voltage and consequently current, too, are rather high, and the input power factor is relative poor due to phase-control [4, 7].

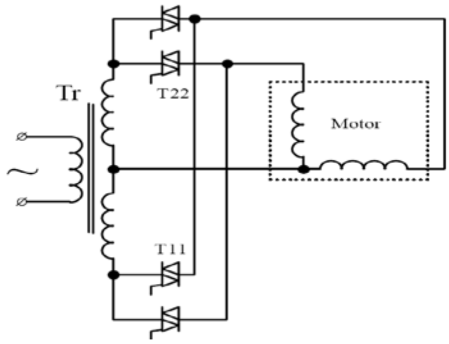


Fig. 3. Circuit diagram of half bridge triacs-converter

Simple utilization of phase-control of triac or thyristor devices can not provide sinusoidal wave-form of output quantities namely of current. So, it would be better to considered current supply system, which is suitable e.g. for two-phase brushless DC motor (synchronous one) or two-phase current fed induction motor, respectively.Let us apply such voltage to passive *R-L* circuit whose complex impedance is, Fig. 4.

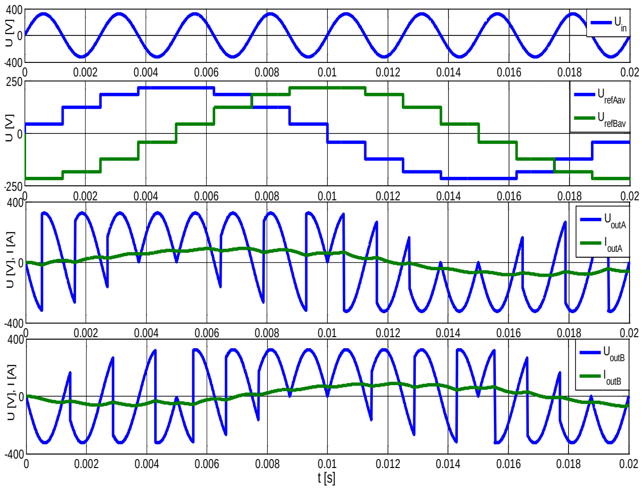


Fig. 4. Output voltages of half-bridge triacs-converter with phase-control supplied from AC network

In low frequency applications using triacs or thyristors is possible to replace these device by IGBT transistors in bidirectional switch connection (conductivity of triac or thyristor is ended when current is reduced to zero but on the other side conductivity of IGBT can be ended according to the actual needs). This substitution enables to use of more effective control of power switches. The result of this is the possibility to create symmetrical output voltages and thus achieve a higher quality of output quantities [6]. On the other side, matrix converters with fast IGBT and MOSFET switching devices can operate with relatively high frequencies of 10- up hundreds of kHz. Then the quality of output quantities is high and frequency range is not limited by input frequency.

Two-phase systems with HF AC interlink and matrix converters

Matrix converter system DC/HF_AC/2AC with high frequency AC interlink can generate two-phase orthogonal output with both variable voltage and frequency ([5, 7] and others), Fig. 2a. Usually, the switching frequency of the converter is rather high (~tens of kHz). Since the voltages of the matrix converter system should be orthogonal ones, the second phase converter is the same as the first one and its voltage is shifted by 90 degree. Such system usually consist of single-phase voltage inverter, AC interlink, HF transformer, 2-phase converter and 2-phase AC motor. Due to AC interlink direct converter (cyclo-converter or matrix converter) is the best choice.

Each matrix- or cyclo-converter can be connected as:
1. full bridge converters connection, Fig. 2a,
2. two half bridge ones with central point of the source using HF transformer Fig. 5a or
3. half-bridge ones with central points of the motor load Fig. 5b.

