УДК 621.314.572

MULTIPHASE POWER CONVERSION SYSTEM WITH HYBRID SWITCHING STRATEGY OF MODULATED INVERTERS

V.Oleschuk, **V.Ermuratskii**
Institute of Power Engineering of the Academy of Sciences of Moldova,
5 Academy Str., Kishinev, MD-2028, Moldova. **E-mail: oleschukv@hotmail.com**

In this paper, two switching strategies have been combined for control of cascaded PWM inverters of dual three-phase adjustable speed drive with asymmetrical induction motor. The presented combined switching techniques allow insuring elimination of common-mode voltages in drive system. Algorithms of synchronized modulation insure symmetries of voltage waveforms of inverters of system for a whole control diapason. Simulations validate performance of systems with combined control strategy of modulated voltage source inverters with low switching frequency. References 9, figures 5.

Keywords: dual three-phase (six-phase) electric drive, multi-inverter configuration, control strategy, combined algorithms of pulsewidth modulation (PWM).

Introduction. Nowadays, multiphase converters and drives are powerful alternative of existing three-phase solutions for the medium-power and high-power adjustable speed drive systems [3, 4, 6, 9]. Topology of six-phase drive systems with asymmetrical induction machine with two sets of winding, spatially shifted by 30 el. degrees, can be based on four inverters, supplying open-end windings of ac motor [2, 8]. Structure of such system (with two dc-links), based on control with elimination of common-mode voltages, is presented

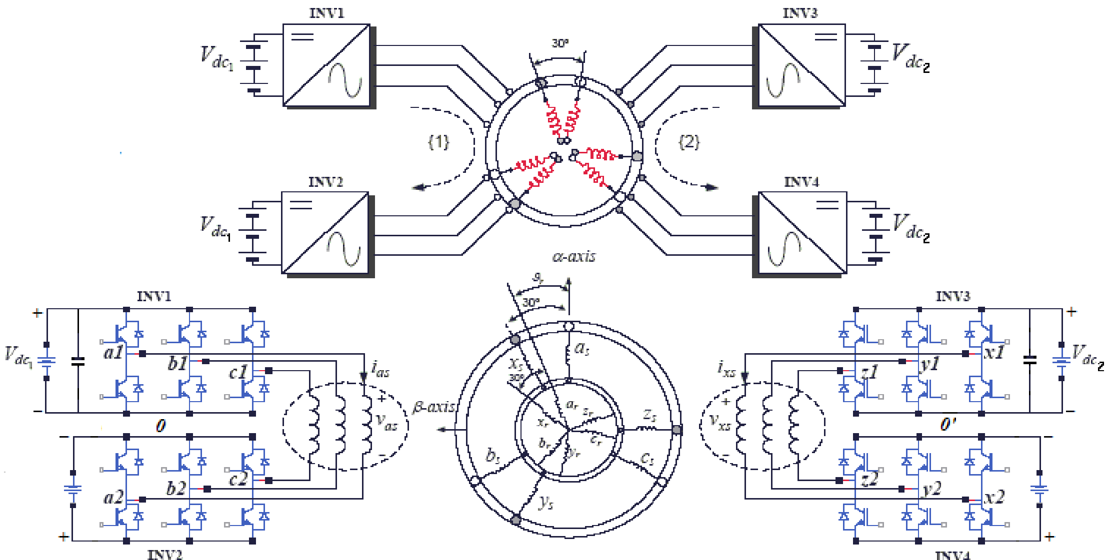


Fig. 1

in Fig. 1. In this case in-creased number of inverters allows using combinations of schemes and techniques of modulation for control of inverters of the system. So, this paper presents results of analysis of operation of six-phase system with hybrid switching strategy used for control of three-phase PWM inverters.

Switching schemes providing cancellation of common mode voltage in multiphase system. To insure elimination of undesirable common-mode voltages in drive systems on the basis of cascaded modulated inverters, specific switching techniques can be used [1, 7]. Fig. 2, *a* illustrates switching scheme (voltage space vectors) perspective for control of cascaded (dual) inverters of six-phase drive system (conventional definition of numbering switching sequences **1, 3,-5** (for the first inverter of each section) and **1', 3', 5'** (for the second inverter of the same section) is used here [7]). Fig. 2, *b* presents switching states and basic voltages (pole voltages V_{a1} and V_{a2}, and phase voltage of the system $V_{as}= V_{a1}-V_{a2}$, controlled by one of two basic strategies of pulsewidth modulation of dual inverters with cancellation of common-mode voltage

