НАПІВПРОВІДНИКОВІ ПЕРЕТВОРЮВАЧІ

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DOUBLE-DELTA-WINDING SYSTEM WITH NEUTRAL-POINT-CLAMPED CONVERTERS CONTROLLED BY SYNCHRONOUS MULTI-ZONE PWM

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In this paper, algorithms of the universal scheme of synchronous multi-zone modulation have been developed and disseminated for adjustment of two neutral-clamped inverters of double-delta-winding system (which is perspective for application in high power variable speed ac drives), providing synchronization and symmetry of waveforms of inverter-side voltage of power transformer for any control modes of operation including regimes with fractional relationship between the switching frequency of inverters and fundamental frequency of system. In this case inverter-side winding voltage of double-delta-winding system has quarter-wave symmetry, and its spectra do not contain even harmonics and undesirable subharmonics. Simulation results show behavior of system with two neutral-clamped inverters controlled by three basic versions of synchronous multi-zone modulation. References 9, figures 5, table.
Key words: inverter, ac drive, pulsewidth modulation.

Introduction. Recently, novel electrical power conversion systems based on double-delta sourced windings, which are perspective for application in motor drives, have been investigated [1-6]. So, this paper presents results of research of this type of systems on the base of two neutral-point-clamped inverters (NPCI) regulated by the universal scheme of synchronous multi-zone space-vector modulation, providing synchronization and symmetry of waveforms of voltage of inverter-side windings of power transformer for cases of fractional ratio between the switching frequency of inverters and fundamental frequency of system.

Topology, structure, and features of double-delta-winding system with two NPCIs. Fig. 1, *a* presents structure of double-delta-winding system [1] with two NPCIs (NPCI1 and NPCI2), outputs of which are specifically (see bold lines in Fig. 1 *a* connected to the corresponding windings. Fig. 1 *b* shows topology of NPCI. Fig. 1 *c* shows (by the big arrows) its basic voltage vectors and definitions of switching state se-quence for these vectors [7]. This control scheme assures cancellation of common-mode voltage in system. Fig. 1 *d* shows switching state sequences of three basic schemes of synchronous multi-zone PWM, applied for control of NPCIs [7]. **Peculiarities of synchronous multi-zone space-vector PWM.** Principle of synchronous multi-zone PWM of NPCIs is based on continuous determination of intermediate frequencies $F_i = \frac{1}{6(2i-1)\tau}$ and $F_{i-1} = \frac{1}{6(2i-3)\tau}$ (as functions of switching sub-cycle τ) on the axis of the fundamental frequency F of system, and in calculation of coefficient of synchronization $K_s = [1-(F-F_i)/(F_{i-1}-F_i)]$, which is component of basic functions for determination of PWM pulse patterns [7-9]. Table presents control correlations for determination of instantaneous values of winding voltages $V_{w11} - V_{w23}$ as functions of the pole voltages of NPCIs.

Instantaneous values of winding voltages $V_{w11} - V_{w13}$ of Double-Delta-Winding System (Fig. 1,a)	Instantaneous values of winding voltages $V_{w21} - V_{w23}$ of Double-Delta-Winding System (Fig. 1,a)
$V_{w11} = (2V_{a1} - V_{b1} - V_{c1})/3 - (V_{a2} - 2V_{b2} + V_{c2})/3$	$V_{w21} = (V_{a1} - 2V_{b1} + V_{c1})/3 - (2V_{a2} - V_{b2} - V_{c2})/3$
$V_{w12} = (V_{a1} + V_{b1} - 2V_{c1})/3 - (-V_{a2} + 2V_{b2} - V_{c2})/3$	$V_{w22} = (-V_{a1} + 2V_{b1} - V_{c1})/3 - (V_{a2} + V_{b2} - 2V_{c2})/3$
$V_{w13} = (-V_{a1} - V_{b1} + 2V_{c1})/3 - (-2V_{a2} + V_{b2} + V_{c2})/3$	$V_{w23} = (-2V_{a1} + V_{b1} + V_{c1})/3 - (-V_{a2} - V_{b2} + 2V_{c2})/3$

