Comparison of carrier based PWM methods for Cascaded H-Bridge Multilevel Inverter

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Abstract: Multilevel inverters are mainly devised for high power applications, due to higher voltage operating capability, lower dv/dts and more sinusoidal outputs. The Diode Clamped, Flying Capacitor and the Cascaded H-bridge inverter, are the most suitable topologies. The Cascaded H-Bridge, also known as multi-module converter, has been particularly used in very high power applications, due to its modularity and attractive input current harmonics cancellation. Multilevel converters are mainly controlled with sinusoidal PWM technique and it includes two types of multiple carrier arrangements: Level Shifted (LSCPWM) and Phase Shifted (PSCPWM). In this paper comparison between these two modulation techniques is carried out.

Key words: (Cascaded H-bridge) CHB, (Level Shifted) LSCPWM, (Phase Shifted) PSCPWM, (Multilevel Inverter) MLI, PWM (Pulse Width Modulation).

I. INTRODUCTION

Recently, for increasing use in practice and fast developing of high power devices and related control techniques, multilevel inverters have become more attractive to researchers and industrial companies. Multilevel inverters have achieved an increasing contribution in high performance applications. It is not required to have higher power ratings of individual devices to increase the power rating. It can be increased by increasing the number of levels in the inverter [3]. The different multilevel inverter structures are cascaded H-bridge, diode clamped and flying capacitors multilevel inverters. But cascaded H-Bridge has the following advantages over other topology:

- Compare with other types of MLI, it requires the least no of components to achieve same number of voltage level.
- Compared to other topologies such as simple circuit layout.
- Modular in structure and avoid unbalanced capacitor voltage problem [3].

So, in this paper cascaded H-Bridge inverter was selected.

Multilevel converters are mainly controlled with sinusoidal PWM technique and it includes two types of multiple carrier arrangements: Level Shifted (LSCPWM), which includes in-phase disposition (IPD), where all carriers are in phase; alternative phase opposite disposition (APOD), where all carriers are alternatively in opposite disposition; and phase opposite disposition (POD), or they can be Phase Shifted (PSCPWM) [6].

Phase Shifted PWM is mainly conceived for multicell topologies, since each carrier can be related to a particular and independent power cell.

A proper phase shift is introduced among the carriers in order to produce the typical multilevel stepped waveform. For this reason, all the power cells operate under the same switching conditions and therefore present an even power distribution. In addition, when using an input transformer with appropriate angle shifts between the windings, and some low order input current harmonics can be cancelled, which is a very attractive feature for high power applications. However, since the carrier signals are not synchronized, the output line-line and load voltages have some additional dv/dts that are not produced with Level Shifted methods where all the carriers are in phase. This leads to a higher voltage distortion [6].

On the other hand, Level Shifted methods are based on amplitude shifts between carriers. Each carrier is associated to a specific voltage level. When the reference is over one carrier, the corresponding level is generated. Therefore, when LSCPWM is used with cascaded H-bridge inverters, the cells will be used only when the corresponding level is reached, producing an uneven power distribution and switching conditions between the cells. This will avoid the current harmonic cancellation at the input, and increase the input current distortion. These harmonics can be important due to the amount of power involved in high power applications, making it more difficult to meet standards [6].

II. CASCaded H-BRIDGE INVERTER

A. Topology Description

As the name suggests, the cascaded H-bridge multilevel inverter uses multiple units of H-bridge power cells connected in a series chain to produce high ac voltages. Fig. 1 shows the configuration of a five-level cascaded H-bridge inverter. In this configuration each phase leg consists of two H-bridge cells powered by two isolated dc supplies of equal voltage E [7].

Fig. 1: Five level Cascaded H-Bridge multilevel inverter.
The CHB inverter in Fig. 1 can produce a phase voltage with five voltage levels. When switches S11, S21, S12, and S22 conduct, the output voltage of the H-bridge cells H1 and H2 is \( V_{H1} = V_{H2} = E \), and the resultant inverter phase voltage is \( V_{AN} = V_{H1} + V_{H2} = 2E \), which is the voltage at the inverter terminal A with respect to the inverter neutral N. Similarly, with S31, S41, S32, and S42 switched on, \( V = -2E \) [7].

The number of voltage levels in a CHB inverter can be found from \( m = (2H + 1) \). Where H is the number of H-bridge cells per phase leg. The voltage level m is always an odd number for the CHB inverter while in other multilevel topologies such as diode-clamped inverters; it can be either an even or odd number [7].

### III. CascaDED H-Bridge Inverter Modulation

Multilevel converters are mainly controlled with sinusoidal PWM technique and it includes two types of multiple carrier arrangements: Level Shifted (LSCPWM) and Phase Shifted (PSCPWM) [6].