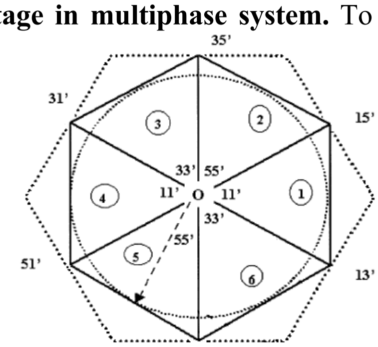
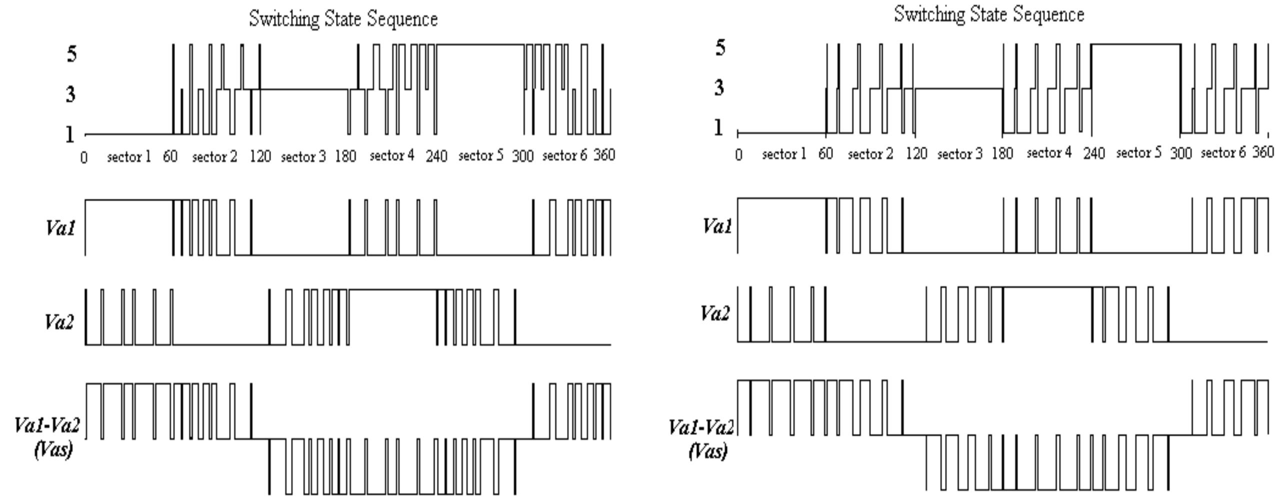


Fig. 2, *a*

(**N**o-**C**ommon-**M**ode voltage **P**ulse **W**idth **M**odulation **1** (**NCMPWM1**)). Fig. 2,*c* shows the corresponding curves of the second basic version of such PWM strategy for dual inverters (**NCMPWM2**).

In order to provide voltage waveform symmetries of modulated inverters, method of synchronized PWM [5] can be used for modulation of voltage waveforms of each inverter of the system.



b ***c***

Fig. 2

Simulation of processes in multiphase system with hybrid switching strategy of inverters.

Figs. 3 – 4 present results of MATLAB simulation (in the general form) of six-phase system on the basis of four (two + two) cascaded inverters (Fig. 1). The first inverter group (**INV1+INV2**) is controlled by **NCMPWM1** control scheme, and the second inverter group (**INV3+INV4**) is controlled by **NCMPWM2** control algorithm. Determination of voltage pulse patterns and dwell-times of duty cycles of inverters is based in this case on techniques of synchronous pulsewidth modulation, described in [5, 6].

Fig. 3, *a*, *b* shows output voltages and spectral composition of two phase voltages for the system with equal voltages of dc-links, operating in the zone of low fundamental frequency (F=20 Hz, coefficients of modulation of four inverters $m_1=m_2=m_3=m_4=0.4$). Switching frequency of inverters is equal to F_s=1 kHz for the all presented control modes.

Fig. 3, *c*, *d* presents output voltages and harmonic composition of the phase voltages of system with non-equal dc-voltages ($V_{dc2}=0.75V_{dc1}$, $m_1=m_2=0.7$, $m_3=m_4=0.933$), operating in the zone of medium fundamental frequency (F=35 Hz).