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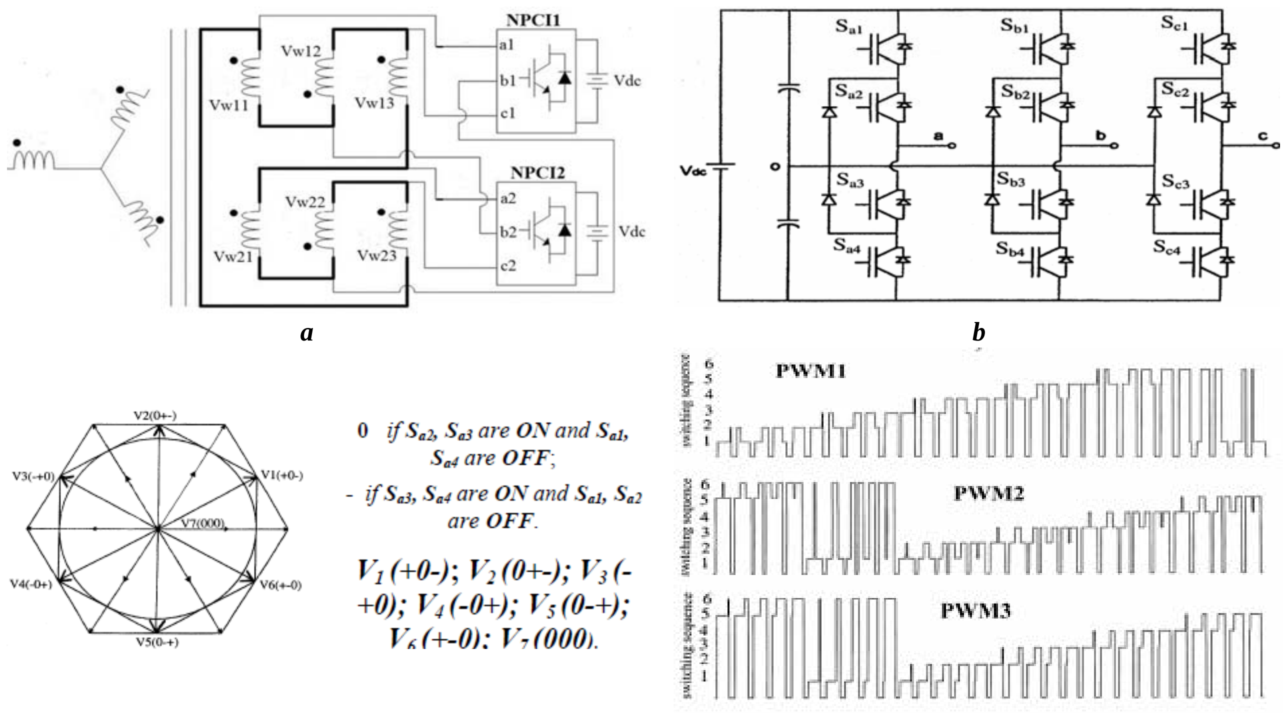
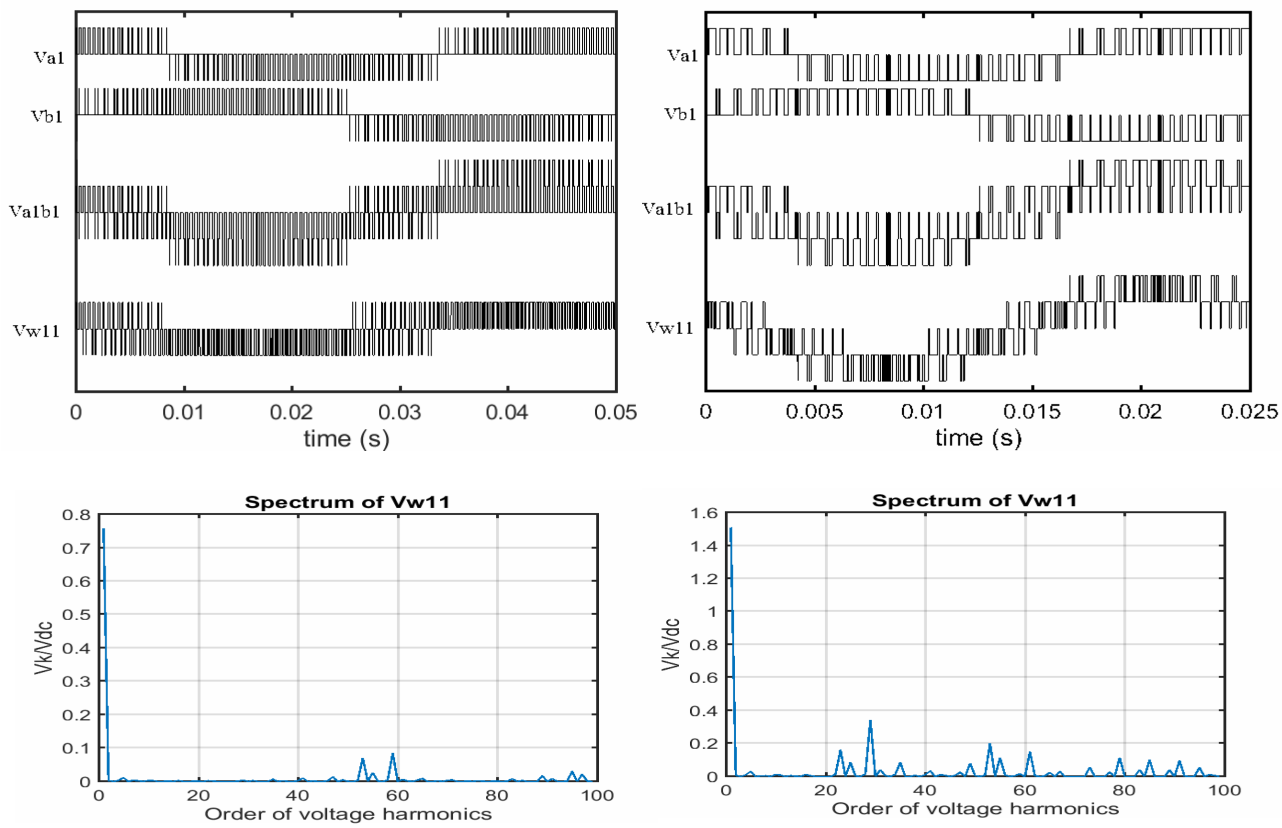