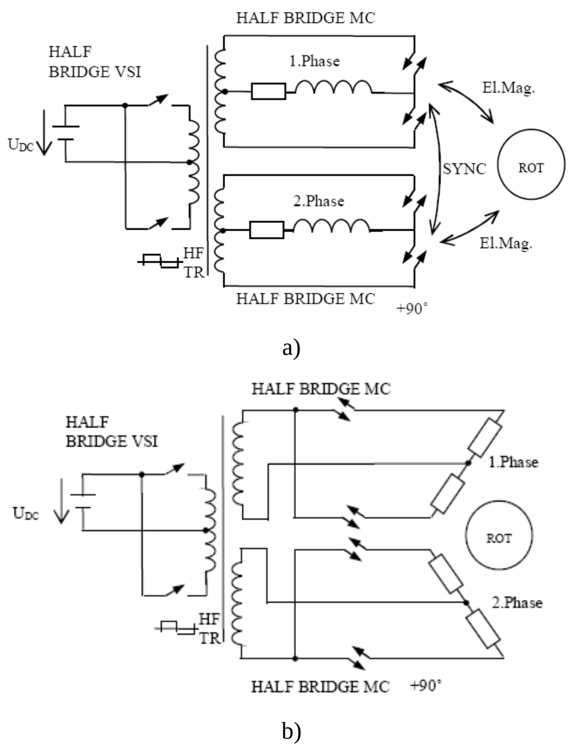
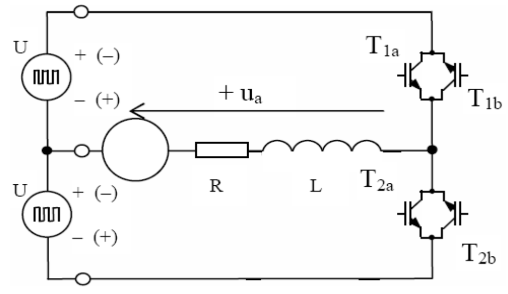


Fig. 5. Circuit diagram of half-bridge converters system with a – central points of AC source; b – central points of motor loads

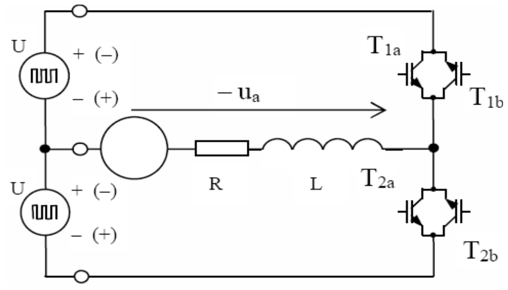
Since the switches of the inverter operate with hard commutation, switches of matrix converters are partially soft-commutated in the zero-voltage instants of the AC voltage interlink using bipolar PWM. Therefore, the expected efficiency of the system can be higher than for usual system with classical three-phase inverter.

Modelling and simulation of HF half – bridge matrix convereter system with central points of source

Theoretical analysis of single-phase matrix converter has been done, e.g. [6, 7, 9]. Substituted circuit diagram of half-bridge single-phase matrix converter is depicted in Figs. 6a, b. Contrary to bridge matrix converter the half-bridge connection doesn't provide unipolar PWM control, so the bipolar pulse switching technique should be used [6, 7]. The orthogonal voltages with bipolar PWM control are depicted in Figs. 7a, b.

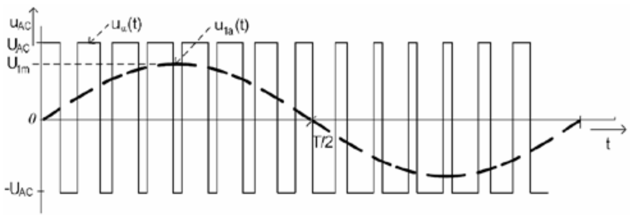


a)



b)

Fig. 6. Equivalent circuit diagram of half-bridge single-phase matrix converter for 2nd stage for a – positive and b – negative half period of operation



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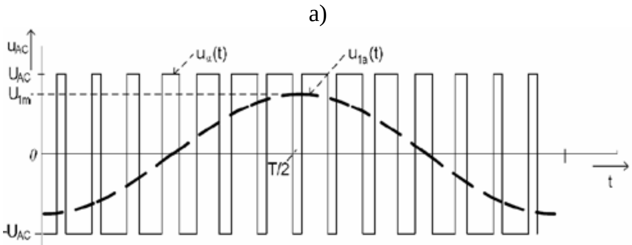
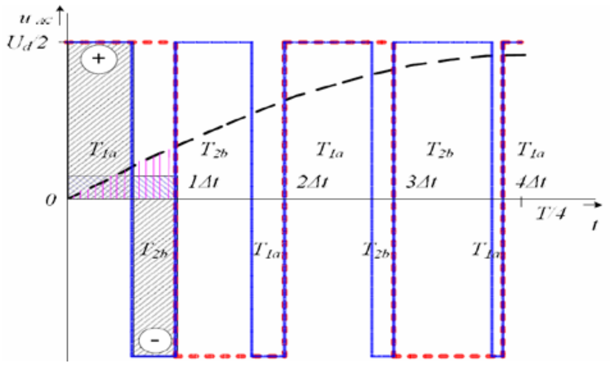