Fig. 4, *a*, *b* shows output voltages and spectra of two phase voltages for the system with other distribution of non-equal dc-sources ($V_{dc1}=0.8V_{dc2}$, $m_1=m_2=0.875$, $m_3=m_4=0.7$, F=35 Hz).

Fig. 4, *c*, *d* illustrates operation of system with equal voltages of dc-links in the zone of higher fundamental frequency (in the zone of overmodulation, F=47,5 Hz, $m_1=m_2=m_3=m_4=0.95$).

Presented in Figs. 3,*b*, 3,*d*, 4,*b* and 4,*d* spectrograms show, that spectra of the phase voltages of six-phase system with hybrid control and modulation strategy of inverters include only odd (non-triplen) components, without other undesirable spectral components. Comparison of spectrograms, presented in Fig. 3, *d* and Fig. 4, *b*, shows, that the proposed hybrid switching techniques of inverters insure, by the corresponding linear variation of coefficients of modulation of inverters, equal value of the fundamental harmonics of the phase voltages for different ratios between magnitudes of dc-voltages of dual three-phase (six-phase) system.

For comparison of integral harmonic characteristics of phase voltages of asymmetrical dual three-phase (six-phase) system with hybrid switching strategy of modulated inverters, Fig. 5 presents calculation results of averaged Weighted Total Harmonic Distortion factor (*WTHD*) versus coefficient of modulation m (m_1) for the motor phase voltage V_{as} (averaged values of $WTHD=(1/V_{as_1})(\sum_{k=2}^{1000}(V_{as_k}/k)^2)^{0.5}$) for systems with the two mentioned above control schemes (**NCMPWM1** and **NCMPWM2**), for conventional *Volts/Hertz* adjustment mode of the system (F_s=1 kHz). Three control modes have been analyzed: a) $V_{dc1}=V_{dc2}$ (solid curves); b) $V_{dc2}=0.85V_{dc1}$ (dash-dot lines); c) $V_{dc2}=0.7V_{dc1}$ (dotted lines) in Fig. 5.

