Modeling and Control of a Three-Phase Neutral-Point-Clamped Inverter by Means of a Direct Space Vector Control of Line to Line Voltages

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Abstract
This paper presents a modulation strategy that enables to copy directly modulated waveform onto output voltages of a three-phase N.P.C. inverter. A particular modeling of this converter is presented. The feasibility of a space vector scheme without using a Park transform is studied. All voltage vectors are drawn into the line to line voltage frame. Then three voltage vectors are selected for the modulation and simultaneously their durations are calculated. The effect of the modulation on the capacitor divider is studied and a balancing strategy is deduced.

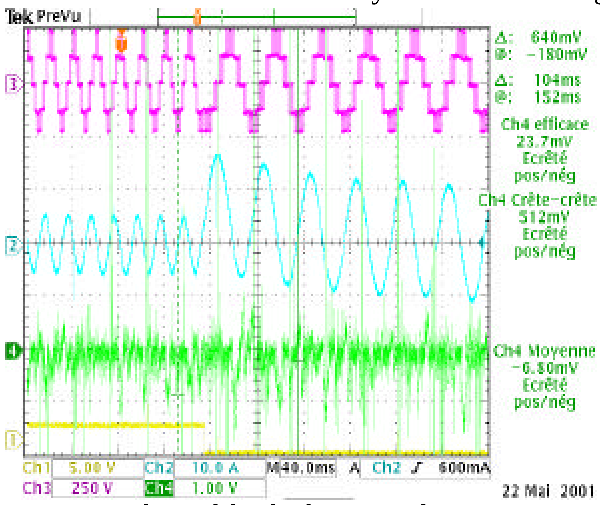
I. Introduction

The interest towards enhancing the performance of multilevel converters has increased, specially in the least decade. The main reason is their capabilitie for reducing the harmonic distortion in the generated multilevel waveform and for increasing the voltage ratings (and so the power ratings). For Neutral Point Clamped inverters (NPC), it is critical to balance the neutral point voltage in case of disturbed or even continuous load conditions. So far, several vector control schemes for NPC inverters have been proposed.

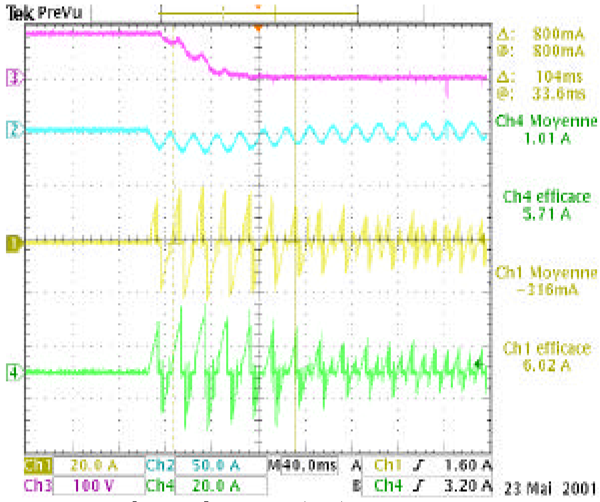
High performance control strategies of N.P.C. inverters are based on the space vector approach (see [1] as example). The line-to-line output voltages are generated by switching PWM patterns among three vectors in triangular working areas. The vector selection is done in order to minimize the neutral point voltage variations but the complexity of involved calculations requires a very powerful microprocessor or DSP [2], [3]. Transformation of voltages into synchronously rotating reference co-ordinates has been explored in order to control direct and quadrate axis components by using hysteretic comparators [4], [5]. But, the obtained moving modulation frequency is a strong constraint for power applications with high voltage semiconductors. The major limitation of N.P.C. converters is still the capacitive voltage unbalance and it restrains the industrial development of N.P.C. converters [6] [7].

In this paper, the principles of a neutral point voltage modulation system without Park transformation (in a d,q frame) are discussed. We first present the multilevel inverter operating principle and the converter modeling. A more appropriate average modeling for the control design is given. Then the proposed vector control scheme is presented. As usual, the plane is divided in triangular areas. The three vectors related with the area that includes the reference are used to create the PWM waveform. The innovation is that the space frame is not obtained through a mathematical transformation but is directly the line to line voltage space. 19 voltage vectors are used for the modulation. A few of these 19 vectors are redundant vectors: they are then used-for the dc bus balancing and the losses minimization. A practical implementation of this modulator is detailed. Then, experimental results on a 2.5 kVA prototype are given.

The second presented test consists in a start-up with an unbalanced capacitor load (fig. 13). It was performed to verify the self-balancing capabilities of the modulation technique and was done by connecting a resistor in parallel with capacitor C_2. In consequence, a voltage drop of 80V appears and causes an additional difficulty to reach a correct multilevel operation. The modulation system erases this drop in 80 ms with a 8A rms load current. Dissymmetrical waveforms of chopped currents justify the balancing process of the modulation strategy. Other tests for different current load values have been done to characterize the dynamic of the voltage stabilization.



1: Control signal for the frequency drop
2: Load current (*is*)
3: Modulated voltage (*um*)
4: DC voltage error (us_1-us_2)
Fig. 12. Dynamical results with a frequency drop.



1: Chopped current (im_2)
2: Load current (*is*)
3: DC voltage error (us_1-us_2)
4: Chopped current (im_1)
Fig. 13. Start-up with unbalanced conditions.

IV Conclusion

In this paper a particular voltage space vector modulation system without Park transformation (in a d,q frame) have been presented. A Capacitor voltage divider equalization is obtained via the use of redundant configurations.
The fundamental work is to formulate a modulator as capable of drawing balance power of the dc bus.

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XI. Biographies

Bruno Francois received the Ph. D. degree from the University of Lille, France in 1996. He is Associate Professor at the department of Electrical Engineering of: Ecole Centrale de Lille. He is a member of Laboratory *of Electrical Engineering* (L2EP), Lille. He is currently working on the design of modulation and control systems for multilevel converters and also the development of next-generation power systems. Web site : http://www.univ-lille1.fr/l2ep/c-br-fr.htm.

Eric Semail is graduated from the Ecole Normale Supérieure, Cachan, France. He received the teaching degree "Agrégation" in 1986. From 1987 to 2001, he has been professor (holder of agrégation) in University of Lille (USTL). He received Ph.D. degree in 2000 and became associate professor at ENSAM Lille in 2001. In L2EP (Laboratory of Electrical Engineering of Lille) his fields of interest include modeling, control and design of polyphase systems (converters and AC Drives)