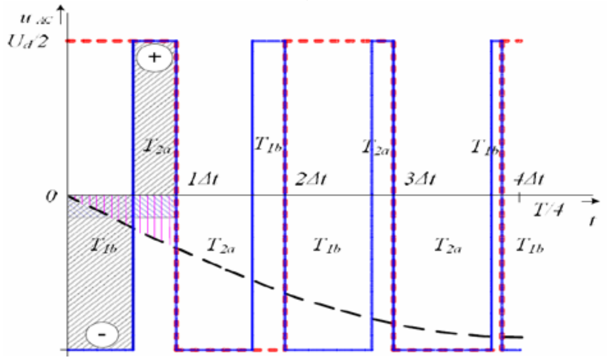
b)

Fig. 7. Output orthogonal voltages of the half-bridge matrix converter system with bipolar PWM: a – u_{α}; b – u_{β}

Switching frequency is supposed two multiply of inverter frequency in the first stage of the system. Then the quality of output quantities and frequency range is higher then low frequency triac applications (Fig. 3) and they are only limited by switching capability of devices. Disadvantage of the half-bridge is, of course, double voltage stress of the semiconductor switching elements. Fourier analysis is useful and needed for determination of total harmonic distortion of the phase current of the matrix converter [6, 8, 10]. Switching strategy of one half-bridge matrix converter, based on ‘even’ bipolar PWM, can be explained using Figs 8a, b. in greater details.



a)



b)

Fig. 8. Switching strategy of half bridge converter for a – positive and b – negative half period of operation

Important is and it’s clear from these figures that during switching at the end of the period of HF AC supply ($n.T_s$) the switching losses will be zero due to zero value of commutation voltage. Switching frequency can be set from some kHz for high power applications up to several tens of kHz for low power applications.

PC simulation of two-phase systems with HF AC interlink and matrix converters and low frequency triac converter with *R-L* load

Both models for R-L load and PMSM motor has been modelled in MatLab 2007b programming environment.

Simulations results

System with using Matrix Converter. Simulated waveforms of output voltages and currents under R-L load are shown in Fig. 9.

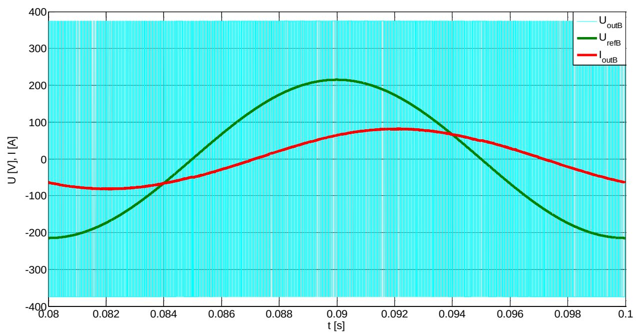
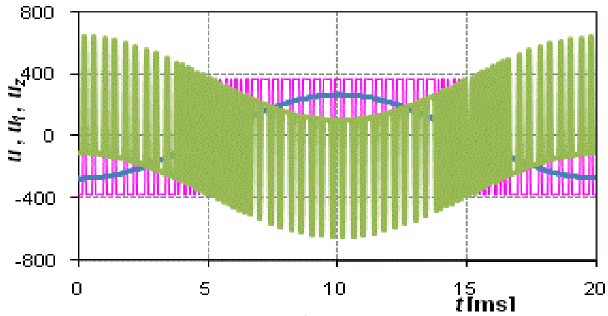


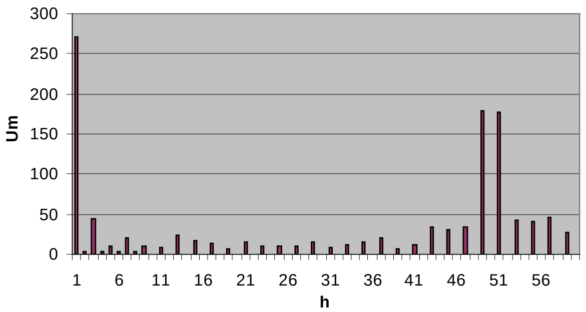
Fig. 9. Simulated waveforms of output voltages and currents of the DC/AC/AC converter under R-L load

Comparision of different types power converters based on harmonic analysis is shown in the following figures ("magenta" waveform is output quantity, "blue" is the first harmonic and "green" are higher harmonics).

