International Journal of Research Studies in Science, Engineering and Technology [IJRSSET]
Volume 1, Issue 2, May 2014, PP 12-16

Current Waveform Improvement by Control of Hybrid Multilevel Converter with FDC Links

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Abstract: *Multilevel converters offer advantages in terms of the output waveform quality due to the increased number of levels used in the output voltage modulation. This advantage is particularly true for cascaded H-bridge converters that can be built to produce a large number of levels thanks to their modular structure. Nevertheless, this advantage comes at the cost of multiple DC-links supplied by independent rectifiers through the use of a multi-output transformer for inverters. This frontend complicates the implementation of converters that have a high number of levels. An alternative method of using lower voltage cells with floating dc-links to compensate only for voltage distortion of an NPC converter is considered for active rectifier applications. The analogy between the floating H-bridges and series active filters is used to develop a strategy for harmonic compensation of the NPC output voltage and the control of the floating dc-link voltages. This simplifies the current control scheme and increases its bandwidth. Experimental results with a low power prototype that show the good performance of the proposed modulation technique and the resulting improvement in the output waveform are provided.*

Keywords: *Power electronics, current control, and harmonic distortion.*

1. Introduction

In the last decade, medium-voltage high-power converters have become widely used as drives for pumps, fans and material transport in a number of industries, as well as for VAR compensation in grid applications [1,2]. At this voltage range, multilevel converters are preferred to overcome the voltage blocking limitations of the available switches. Another important advantage of this technology is the improved output waveforms due, to the higher number of levels in the output voltage waveform, compared to the conventional three-phase two-level inverter. Similarly, an increased number of voltage levels will result in a reduced input filter size for grid connected applications. Moreover, high number of levels allows the device switching frequency to be reduced for a given current distortion.

The multilevel topologies can be classified into three main categories: the neutral point clamped (NPC) [3], the flying capacitors (FC) [4,5] and the cascaded H-bridge (CHB) converters [6,7]. The three levels NPC-Bridge is probably the most widely used topology for medium voltage AC motor drives and PWM active rectifiers [8,9]. NPC converters with more levels are also possible, although there are significant problems in the balancing of their dc-link capacitor voltages [10,11], unless modified modulation strategies [12]or additionally circuitry [13] are used. On the other hand, the CHB converter is normally implemented with large number of levels, but at the cost of complicated and bulky input transformers with multiple rectifiers [7] or multi-winding three-phase output transformers. For this reason, in applications with no active power transfer, such as in reactive power compensation, where the converter can operate without the rectifier front-end, the CHB is a highly attractive solution.

In recent years an increased interest has been given to hybrid topologies integrating more than one topology in a single converter. Some authors have proposed the use of cascaded H-bridges fed by multilevel dc-links generated which are implemented with another converter topology, a hybrid configuration based on the combination of an active NPC and a flying capacitor cell has been proposed to implement a five level converter. An hybrid converter formed by the series connection of a main three-level NPC converter and auxiliary floating H-Bridges (NPC-HBs) has been presented. In this topology, the NPC is used to supply the active power while the HBs operate as series active filters, improving the voltage waveform quality by only handling reactive power. In this way, this topology reduces the need for bulky and expensive LCL passive filters, making it an attractive alternative for large power applications.

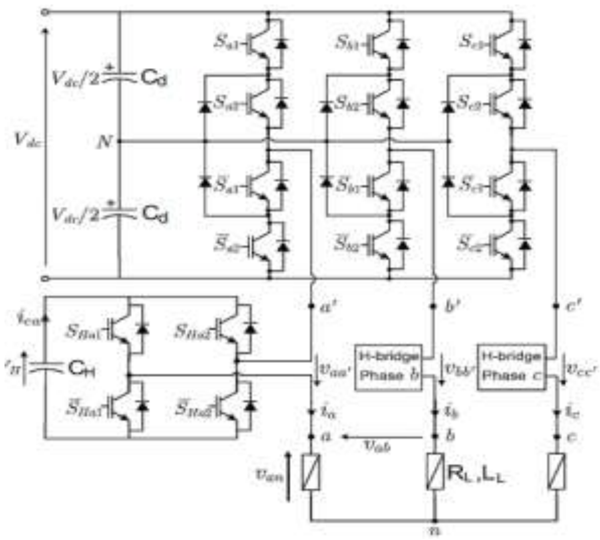
In this work, the control strategy for the NPC-HBs hybrid converter, previously introduced in, is experimentally verified. This includes: low frequency synchronous modulation of the NPC and the generation of the HBs voltage references for dc-link voltage control.

