Photovoltaic Power Conversion System Based on Cascaded Inverters with Synchronized Space-Vector Modulation

V. Oleschuk¹, J. Tlusty² and V. Valouch³

¹ Institute of Power Engineering of the Academy of Sc., Kishinau, Moldova, and Politecnico di Torino, Turin, 10129, Italy
Phone: +039 011 0907111, Fax: +039 011 0907111, E-mail: oleschukv@hotmail.com

² Department of Power Engineering, Faculty of Electrical Engineering, CTU, Prague, Czech Republic
E-mail: tlusty@fel.cvut.cz

³ Institute of Thermomechanics of the Academy of Sc. of Czech Republic, Dolejskova 5, Prague, Czech Republic
E-mail: valouch@it.cas.cz

1. Introduction

Some of the perspective topologies of power converters are now cascaded (dual) two-level converters which utilize two standard three-phase voltage source inverters [1]-[3]. In particular, dual inverter-fed open-end winding motor drives have some advantages such as redundancy of the space-vector combinations and the absence of neutral point fluctuations [4]-[7].

Almost all versions of classical space-vector PWM are based on the asynchronous principle, which results in sub-harmonics (of the fundamental frequency) in the spectrum of the output voltage of converters, which are very undesirable in medium/high power applications [8]-[9]. In order to provide voltage synchronization in dual inverter-fed drives, a novel method of synchronized PWM has been applied for control of these systems with single dc voltage source [10], and for the systems with two dc sources: without power balancing between sources [11], and also with power balancing PWM algorithms in a linear control range [12].

Besides adjustable speed ac drives, photovoltaic systems are between perspective areas of application of the dual-inverter topology [13]. In particular, Fig. 1 presents dual inverter system supplied by two insulated strings of photovoltaic panels with the resulting dc voltages \( V_L \) and \( V_H \) [13]. Direct connection of photovoltaic modules to inverters, or their connection through dc/dc link (dashed lines in Fig. 1) is available in this case. Dual inverters are connected to grid by a three-phase transformer with the open winding configuration on primary side. So, this paper presents results of dissemination of novel method of synchronized pulsewidth modulation for control of cascaded-inverter-based power conversion system for photovoltaic high power/high current application.

2. Features of the Method of Synchronized PWM

In order to avoid asynchronous operation of inverters with conventional space-vector modulation, novel space-vector-based method of synchronized PWM [14],[15] can be used for control of each inverter in a dual system for photovoltaic application. One of the basic ideas of the proposed PWM method is in continuous synchronization of the positions of all central switch-on signals in the centers of the 60⁰ clock-intervals of three-phase inverters, and then – to generate symmetrically all other active signals together with the corresponding notches [14],[15].

3. Synchronous Operation of Dual Inverters

Synchronous control of the output voltage of each inverter of dual-inverter system with synchronized PWM provides synchronous symmetrical regulation of the phase voltages \( V_1 \), \( V_2 \) and \( V_3 \) of the system. Rational phase shift between output voltage waveforms of the two
inverters is equal in this case to one half of the switching interval (sub-cycle) $\tau$ [1].

As an example of operation of the dual-inverter system with synchronized PWM, Fig. 2 presents basic voltage waveforms (period of the pole voltages $V_{1H}$, $V_{1L}$ ($V_{1H}=V_{1L}$, $m_{H}=m_{L}=0.45$), line-to-line voltages $V_{1L2L}$, $V_{1H2L}$ of the two inverters, and phase voltage $V_{1}$ (with its spectrum)) for the system with continuous synchronized PWM. The fundamental and switching frequencies are equal to 50Hz and 1.35kHz.

![Fig. 2. Basic voltages waveforms and voltage spectrum.](image)

Fig. 3 presents the calculation results of Total Harmonic Distortion factor (THD) in the function of modulation index $m=m_{H}=m_{L}$ for the phase voltage $V_{1}$ ($THD=(1/V_{1})\sqrt{\sum_{k=2}^{100}(V_{k})^{2}}$) of dual-inverter system with equal dc-links voltages ($V_{H}=V_{L}$), controlled by algorithms of continuous (CPWM) and discontinuous (DPWM) schemes of synchronized modulation. The fundamental and switching frequencies are equal to 50Hz and 1.35 kHz. The calculation results show that continuous scheme of synchronized PWM provides better spectral composition of the phase voltage in the systems with operating modulation indices $m<0.8$.

![Fig. 3. THD factor of the phase voltage $V_{1}$.](image)

4. Conclusion

Novel method of synchronized space-vector modulation, applied for control of dual-inverter system with two insulated photovoltaic dc-links, allows both continuous phase voltage synchronization and required regulation of the system by the corresponding control of modulation indices of two inverters.

The spectra of the phase voltage of photovoltaic systems with algorithms of synchronized PWM do not contain even harmonics and sub-harmonics for any control regime of the systems, with both equal and different voltages of two dc-sources, which is especially important for high power/high current applications.

References