

## Investigation of THD for Cascaded Multi-Level Inverter Using Multicarrier Modulation Techniques

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### Abstract

A novelty kind of Multilevel converters are used in high voltage and high power application of industry field, can able to produce near sinusoidal voltage/currents with only operating at fundamental frequency switching. This paper presents a initial level of 5-level up to its giant level 13-level cascaded multilevel converter. In now a days multilevel inverters has become very popular for motor drive applications of industry. Multicarrier pulse width modulation techniques is an effective solution for increases the number of levels of the output wave form and thereby dramatically reduced the harmonics and total harmonic distortion(THD). The output waveform has 5,7,9,11 and 13 levels. In this paper three multicarrier pulse width modulation techniques such as phase shifted, level shifted and the wave level shifted Multi-carrier modulation PWM techniques are discussed. These methods are modeled for all level CMC by using the MATLAB/SIMULINK and the THD of the these methods are compared.

**Index Terms** - Cascade inverter, Multilevel, Modulation, PSHM, LSHM and WLSM.

### I. INTRODUCTION

Recently the “multilevel converter” has drawn tremendous interest in the power industry. Recent advances in power switching devices enabled the suitability of MLC’s for high voltage and high power applications. The general structure of the multilevel converter is to synthesize a sinusoidal voltage from several levels of voltages. The so-called “multilevel” starts from three levels. A three-level converter, also known as a “neutral-clamped” converter, consists of two capacitor voltages in series and uses the center tap as the neutral. Each phase leg of the three-level converter has two pairs of switching devices in series. The center of each device pair is clamped to the neutral through clamping diodes. The waveform obtained from a three-level converter is a quasi-square wave output.

The diode-clamp method can be applied to higher level converters. As the number of levels increases, the synthesized output waveform adds more steps, producing a staircase wave which approaches the sinusoidal wave with minimum harmonic distortion. Ultimately, a zero harmonic distortion of the output wave can be obtained by an infinite number of levels. More levels also mean higher voltages can be spanned by series devices without device voltage sharing problems. Unfortunately, the number of the achievable voltage levels is quite limited not only due to voltage unbalance problems but also due to voltage clamping requirement, circuit layout, and packaging

constraints. The general structure of the MLC is to synthesize a sinusoidal voltage by several levels of voltages, typically obtained from capacitor voltage sources.

There are three types of multilevel converters are reported as follows[1]:

1. Diode-Clamped Multilevel Converter (DCMC).
2. Flying-Capacitor Multilevel Converter (FCMC).
3. Cascaded Multilevel Converters (CMC)

Compared DCMC and FCMC converters, a CMC converter is mostly used because of it is easy to design and assemble. And also uniform circuit structure of the converter units and modularized circuit layout. Easy packaging is also possible in CMC topology as each level has the same structure, and there are no extra clamping diodes or voltage-balancing capacitors, which are required in the DCMC and the FCMC. The number of output voltage levels can then be easily adjusted by changing the number of full-bridge converters. The CMC synthesizes a desired voltage from several independent sources of DC voltages, which may be obtained from batteries, fuel cells or solar cells [2]. A 13 level CMC of one phase as shown in Fig.1 as in form of six H-bridges are connected in series per each phase leg. In general, the output voltage of CMC is controlled as follows:

FFS modulation can be easily implemented for the CMC due to its unique structure. All switching angles can be calculated off-line and then stored in a look-up table for digital implementation. Compared

with the carrier-based PWM schemes, FFS features low switching losses since all the IGBT switches operate at fundamental frequency[4]. Various PWM techniques applied to the multilevel converters are discussed in [5]-[7]. The PWM techniques can be classified into two categories: the triangle intersection technique and the direct digital technique (space vector modulation). With the development of digital technology, the space vector modulation is widely used, due to not only relatively easy hardware implementation, but also its features of good dc link voltage utilization and low current ripple.

