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Selective Harmonic Mitigation Technique to Control Power Flow in Cascaded H-Bridge Multilevel Inverter with Non-equal Dc Link Voltages and Energy Storage

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Abstract:
This paper presents a new SHM-PWM technique based on multilevel waveforms which enables the required control of power flow in a CHB converter while fully utilizing the waveform degrees of freedom. The method uses the interpolation of LUT based solutions for a number of imbalances to control the power flow through the H-bridges asymmetrically, thus avoiding the requirement of very large LUTs apparent in previous methods. This paper also focuses on the SHM-PWM control strategy which is capable of meeting grid codes even under non-equal dc link voltages. Theoretical and simulated result is experimentally verified using a five level cascaded H-bridge topology operating as an inverter.

***Keywords**: SHM-PWM technique, cascaded H-bridge (CHB) converter, Look up Table, grid codes*

1. Introduction

Numerous industrial applications have begun to require high power apparatus in recent years. Multilevel inverters have become more popular over the years in industrial propel applications and high power applications with the promise of less disturbances, smaller common-mode voltage, the possibility to function at lower switching frequencies, and good potential for further developments than ordinary two-level inverters. In multilevel inverters the Cascaded H-Bridge (CHB) configuration has recently become very popular in high-power AC supplies and adjustable-speed drive applications. A cascade multilevel inverter consists of a series of H-bridge (single-phase full bridge) inverter units in each of its three phases. The cascaded multilevel inverter was invented for use in medium to high power applications. The traditional cascaded multilevel inverter interfaces DC energy sources.

The advantages of cascaded multilevel inverters are:

- Requires less number of components per level.
- Modularized structure without clamping components.
- Simple voltage balancing modulation.

Hybrid cascaded multilevel converters provide an attractive option for high power and high performance motor drive applications. Traditional H-bridge HCMC use multiple dc sources, but recently, energy storage elements have been used to replace some of the dc sources, mainly to provide reactive power compensation. Most of the research that has been conducted on the use of energy storage for motor drive applications is based on the use of converter for interface between the ultra-capacitors (UC) and the induction motor.

In most applications, a power converter needs to transfer real power from ac to dc (rectifier operation) or dc to ac (inverter operation). When operating at unity power factor, the charging time for rectifier operation (or discharging time for inverter operation) for each capacitor is different. Such a capacitor charging profile repeats every half cycle, and the result is unbalanced capacitor voltages between different levels. The voltage unbalance problem in a multilevel converter can be solved by several approaches, such as replacing capacitors by a controlled constant dc voltage source such as pulse-width modulation (PWM) voltage regulators or batteries. The use of a controlled dc voltage will result in system complexity and cost penalties. With the high power nature of utility power systems, the converter switching frequency must be kept to a minimum to avoid switching losses and electromagnetic interference

(EMI) problems. When operating at zero power factors, however, the capacitor voltages can be balanced by equal charge and discharge in one-half cycle. This indicates that the converter can transfer pure reactive power without the voltage unbalance problem.

2. Proposed Topology

In many applications, it is desirable to share the power flow among all the cells equally in order to avoid overheating of some specific switching devices and consequently extend the lifetime of all the elements of the converter.

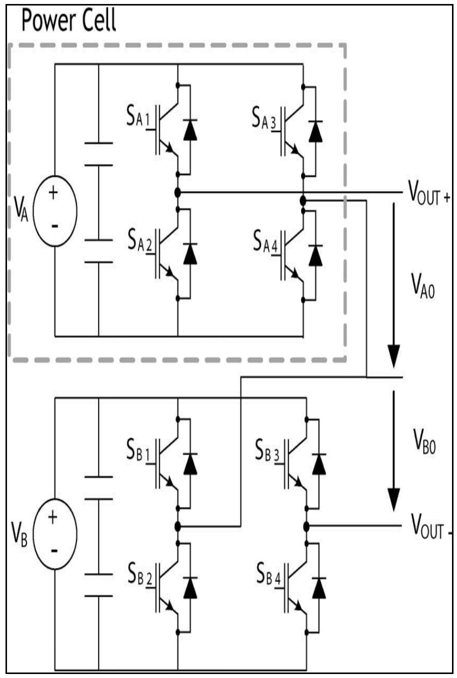

Figure 1: Five-level cascaded H-bridge converter based on the series connection of two three-level power cells

CHB-based converter structures may require the power flow to be controlled asymmetrically through the converter cells. In both cases, assuming that the current is undistorted, the power flow from each cell of the converter can be determined by considering the fundamental frequency component of each cell only. It is possible to manipulate SHM-PWM technique to control the power flow through a CHB converter. This method considered the use of a low switching frequency SHM-PWM to control power flow through the cells of a CHB converter while still producing high quality waveforms.

The proposed topology shown in figure.1 can be extended to produce converters with as many levels as required for a particular application. In general, if n power cells are connected in series to build the converter and all number of levels that can be achieved is $2n + 1$. In the proposed topology, *VA* is the dc voltage of the upper cell and *VB* represents the voltage of the lower cell. However, this increase in voltage levels is achieved at a cost of reduced converter structure modularity.

3. Energy Storage

Electrical energy storage is emerging as a key technology with applications in areas such as improved reliability and power quality in the utility sector and other non-stationary power applications, integration of renewable sources into distributed generation systems, improved energy efficiency and productivity in conventional power generation plants, and regenerative motor drive systems. Energy storage systems can be characterized by their specific requirements such as power levels, energy storage capacity, and response time (determined by storage times or discharge times). The ultra-capacitor as an energy storage device dedicated for power conversion applications. In comparison to state of the art electrochemical batteries, the ultra-capacitors have higher power density, higher efficiency, longer lifetime and greater cycling capability. In comparison to the state of the art electrolytic capacitors, the ultra-capacitors have higher energy density. All these advantages make the ultra-capacitors good candidate for many power conversion applications.