a *b* *c* *d*

Fig. 1



a *b*

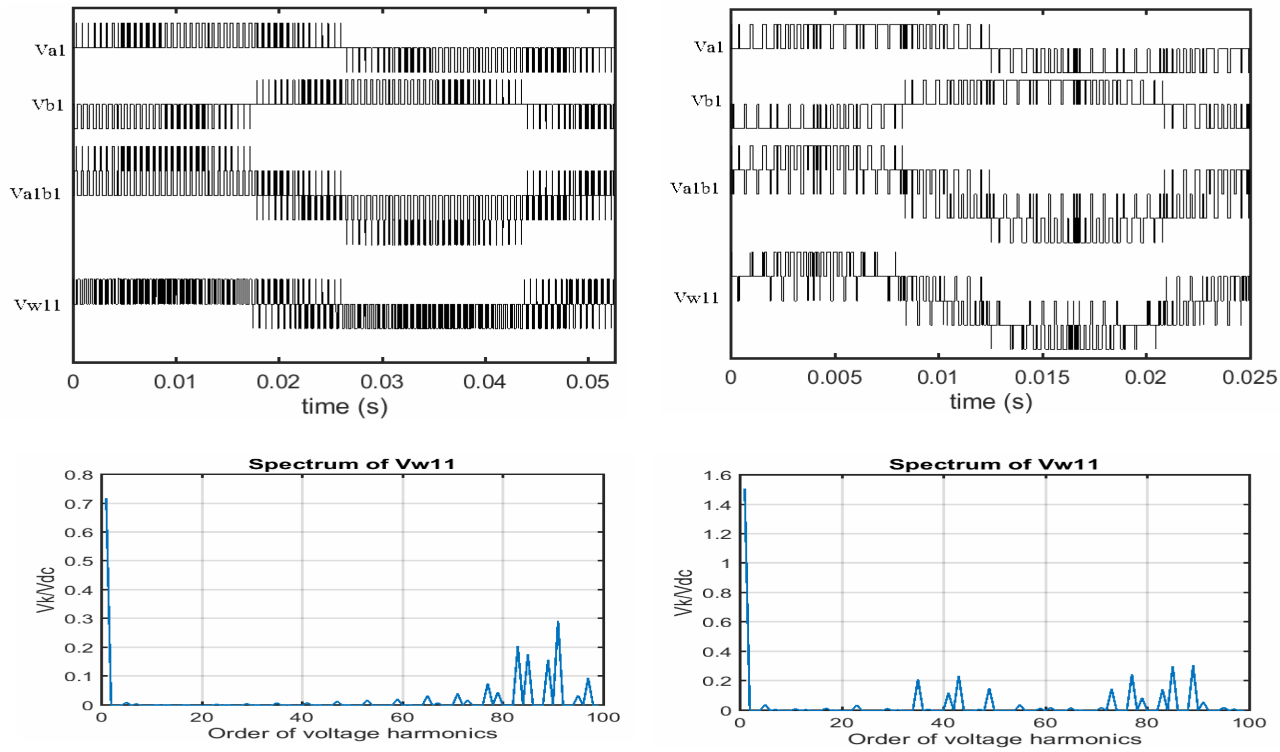
Fig. 2

Synchronous control of double-delta-winding system with two NPCIs. Rational synchronous adjustment of double-delta-winding system with two modulated NPCIs is based on the corresponding phase shifts of signals of two inverters including an additional phase shift between signals of inverters equal to one half of switching sub-cycle [1, 4, 6, 7].

To underline properties of the used (for control of NPCIs) scheme of synchronous multi-zone PWM, simulation of processes in double-delta-winding system with two NPCIs had been executed for scalar control mode of system with fractional relationship between switching frequency of inverters (equal to *1.1kHz*) and fundamental frequency of system equal correspondingly to *21Hz* and *40Hz* for two simulation modes. Results of simulation of processes in system with two NPCIs are presented in Fig. 2–4. Fig. 2 shows basic voltage waveforms and spectra of winding voltage of double-delta-winding system with NPCIs (relative values of pole and line voltages of the first NPCI (V_{a1}, V_{b1}, and V_{a1b1}), winding voltage V_{w11}, and also spectra of the winding voltage), adjusted by the PWM1 scheme of modulation, presented in Fig. 1 *d*. Curves in Fig. 2 *a* correspond to low fundamental frequency *F* of system and low modulation index *m* of inverters (*F=21Hz, m=0.42*), and diagrams in Fig. 2 *b* correspond to the medium fundamental frequency of system, equal to *F=40Hz, m=0.8* in this case. Fig. 3 *a,b* presents the corresponding diagrams for system with NPCIs controlled by the PWM2 algorithm, and Fig 4 *a,b* shows diagrams for system with NPCIs regulated by the scheme of synchronous modulation with switching state sequence PWM3, presented in Fig. 1 *d*.