#### A. Phase shifted carrier PWM (PSCPWM)

Fig. 2: Phase shifted carrier pulse width modulation for three-level inverter.

Fig. 2 shows the Phase shifted carrier pulse width modulation. In general, a multilevel inverter with \( m \) voltage levels requires \( (m-1) \) triangular carriers. In the phase shift multicarrier modulation, all the triangular carriers have the same frequency and the same peak-to-peak amplitude, but there is a phase shift between any two adjacent carrier waves, given by \( \phi_{cr} = \frac{360}{m-1} \). The modulating signal is usually a three-phase sinusoidal wave with adjustable amplitude and frequency. The gate signals are generated by comparing the modulating wave with the carrier waves.

It means that, if five level inverter, four triangular carriers are needed with a 90° phase displacement between any two adjacent carriers. In this case the phase displacement of \( V_{cr1} = 0° \), \( V_{cr2} = 90° \), \( V_{cr1-} = 180° \) and \( V_{cr2-} = 270° \) [5].

#### B. Level shifted carrier PWM (LSCPWM)

The Level shifted carrier pulse width modulation. An \( m \)-level Cascaded H-bridge inverter using level shifted modulation requires \( (m-1) \) triangular carriers, all having the same frequency and amplitude. The frequency modulation index is given by \( mf = f_{cr} / f_m \), which remains the same as that for the phase-shifted modulation scheme. The multilevel converter with multilevel requires \( (m1) \) triangular carriers with same amplitude and frequency [5].

The amplitude modulation index ‘ma’ is defined by \( ma = \frac{V_m}{V_{cr}} (m-1) \) for \( 0 \leq ma \leq 1 \). Where \( V_m \) is the peak value of the modulating wave and \( V_{cr} \) is the peak value of the each carrier wave. The triggering circuit is designed based on the three phase sinusoidal modulation waves \( V_a \), \( V_b \), and \( V_c \). Three of the sine wave sources have been obtained with same amplitude and frequency but displaced 120° out of the phase with each other [5].
IV. SIMULATION

A. Simulation Parameters
- Each H-bridge module input voltage = 100v dc
- System frequency = 50Hz
- Carrier frequency = 1KHz
- Load: Active power = 10KW, Inductive Reactive power = 500VAR
- Smoothening Reactor=100mH
- ma=1
- mf=20

B. Simulation block diagram

V. SIMULATION RESULTS

A. Phase shift carrier PWM method

Fig. 6: Simulation block of 1-phase.
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Fig. 13: FFT Analysis of phase to phase of PD with LSCPWM

Fig. 14: FFT Analysis of current of PD with LSCPWM

C. Phase opposition disposition with LSCPWM

Fig. 15: POD with LSCPWM

Fig. 16: Phase to phase Voltage and current wave form of POD with LSCPWM

Fig. 17: FFT Analysis of phase to phase voltage of POD with LSCPWM

D. Alternate Phase opposition disposition with LSCPWM

Fig. 18 FFT Analysis of current of POD with LSCPWM

Fig. 19: APOD with LSCPWM

Fig. 20: Phase to phase Voltage and current wave form of APOD with LSCPWM

Fig. 21: FFT Analysis of phase to phase voltage of APOD with LSCPWM

Fig. 22: FFT Analysis of current of APOD with LSCPWM
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E. Simulation Result Table

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Modulation technique</th>
<th>THD (%) in Voltage</th>
<th>THD (%) in Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>PSCPWM</td>
<td>29.09</td>
<td>4.49</td>
</tr>
<tr>
<td>2.</td>
<td>PD with LSCPWM</td>
<td>17.12</td>
<td>2.65</td>
</tr>
<tr>
<td>3.</td>
<td>POD with LSCPWM</td>
<td>21.49</td>
<td>2.65</td>
</tr>
<tr>
<td>4.</td>
<td>APOD with LSCPWM</td>
<td>25.11</td>
<td>2.69</td>
</tr>
</tbody>
</table>

Table 1: THD in Current and Phase To Phase Voltage For Different Technique

VI. CONCLUSION

From the MATLAB/SIMULINK based simulation of the Multilevel Inverter, results were obtained for all the carrier based PWM techniques. Comparison of outputs gives the idea that Phase Disposition technique gives good harmonic performance. Also, comparison of H-Bridge voltage of PSCPWM and LSCPWM gives the idea that the H-Bridge output voltages produced by phase-shifted modulation are almost identical.

However, voltages produced by the level-shifted modulation are not identical so switching frequency and conduction period are different for all devices. But, for phase shifted modulation has same switching frequency and conduction period for all devices.

REFERENCES