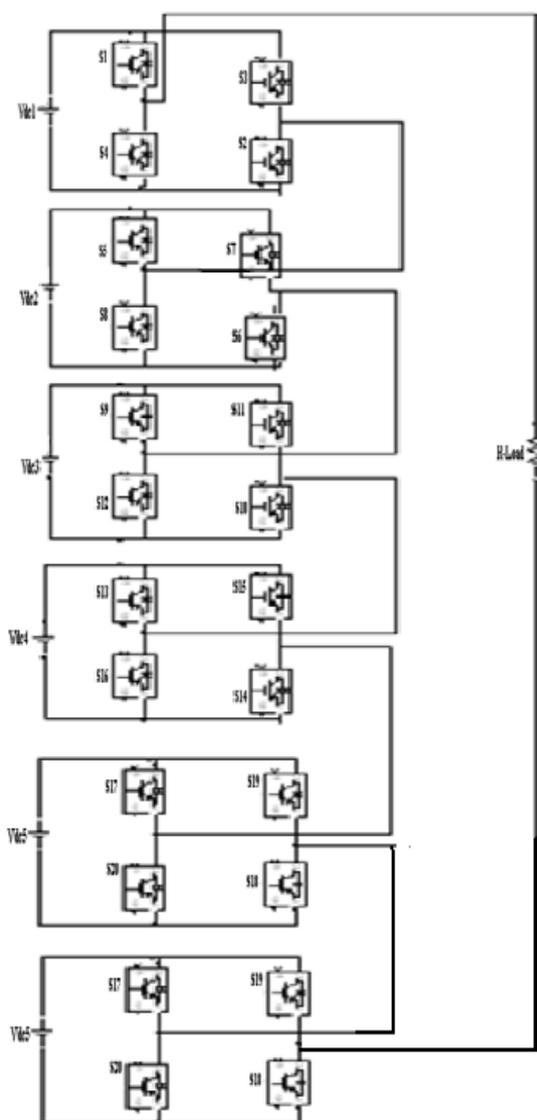


Fig.1. One phase of thirteen-level CMC

But this method has a very significant drawback that if the voltage level is more than five, the control algorithm becomes too complex to implement [3]. Thus it is reasonable to adapt in this paper the triangle intersection techniques in the high level application.

## II. PHASE SHIFT MULTI - CARRIER MODULATION (PSHM)

CMC with  $m$  voltage levels requires  $(m - 1)$  triangular carriers. In the phase-shifted multi-carrier 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:

$$\Phi_{sh} = 360^\circ / (m-1) \quad (1)$$

The gate signals are generated by comparing the modulating wave with the carrier wave. where twelve triangular wave carriers are required with a  $30^\circ$  phase displacement between any two adjacent carriers. The advantage of PSHM is that the switching frequency and conduction period is same for all devices and rotating of switching patterns is not required.

INITIAL CONDITIONS: for PSHM

Sine wave block parameters:

[ Same for all switches ]

Amplitude : 1 Units

Frequency :  $2 * \pi * 50$

Repetitive sequence(triangle wave) parameters:

[ Same for all switches ]

Time values :

0 1/3050/4 1/3050/2 3/3050/4 1/3050

Output values:

0 1 0 -1 0

Figs. 2 and 3 shows the simulated voltage waveforms and their harmonic content of single-phase thirteen levels CMC using PSHM under the condition of Modulation frequency,  $f_m = 50$  Hz, Carrier frequency,  $f_{cr} = 3050$  Hz, amplitude modulation index,  $ma = 1.0$  and frequency modulation index,  $mf = 61$ . The phase voltage harmonic spectrum shown in Figs. 3 is based on 50 Hz base frequency and the THD considered for the first 200 harmonics.

### Simulation of Single Phase Thirteen-Levels CMC by Using PSHM

The simulation results of single phase eleven level cascaded multilevel converter of output phase voltage magnitude and output phase voltage harmonics of order of first 200 harmonics and total harmonic distortion(THD) is be shown