In the proposed topology the cascaded multilevel inverter consists of capacitors as shown in figure.1, these capacitors are replaced by the ultra capacitors which are very efficient for energy storage due to the advantages of ultra capacitors.

4. Experimental Results

In the proposed topology, the SHMPWM technique, keeps some specific harmonics below a safe level to meet the grid codes instead of making them zero as in SHEPWM, As a consequence, it is possible to fulfill the grid codes with a lower switching frequency.

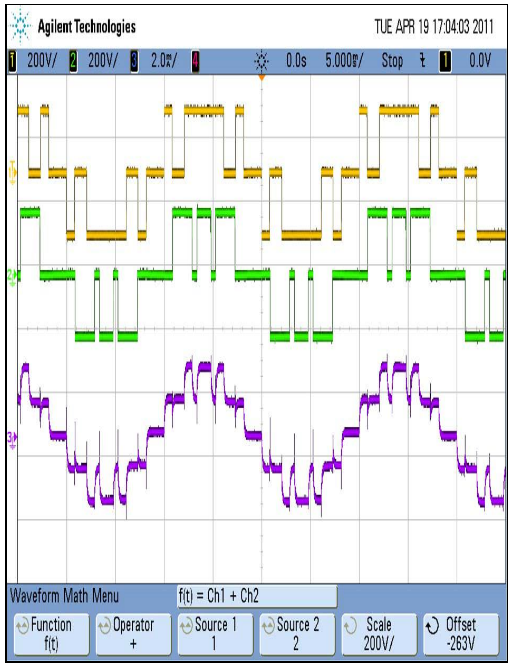

Figure 2: Voltage of both cells and current (bottom) for an imbalance of 0%

By using 15 switching angles, the proposed SHMPWM technique achieves switching patterns that fulfill the applied grid code for any modulation index up to 1.19; therefore, the bulky grid connection tuned filters can be avoided.

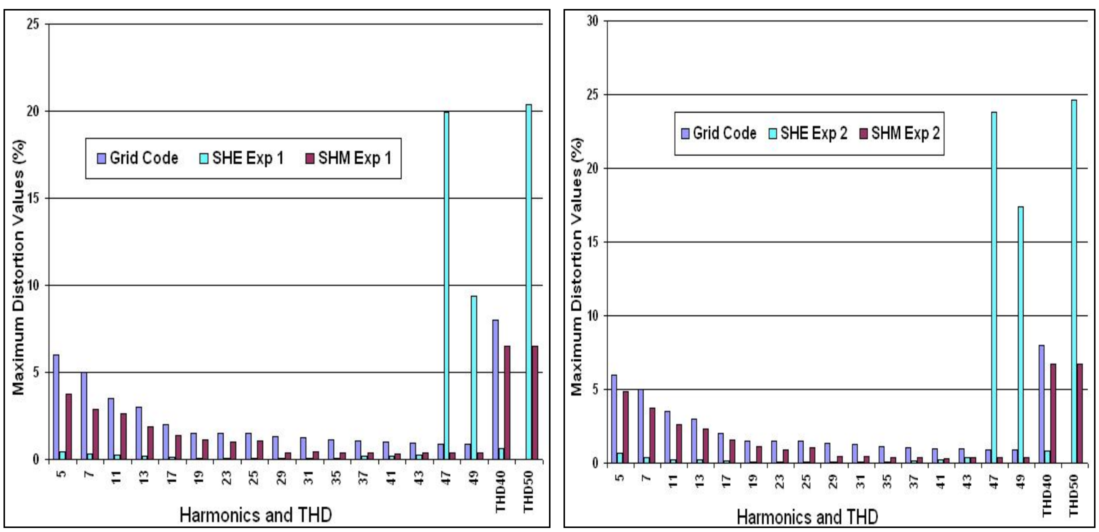

Figure 3; Maximum harmonic contents obtained in the experimental results in the modulation index range between 0.75 and 1.16

The results of experiment I shown in fig.3 above that, using SHMPWM technique, all harmonics are taken into consideration, remains under the grid code specific limit and the same happens with the total harmonic distortion, even considering harmonics up to 49th. However, with SHEPWM technique, the pre computed data make almost zero all the harmonics except for harmonics 47th to 49th which are left completely uncontrolled which generates values far over the grid code limits.

By this simulation results, we can observe that the control of power flow among the cells of cascaded multilevel converter regulation is achieved effectively by using selective harmonic mitigation technique.

5. Conclusion

A cascaded H-bridge multilevel converter with nonequal dc link voltages has been analyzed. A new control method, SHM-PWM method is used to control the power flow among the H-bridge cells of the cascaded multilevel inverter. The capacitors in this inverter replaced by ultra capacitors for energy storage. The proposed method offers an effective power flow control of the capacitor voltage and the energy storage using ultra-capacitors as they have higher power density, higher efficiency, longer life and greater cycling capability with hybrid cascaded multilevel inverter topologies for high performance motor drive applications. The experimental results show the effectiveness of this method and reduce the voltage ripple of the capacitors, which leads to higher power conversion efficiency with equal power distribution, reduces the initial cost, and complexity hence it is apt for industrial applications.

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