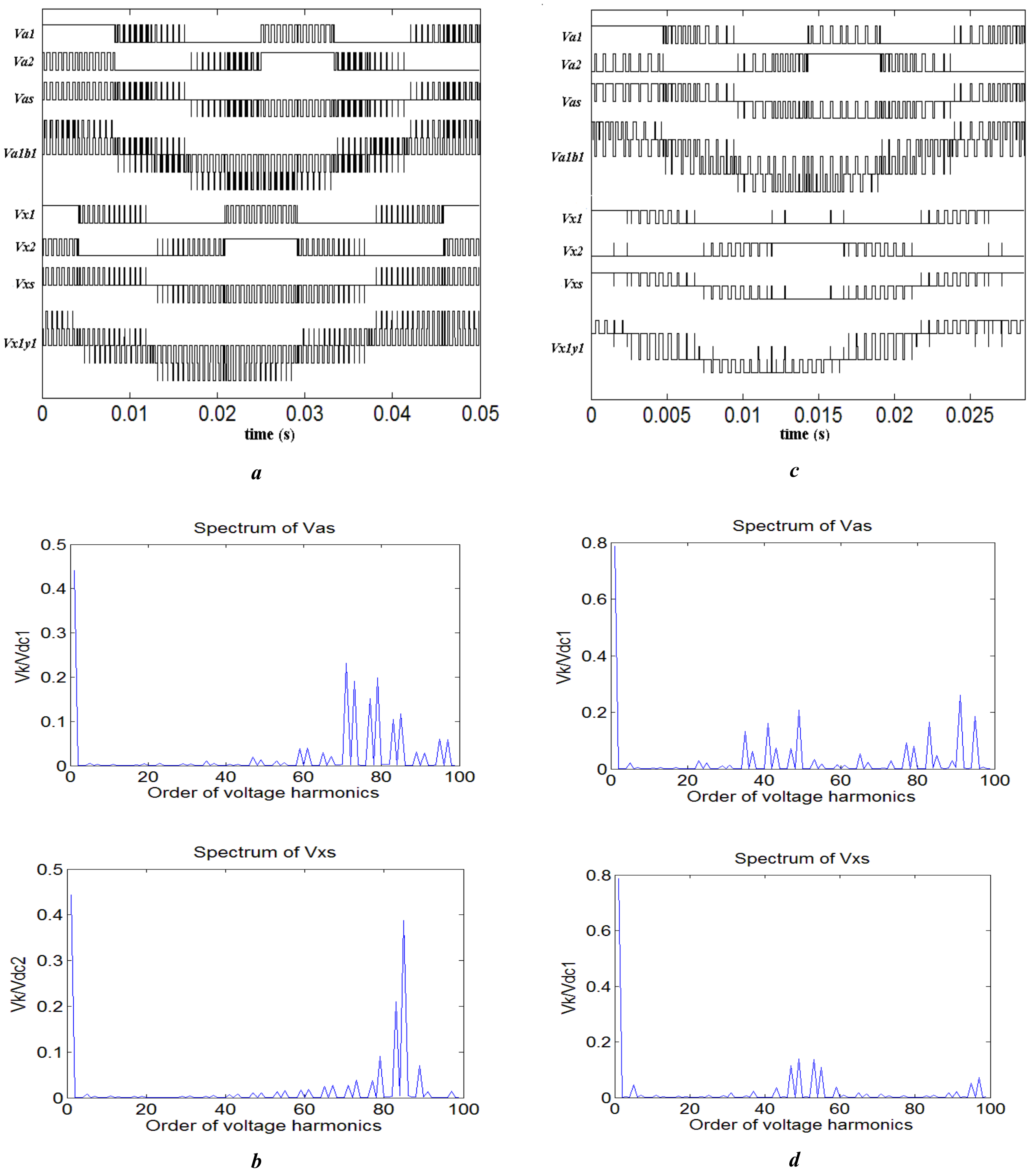
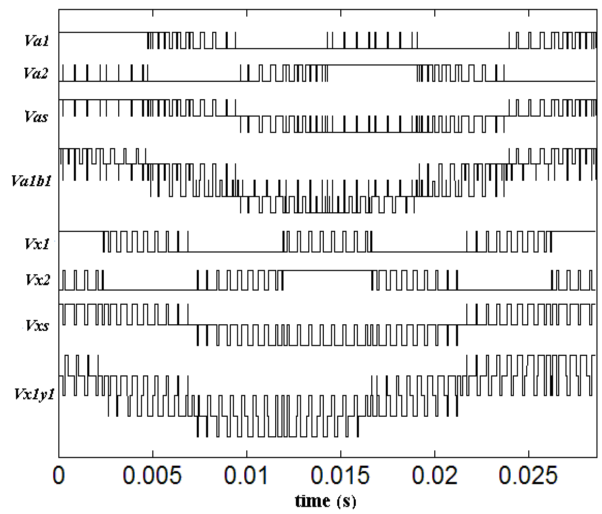
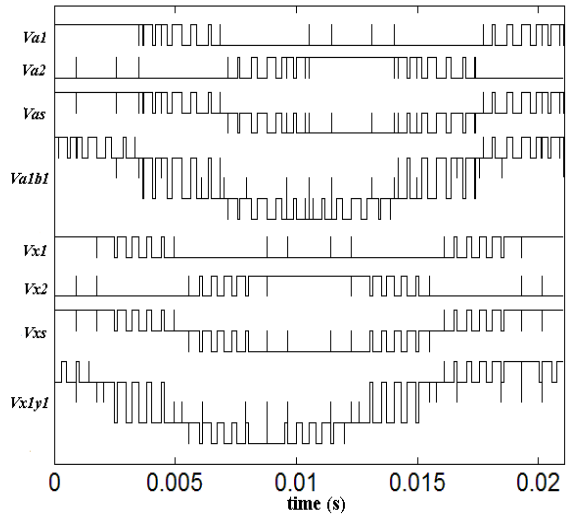