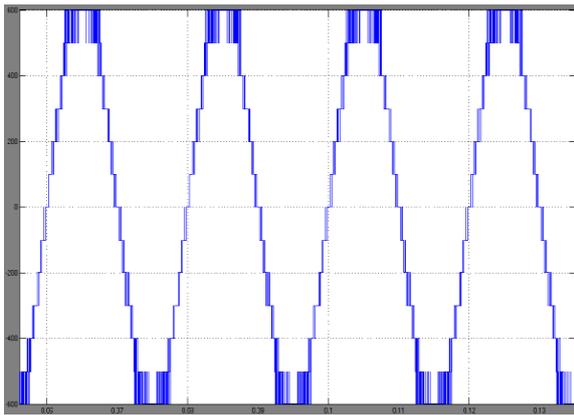


Fig.2. Output phase voltage of thirteen-level CMC

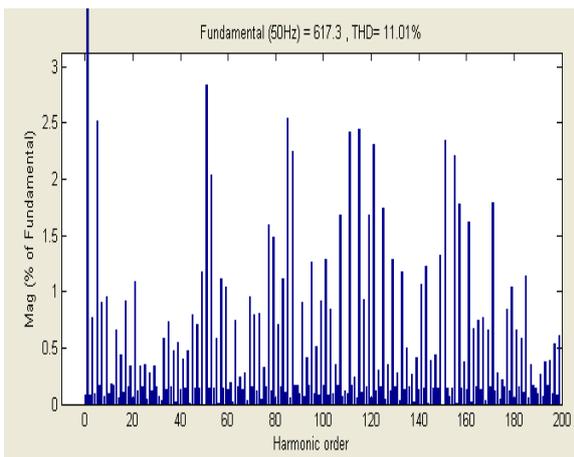


Fig.3. Thirteen level CMC phase output voltage harmonics (THD = 11.01 %)

### III. LEVEL SHIFT MULTI-CARRIER MODULATION (LSHM)

For m-level CMC using level-shifted multicarrier modulation scheme, (m – 1) triangular carriers are required, all having the same frequency and amplitude. The (m – 1) triangular carriers are vertically disposed such that the bands they occupy are contiguous. The amplitude modulation index is defined as:

$$m_a = V_m / V_{cr}(m-1) \quad (2)$$

Where  $V_m$  is the peak amplitude of the modulating wave and  $V_{cr}$  is the peak amplitude of each carrier wave. There are three schemes for level shift multi-carrier modulation listed as follows:

- (i) In-phase disposition (IPD), where all carriers are in phase.
- (ii) Alternative phase opposite disposition (APOD), where all carriers are alternatively in opposite disposition.
- (iii) Phase opposite disposition (POD), where all carriers above the zero reference are in phase but in opposition with those below the zero reference.

In this paper only IPD modulation scheme is addressed as it provides the best harmonic profile of all level shift multicarrier modulation schemes [4].

#### INITIAL CONDITIONS: for LSHM

Sine wave block parameters:

[ Same for all switches ]

Amplitude :6 Units

Frequency :  $2 * \pi * 50$

Repetitive sequence(triangle wave) parameters:

[ Different for all switches ]

Time values : 0 1/3050/2 1/3050

Output values: X Y X

Where,

X= Triangle wave lower peak output value

Y= Triangle wave upper peak output value

#### Simulation of Single Phase Thirteen-Levels CMC by Using LSHM

Fig.4 and Fig.5 shows the simulated voltage waveforms and their harmonic content of single phase thirteen level CMC using LSHM under the same conditions of PSHM simulation

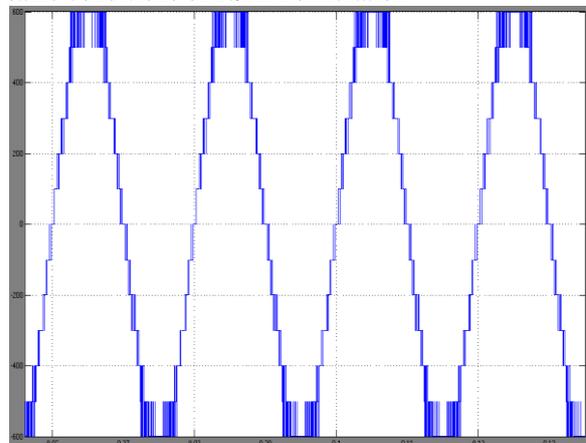


Fig.4. Output phase voltage of thirteen-level CMC

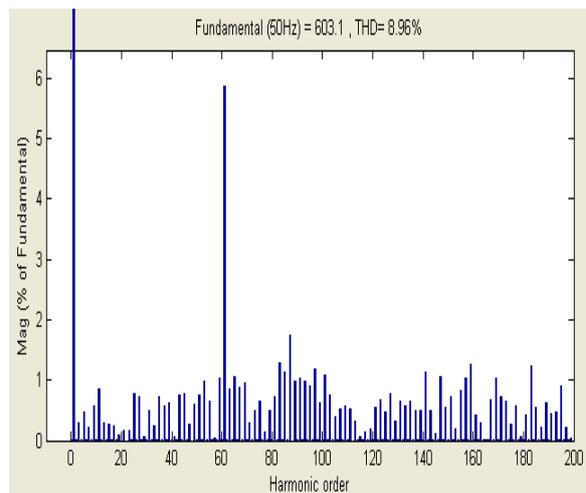


Fig.5. Thirteen-level output phase voltage harmonics (THD = 8.96%)