Waveforms of output voltage, the first harmonic, higher harmonics and voltage amplitude spectrum are shown in Figs. 10a, b. and the same for the currents are in Figs. 11a, b.

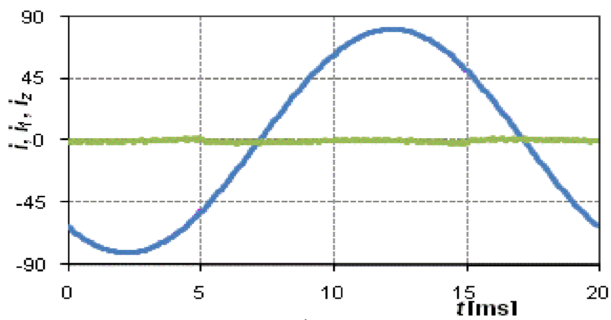


a)

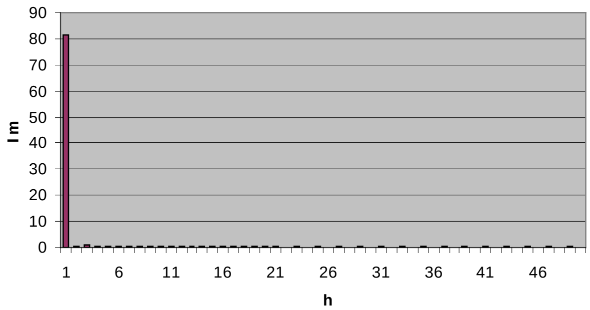


b)

Fig. 10. a – waveforms of output voltage, first harmonic and high harmonics; b – voltage amplitude spectrum of high frequency DC/AC/AC converter



a)



b)

Fig. 11. a – waveforms of output current, first harmonic and high harmonics; b – current amplitude spectrum of high frequency DC/AC/AC converter

Low frequency triac converter. Simulated waveforms of output voltages and currents under R-L load at f_{in} = 400Hz are shown in Fig. 12.

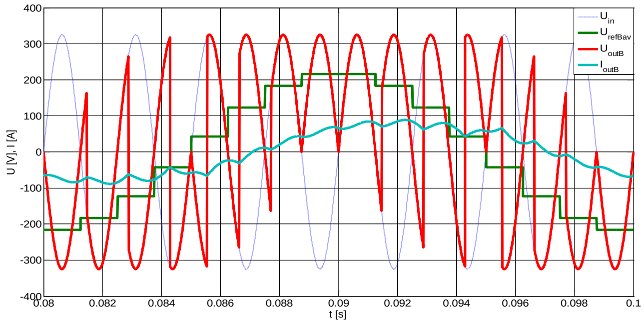
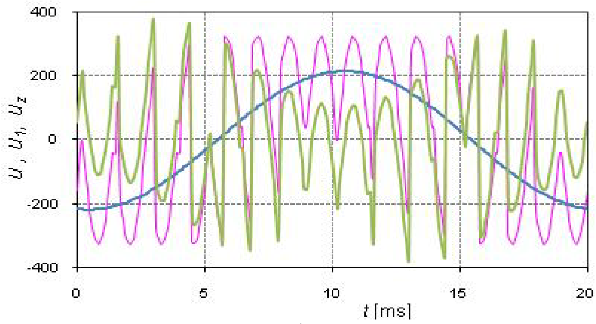
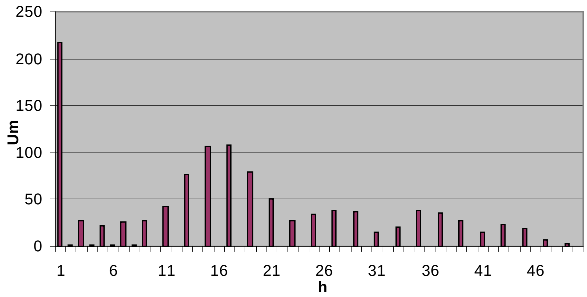


Fig. 12. Simulated waveforms of output voltages and currents of the low frequency triac converter under R-L load at input frequency f_{in} = 400Hz

Results of harmonic analysis of low frequency triac converter are shown in next figures. Waveforms of output voltage, the first harmonic, higher harmonics and voltage amplitude spectrum are depicted in Fig. 13a, b. and the same for the currents are in Fig. 14a, b.