Fig. 3

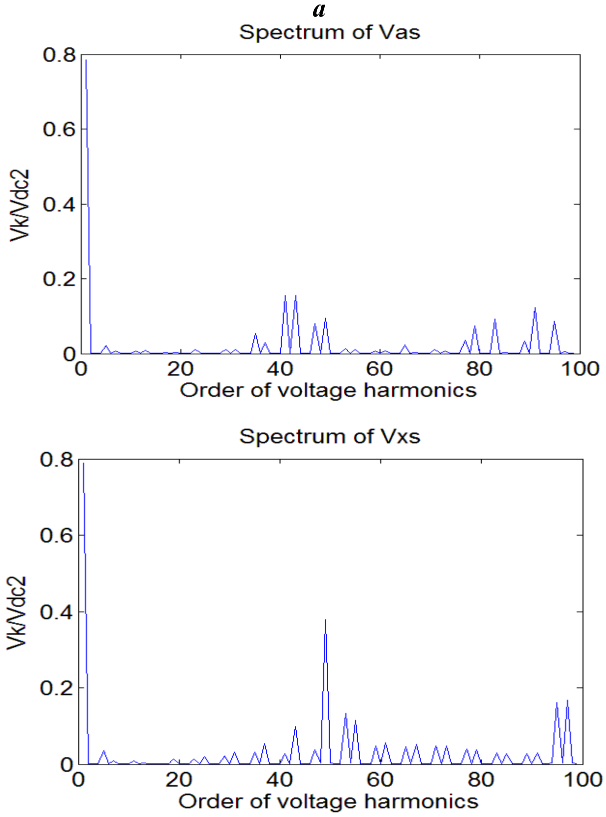
Conclusion. It has been shown possibility of hybridization of switching strategies for modulated inverters of six-phase multi-inverter drive. Hybrid switching techniques can be used successfully for control of power system (with low switching frequency of inverters) with non-equal voltages of dc-links. In this case the proposed combined switching techniques of inverters insure, by the corresponding linear variation of coefficients of modulation of inverters, equal magnitude of the fundamental harmonics of the phase voltages for different ratios between dc-voltages of six-phase system. Hybrid PWM strategy can be used also for further optimization of processes in multi-inverter systems. Combination of hybrid switching schemes with algorithms of synchronous PWM for control of inverters assures waveform symmetries of the phase voltages of the system. Voltage spectrograms do not contain in this case undesirable sub-harmonics.



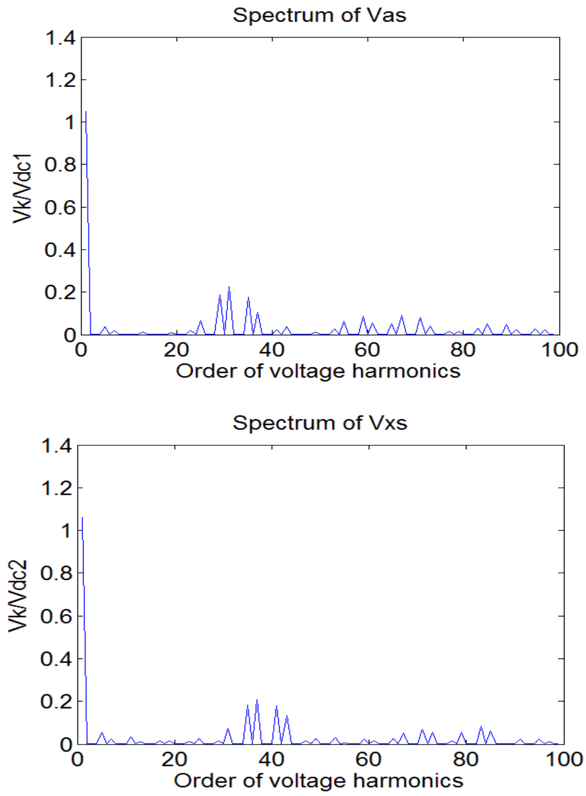
a



c



b



d

Fig. 4

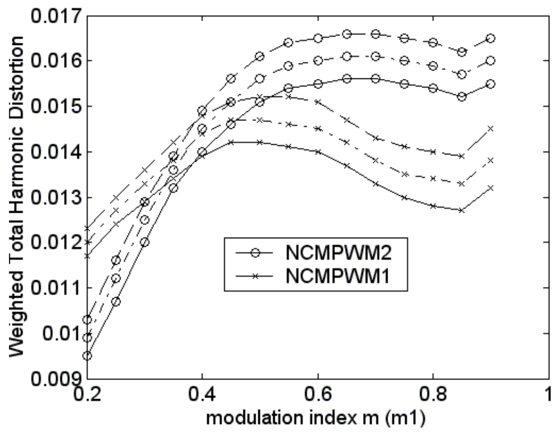


Fig. 5

1. *Baiju M.R., Mohapatra K.K., Kanchan R.S., Gopakumar K.* A dual two-level inverter scheme with common mode voltage elimination for an induction motor drive // IEEE Trans. on Power Electron. – 2004. – Vol. 19. – No 3. – Pp. 794-805.
2. *Grandi G., Sanjeevkumar P., Casadei D.* Preliminary hardware implementation of a six-phase quad-inverter induction motor drive // Proc. of the European Power Electronics Conf. (EPE'2011). – 2011. – 9 p.
3. *Hadiouche D., Baghli L., Rezzoug A.* Space-vector PWM techniques for dual three-phase ac machine: Analysis, performance evaluation, and DSP implementation // IEEE Trans. on Ind. Appl. – 2006. – Vol. 42. – No 4. – Pp. 1112–1122.