#### IV. WAVE LEVEL SHIFT MULTI-CARRIER MODULATION (WSHM)

The proposed modulation technique is a combination of phase shift multi-carrier and level-shifted multi-carrier modulation (in-phase disposition (IPD)) schemes which overcomes the problem of rotating of switching pattern of level-shifted multi-carrier modulation and small phase displacement at phase voltage of CMC. For  $m$  level CMC in the proposed method,  $(m - 1)$  triangular carriers are required. In the carrier wave all the triangles have the same frequency, same peak to peak amplitude and are vertically disposed, but there is a phase shift between any two disposed carrier waves as in (3).

$$\Phi_{sh} = 360^{\circ}/4(m-1) \quad (3)$$

The amplitude modulation index is defined as in (4)

$$m_a = V_m/V_{cr}(m-1) \quad (4)$$

By the principle of the proposed method for one phase of thirteen-level CMC, in which twelve triangular wave carriers are required with a  $7.5^{\circ}$  phase displacement between any two adjacent carriers.

INITIAL CONDITIONS: for WSHM

Sine wave block parameters:

[ Same for all switches ]

Amplitude :6 Units

Frequency :  $2*\pi*50$

Repetitive sequence(triangle wave) parameters:

[ Different for all switches ]

Time values : 0      1/3050/2      1/3050

Output values: X      Y      X

Where,

X= Triangle wave lower peak output value

Y= Triangle wave upper peak output value

Simulation of single phase and Three Phase Thirteen-Level

CMC by Using WLSM.

Figs 6 and Fig.7 shows the simulated voltage waveforms and their harmonic content of single phase thirteen level CMC using the proposed method under the same conditions of WSHM simulation.

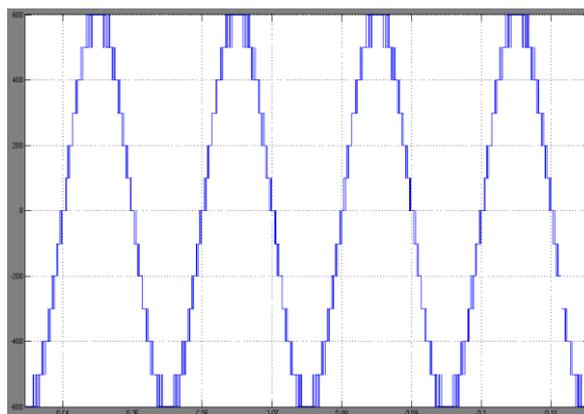


Fig.6. Output phase voltage of thirteen-level CMC

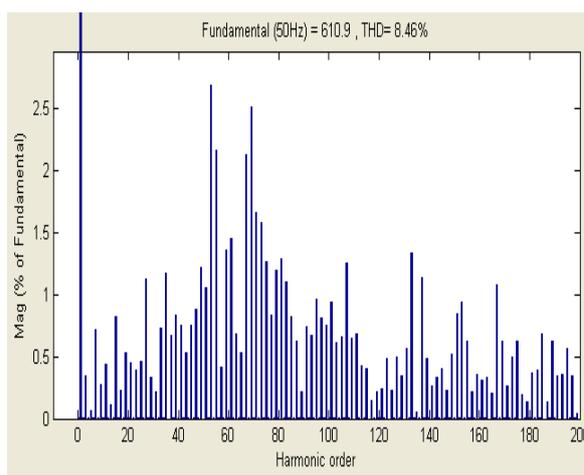


Fig.7. Thirteen-level CMC output phase voltage harmonics (THD = 8.46 %)

#### V. THD INVESTIGATION

	Multi-Carrier PWM techniques		
	LSHM	PSHM	WSHM
7-LEVEL	18.47	17.29	<b>17.07</b>
9-LEVEL	13.40	13.86	<b>13.33</b>
11-LEVEL	11.00	11.48	<b>10.45</b>
13-LEVEL	8.96	11.01	<b>8.46</b>

#### VI. CONCLUSION

This paper presents simulation of various level 7,9,11 and 13-level CMC. Three types of multicarrier based PMW techniques were considered to control the output voltage of CMC. Among those three modulation techniques, it has been found and proved that the Wave level shifted is better than others in terms of THD reduction. The simulation results have demonstrated excellent control capabilities of the

thirteen levels CMC using the new multi-carrier based PWM technique.

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