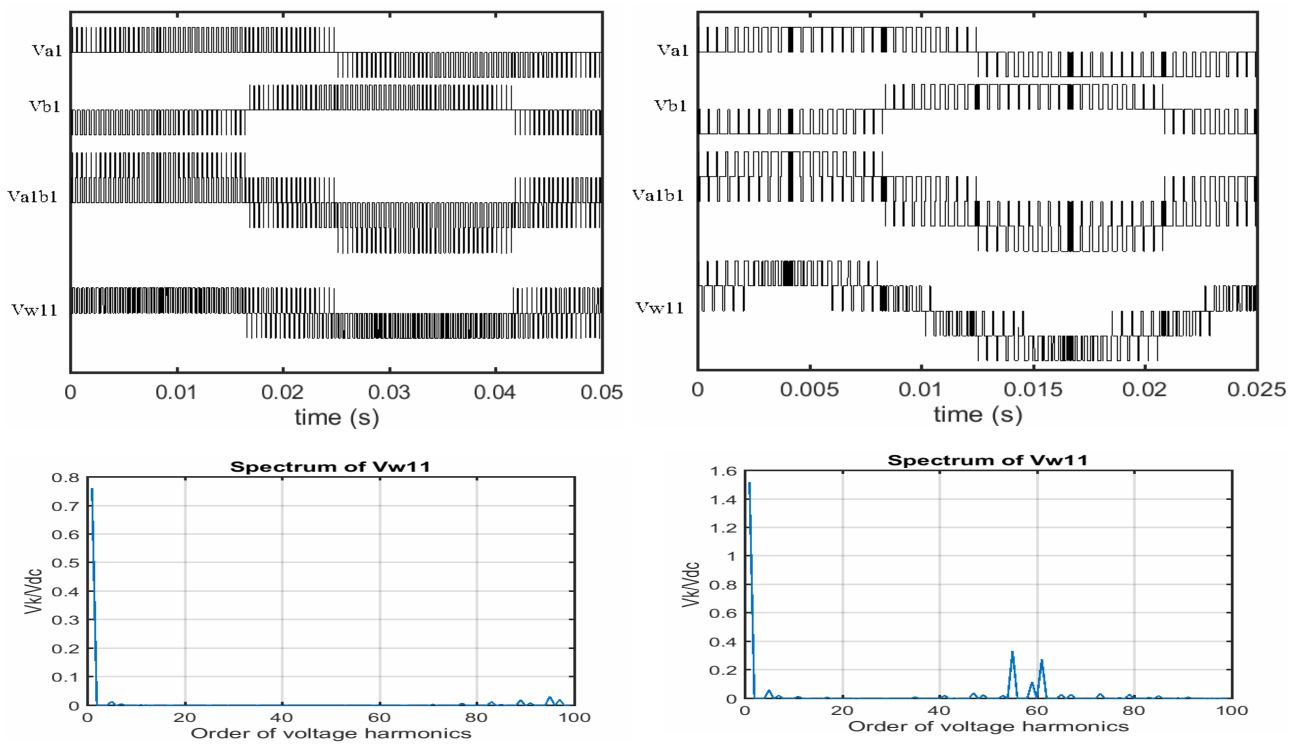
Simulation results, presented in Fig. 2–4, show, that both line voltage of NPCIs and inverter-side winding voltage of double-delta-winding system have quarter-wave symmetry, and its spectra do not contain even harmonics and undesirable subharmonics.

Fig. 5 presents results of determination of averaged Weighted Total Harmonic Distortion factor ($WTHD = (1/V_{w11_1})\sqrt{\sum_{i=2}^{1000}(V_{w11i}/i)^2}$) of the V_{a1b1} and V_{w11} voltages of double-delta-winding system with NPCIs (with average switching frequency equal to *1.1kHz*) controlled by the PWM1, PWM2 and PWM3 schemes of synchronous modulation during scalar *V/F* adjustment mode. The presented results show, that at lower and medium modulation indices algorithms of PWM1 and PWM3 assure better *WTHD* of winding voltage V_{w11}, and at higher modulation indices algorithms of PWM2 insure better spectral composition of V_{w11}.



a ***b***

Fig. 3



a ***b***

Fig. 4

Conclusion. Developed scheme of synchronous multi-zone PWM, applied for regulation of two NPCIs of double-delta-winding system, assure advanced (without even harmonics and subharmonics) spectra of inverter-side winding voltage for any operating conditions, contributing to reduction of power losses in these installations. To underline properties of the used scheme of synchronous multi-zone PWM, simulation results, presented in Figs. 2-4, proved the fact of advanced spectra of winding voltage of system for control modes with fractional relationship between the switching frequency of inverters (equal to *1.1kHz*) and fundamental frequency of system equal correspondingly to *21Hz* and *40Hz* for two simulation regimes.