2. Hybrid Topology

2.1 Power Circuit

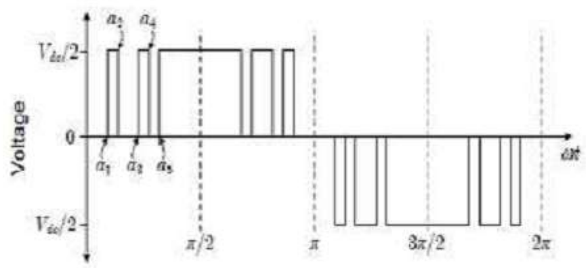
The considered hybrid topology is composed by a traditional three-phase, three-level NPC inverter, connected with a single phase H-bridge inverter in series with each output phase. The power circuit is illustrated in Fig. 1, with only the H bridge of phase a shown in detail. For testing as an inverter, the DC source for the NPC converter is provided by two series connected diode bridge rectifiers, arranged in a twelve-pulse configuration.

The H-bridge DC-links are not connected to an external DC power supply, and they consist only of floating capacitors kept at a constant voltage by the control strategy detailed in Section IIIIn the hybrid topology considered, the NPC inverter provides the total active power flow. For high-power medium voltage NPC, there are advantages to using latching devices such IGCTs rather than IGBTs, due to their lower losses and higher voltage blocking, imposing a restriction on the switching frequency. In this work, an NPC operating at a low switching frequency (of 250Hz) is considered. In contrast, the H-bridges are rated at a lower voltage and need to be commutated at a higher frequency for an effective active filtering effect. This calls for the use of IGBT



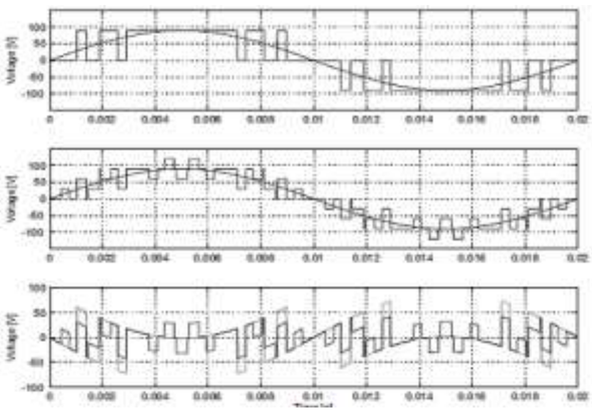
2.2 NPC Selective Harmonic Elimination

Three-level SHE is an established and well documented modulation strategy. A qualitative phase output voltage waveform is presented in Fig. 2 considering a 5-angle realization, so five degrees of freedom are available. This enables the amplitude of the fundamental component to be controlled and four harmonics to be eliminated. Since a three-phase system is considered, the triple harmonics are eliminated at the load by connection, and hence, they do not require elimination by the modulation pulse pattern. Thus, the 5th, 7th, 11th and 13th harmonics are chosen for elimination. For line-connected applications, this 5-angle implementation results in a switching frequency of 250Hz for the NPC portion of the converter and leaves the 17th as the first harmonic component to appear in the steady state load current. On the other hand, for variable frequency drive applications, the number of angles must be varied in order to maintain a near constant switching frequency at any operation point.



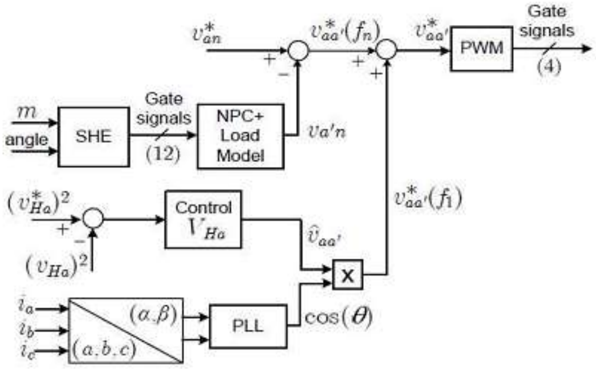
2.3 H-Bridge floating DC-link voltage determination

The addition of the series H-bridge results in more levels being added on the output voltage waveform of the converter VaN. In particular, if the value of VH is smaller than Vdc/4, no redundant switching states are created and the output voltage waveform of the converter will have the maximum number of levels (nine), generating similar waveforms to those achieved by cascade H-bridge inverters with unequal dc sources [1]



3. Control Strategy

Each series H-bridge converter is independently controlled by two complementary references, as shown in Fig. 5. The first reference VVaaaa’(fn) corresponds to the inverse of the harmonics remaining from the SHE pulse pattern, calculated as described in the previous section from the difference between the NPC pulsed voltage pattern and its sinusoidal voltage reference. This calculation provides a fast and straightforward distortion estimation allowing for simple feed-forward compensation.