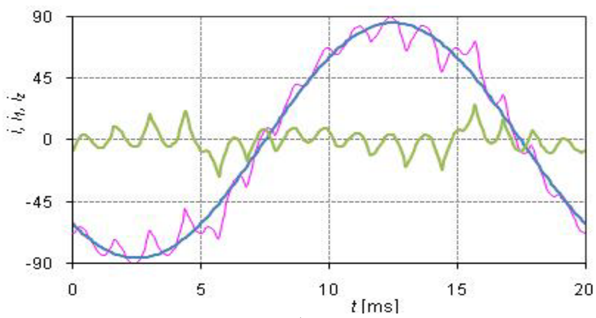


a)

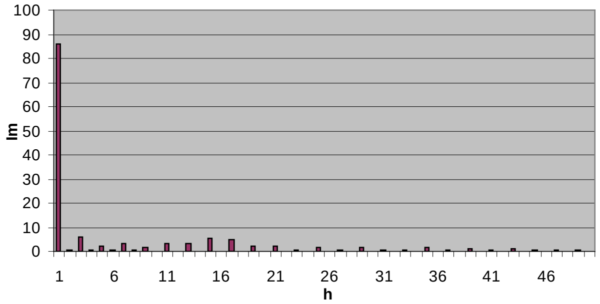


b)

Fig. 13. a – waveforms of output voltage, first harmonic and high harmonics; b – voltage amplitude spectrum of low frequency triac converter



a)



b)

Fig. 14. a – waveforms of output current, first harmonic and high harmonics; b – current amplitude spectrum of low frequency triac converter

Low frequency IGBT converter. Simulated waveforms of output voltages and currents under R-L load at f_{in} = 400 Hz are shown in Fig. 15.

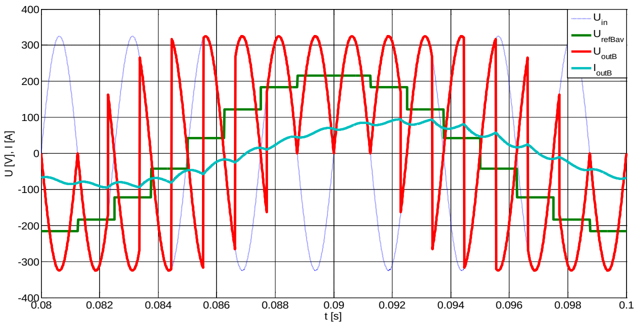
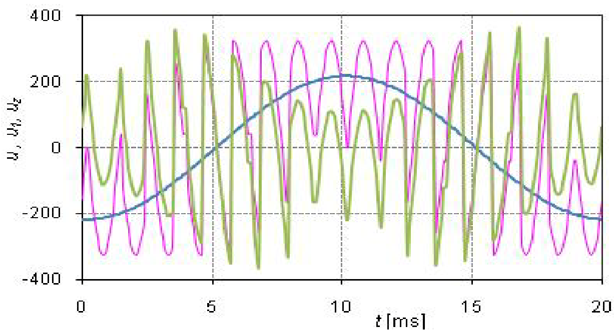
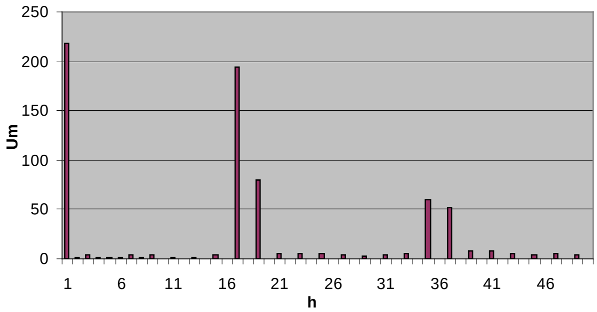


Fig. 15. Simulated waveforms of output voltages and currents of the low frequency IGBT converter under R-L load at input frequency f_{in} = 400Hz.