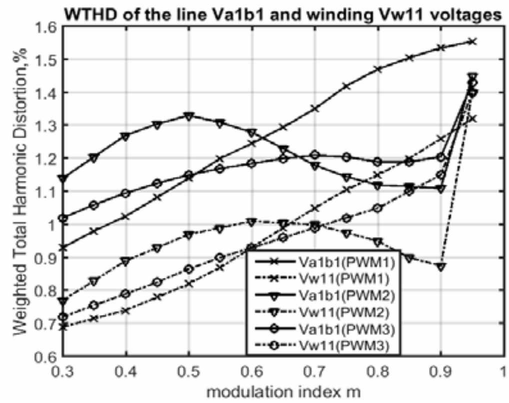


Fig. 5

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ПРЕОБРАЗОВАТЕЛЬНАЯ СИСТЕМА С ОБМОТКАМИ ТРАНСФОРМАТОРА ПО СХЕМЕ ДВОЙНОГО ТРЕУГОЛЬНИКА НА БАЗЕ ИНВЕРТОРОВ СО СРЕДНЕЙ ТОЧКОЙ В ЦЕПИ ПИТАНИЯ И С МНОГОЗОННОЙ СИНХРОННОЙ ШИМ

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Показано, что модифицированные применительно к регулированию двух инверторов со средней точкой источника питания алгоритмы синхронной многозонной ШИМ позволяют обеспечить синхронизацию и симметрию форм напряжения на инверторных обмотках преобразовательной системы трансформаторного типа (перспективной для использования в мощных регулируемых электроприводах переменного тока) при любых режимах функционирования, включая режимы работы при дробных соотношениях между частотой коммутации вентилей инверторов и выходной частотой системы. При этом напряжение на инверторных обмотках трансформатора обладает четвертьволновой симметрией, и в его спектре отсутствуют четные гармоники и субгармоники. Выполнено моделирование процессов в системе с двумя инверторами, регулируемыми на основе трех разновидностей синхронной многозонной ШИМ. Библ. 9, рис. 5, таблица.
Ключевые слова: инвертор, электропривод переменного тока, широтно-импульсная модуляция.

ПЕРЕТВОРЮВАЛЬНА СИСТЕМА З ОБМОТКАМИ ТРАНСФОРМАТОРА ЗА СХЕМОЮ ПОДВІЙНОГО ТРИКУТНИКА НА БАЗІ ІНВЕРТОРІВ ІЗ СЕРЕДНЬОЮ ТОЧКОЮ В КОЛІ ЖИВЛЕННЯ ТА З БАГАТОЗОННОЮ СИНХРОННОЮ ШІМ

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Показано, що модифіковані для регулювання двох інверторів із середньою точкою джерела живлення алгоритми синхронної багатозонної ШІМ дають змогу забезпечити синхронізацію та симетрію форм напруги на інверторних обмотках перетворювальної системи трансформаторного типу (перспективної для використання в потужних електроприводах змінного струму, що регулюються) за будь-яких режимів функціонування, включно з режимами роботи при дробових співвідношеннях між частотою комутації вентилів інверторів і вихідною частотою системи. У такому випадку напруга на інверторних обмотках трансформатора має чвертьхвильову симетрію, а в її спектрі відсутні парні гармоніки та субгармоніки. Виконано моделювання процесів у системі з двома інверторами, що регулюються на основі трьох різновидів синхронної багатоозонної ШІМ. Бібл. 9, рис. 5, таблиця.
Ключові слова: інвертор, електропривод змінного струму, широтно-імпульсна модуляція.

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