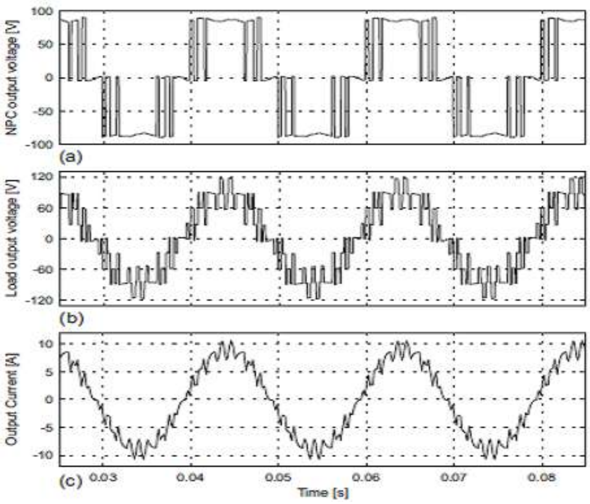
Moreover, this voltage does not have a fundamental voltage component and hence it does not affect the floating average DC-link capacitor voltage. Nevertheless, to achieve start-up capacitor charge and to compensate voltage drift due to transient operation, an additional reference component for DC- link voltage control is included. This second component of the voltage reference VVaaaa′∗(f1) corresponds to a signal in phase with the load current. This voltage is used to inject small amounts of active power into the cell in order to control the H-bridge DC-link voltage at its reference value VVHH∗

4. Results

The first phase of the work was to evaluate the proposed topology and control method. Experimental results are included to show the controlled DC-link voltage of the H-Bridges and the current waveform improvement for the Hybrid Inverter. A second stage with simulation results showing the proposed converter operating as AFE rectifier, using MATLAB/Simulink coupled with the circuit simulator PSIM are also included. The physical ratings of the considered converter are those of a 1kW laboratory prototype with a total DC-link voltage of Vdc = 180V and rated current of 10A. The capacitors used for the H-bridges are CH = 2200µF and their reference voltages have been set to VVHH∗= 30V The control platform for this t of a DSP board with a Texas Instrument TMS320C6713 processor coupled with daughter board based on a

Xilinx/Spartan III FPGA including multiple A/D converters. In this configuration, the FPGA operates as a sampling clock, triggering the A/D conversions and interrupting the DSP. The processor is used for the calculation of all the controllers which results in a voltage reference for the converter, with this voltage reference the processor addresses the SHE tables and passes the information of commutation angles (αx and voltage phase to the FPGA. The FPGA performs the SHE modulation, the calculation of the harmonic references for the H-bridges and its unipolar PWM modulation using a carrier frequency of 2 kHz.

Experimental results are gained feeding a linear load with values RL = 10 and LL = 3mH with the 1kW prototype. As previously discussed in section III-C, the converter is operated with Vdc=180V, while the H-Bridge dc-link voltage reference was set to 30V. For comparison purposes, the below figure shows the results for the NPC inverter operating without H-bridge compensation. In this result the NPC inverter is modulated by a 5-angle SHE pattern and m = 0:8. The first waveform corresponds to the NPC inverter output phase voltage VVaa′NN which results in the 9-levelload voltage waveform Van of b, c shows the resulting output current waveform with its characteristic low frequency distortion.



5. Conclusion

This paper presents the series connection of a SHE-modulated NPC and H-bridge multilevel inverter with novel control scheme to control the floating voltage source of the H-bridge stage. The addition of the H-bridge series active filter or additional converter stage is not intended to increase the power rating of the overall converter. Rather, the main goal is to improve, in a controllable or active way, the power quality of the NPC- Bridge which may have a relatively low switching frequency. This enables superior closed loop performance for medium-voltage NPC-SHE based schemes, where this modulation strategy has been selected for efficiency purposes. It also allows the use of smaller inductive filters when connecting to the utility supply in AFE applications. Since no changes are made to the power circuit and modulation stage of the NPC inverter, the series H-bridge power circuit and its control scheme can be easily added as an upgrade to existing NPC driven applications.

The proposed series H-bridge filter control scheme can be used either as a grid or load interface, depending on whether the NPC converter is used as an AFE or inverter respectively. Both possibilities can be combined if used in a back to back configuration. The proposed floating dc-link voltage control scheme can be adapted to other hybrid topologies or cascaded H-bridge converters with the advantage that isolated input transformers can be avoided.

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