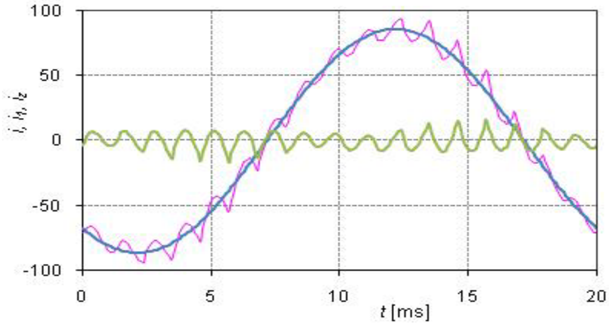
a)



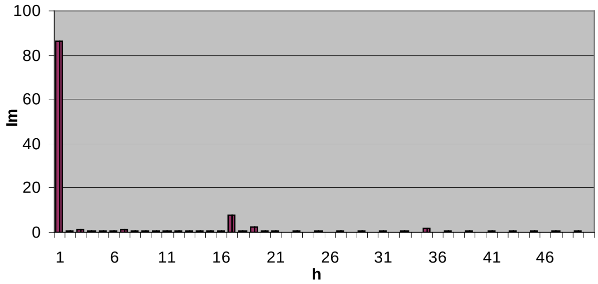
b)

Fig. 16. a – waveforms of output voltage, first harmonic and high harmonics; b – **v**oltage amplitude spectrum of low frequency IGBT converter

Results of harmonic analysis of low frequency IGBT converter are shown in next figures. Waveforms of output voltage, the first harmonic, higher harmonics and voltage amplitude spectrum are displayed in Figs. 16a, b. and the same for the currents are in Fig. 17a, b.



a)



b)

Fig. 17. a – waveforms of output current, first harmonic and high harmonics; b – current amplitude spectrum of low frequency IGBT converter

Parameters of simulation:
DC/AC/AC high frequency converter:
f_{in} = 10kHz, f_{out} = 50Hz, U_{DC} = 750V, U_{outAV} = 215V,
R = 2Ω, L = 0.005H.

Low frequency triac converter:
f_{in} = 400Hz, f_{out} = 50Hz, U_{in} = 325V, U_{outAV} = 215V,
R = 2Ω, L = 0.005H.

Conclusion

Based on harmonic analysis, the best of choice for the introduced applications is high frequency DC/AC/AC converter with THD less then 2% according [6], contrary to THD of low frequency triac converter, which is around 13% and to low frequency IGBT converter where THD is around 10%. Main disadvantage of low frequency converters is their limited output frequency (max 1/2 input frequency), while the matrix converter can work with higher frequency range.

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The paper deals with comparison of the characteristics between two-phase electronic systems: DC/AC/AC high frequency two-stage converter system made of two single-phase matrix converters with variable orthogonal output and low frequency triac converter with phase-control supplied from AC network. Low frequency triacs or thyristor converters can be innovated using switches of semiconductor device s (IGBT). Design of two-stage DC/AC/AC high frequency converter with two-phase orthogonal output using single-phase matrix converter in half-bridge connection operated with the bipolar PWM is also introduced. Ill. 17, bibl. 10 (in English; abstracts in English, Russian and Lithuanian).

М. Празеница, Б. Добруцки, М. Бенова, Ю. Касса. Исследование параметров двухкаскадного матричного преобразователя с учетом структуры низкочастотного триодного преобразователя // Электроника и электротехника. – Каунас: Технология, 2010. – № 4(100). – С. 15–20.

Описывается характеристики двухфазных электронных систем. Система соэдана на основе однофазовых матрицных преобразователей с управлением от фазы электросетей. Преобразователи созданы на основе полупроводниковых преобразователей при использовании модуляции широты импульсов. Ил. 17, библ. 10 (на английском языке; рефераты на английском, русском и литовском яз.).

M. Prazenica, B. Dobrucky, M. Benova, J. Kassa. Dvifazio žemadažnio triodinio keitiklio ir aukštadažnio dviejų pakopų matricinio keitiklio lyginamoji analizė // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 4(100). – P. 15–20.

Lyginamos dvifazių elektroninių sistemų charakteristikos. DC/AC/AC aukštadažnė dviejų pakopų keitiklio sistema sukurta naudojant du vienfazius matricinius keitiklius, o žemadažnis triodinis keitiklis – su elektros tinklo fazių valdikliu. Žemojo dažnio triodinis ar tiristorinis keitiklis gali būti sukurtas naudojant puslaidininkinius perjungiklius (angl. IGBT). Apžvelgiamas dvifazis DC/AC/AC aukšadažnis keitiklis su dviem vienfaziais matriciniais keitikliais, kurių dalinei komunikavimo sąsajai naudojama impulsų pločio moduliacija. Il. 17, bibl. 10 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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