4. *Jones M., Dordevic O., Bodo N., Levi E.* PWM algorithms for multilevel inverter supplied multiphase variable-speed drives // Electronics. – 2012. – Vol. 16. – No 1. – Pp. 22-31.
5. *Oleschuk V., Blaabjerg F.* Synchronized scheme of continuous space-vector PWM with the real-time control algorithms // Proc. of the IEEE Power Electronics Specialists Conf. (PESC'2004). – 2004. – Pp. 1207-1213.
6. *Oleschuk V., Bojoi R., Griva G., Profumo F.* Dual three-phase traction drive with dc sources power balancing based on synchronized PWM // Proc. of the IEEE Int'l Electric Machines and Drives Conf. (IEMDC'2007). – 2007. – Pp. 260-265.
7. *Oleschuk V., Profumo F., Griva G., Bojoi R., Stankovic A.M.* Analysis and comparison of basic schemes of synchronized PWM for dual inverter-fed drives // Proc. of the IEEE Int'l Symp. on Industrial Electronics (ISIE'2006). – 2006. – Pp. 2455-2461.
8. *Oleschuk V., Sizov A.* Synchronous PWM control of four inverters feeding asymmetrical six-phase motor drive // Tekhnichna Elektrodynamika. – 2011. – No 4. – Pp. 31-37.
9. *Singh G.K.* Multi-phase induction machine drive research – a survey // Electric Power System Research. – 2002. – No 61. – Pp. 139-147.

УДК 621.314.572

МНОГОФАЗНАЯ ПРЕОБРАЗОВАТЕЛЬНАЯ СИСТЕМА С ГИБРИДНОЙ СТРАТЕГИЕЙ УПРАВЛЕНИЯ ИНВЕРТОРАМИ С ШИМ

Олещук В., докт.техн.наук, **Ермуратский В.**, докт.техн.наук
Институт энергетики Академии наук Молдовы,
ул. Академическая, 5, Кишинев, МД-2028, Молдова.
E-mail: oleschukv@hotmail.com

Предложено и проанализировано гибридное управление каскадно-связанными инверторами системы сдвоенного трёхфазного электропривода с асимметричным шестифазным асинхронным электродвигателем. Рассмотренные алгоритмы комбинированного регулирования и управления обеспечивают устранение напряжения нулевой последовательности в системе. Использование схемы синхронной векторной модуляции обеспечивает симметрию форм выходного напряжения отдельных инверторов и фазного напряжения в системе на всём диапазоне регулирования. Выполнено моделирование процессов в шестифазной преобразовательной системе на базе четырёх инверторов с гибридным управлением. Библ. 9, рис. 5.
Ключевые слова: сдвоенный трехфазный (шестифазный) электропривод, многоинверторная топология системы, стратегия управления, комбинированные алгоритмы широтно-импульсной модуляции.

БАГАТОФАЗНА ПЕРЕТВОРЮВАЛЬНА СИСТЕМА З ГІБРИДНОЮ СТРАТЕГІЄЮ УПРАВЛІННЯ ІНВЕРТОРАМИ З ШІМ

Олещук В., докт.техн.наук, **Єрмуратський В.**, докт.техн.наук
Інститут енергетики Академії наук Молдови,
вул. Академічна, 5, Кишинев, МД-2028, Молдова.
E-mail: oleschukv@hotmail.com

Запропоновано та проаналізовано гібридне управління каскадно-зв'язаними інверторами системи здвоєного трифазного електропривода з асиметричним шестифазним асинхронним електродвигуном. Розглянуті алгоритми комбінованого регулювання та управління забезпечують усування напруги нульової послідовності у системі. Використання схеми синхронної векторної модуляції забезпечує симетрію форм вихідної напруги окремих інверторів та фазної напруги у системі у всьому діапазоні регулювання. Виконано моделювання процесів у шестифазній перетворювальній системі на базі чотирьох інверторів з гібридним керуванням. Бібл. 9, рис. 5.
Ключові слова: здвоєний трифазний (шестифазний) електропривод, багатоінверторна топологія системи, стратегія управління, комбіновані алгоритми широтно-імпульсної модуляції.

Надійшла 14.04.2015