



Power Quality Improvement of DC-AC Converter by Using Cascaded H-Bridge Multilevel Inverter

B.Harish¹, U.Raja Kiran¹, B.Madan Lal¹, Soubhagya Kumar Dash²

P.G scholar, Department of Electrical Engineering, Maulana Azad National Institute of Technology, Bhopal, India¹

Ph.D scholar, Department of Electrical Engineering, Maulana Azad National Institute of Technology, Bhopal, India²

ABSTRACT: Power quality place a major role in power systems. The electronic equipments lead to harmonics in power lines. The two level inverter has more harmonic content and it can be reduced by using filters which are bulky in size and costlier. Multi level inverter (MLI) reduces the harmonic content and achieves nearly sinusoidal wave. It also reduces stress on the switches and increases the power rating of system. The cascaded H-bridge (CHB) inverters are modular type of inverters and can integrate the renewable energy resources like solar, fuel cell, wind energy etc., to the grid with elimination of transformer. In this paper different control strategies (carrier based pulse width modulation) for generating pulses to the inverter are discussed for various levels with its applications. The CHB inverter for various levels (up to 13 levels) has been simulated by using MATLAB/SIMULINK and its results are discussed.

KEYWORDS: Cascaded H-bridge (CHB), multilevel inverter (MLI), Pulse width modulation (PWM) & Total harmonic distortion (THD).

I. INTRODUCTION

Two level inverter such as square wave & quasi square wave inverters are facing major problem of the lower order harmonics. Lower order harmonics are more dominant in nature while compare to higher order harmonics because of high harmonic distortion in waveform. These inverters are limited to low and medium power applications because of their limitations in increasing frequency [1]. To obtain minimum ripple content in waveform, we require high switching frequency along with multi PWM [2]. For high power high voltage applications two level inverters have some limitations in operating at high frequency mainly due to harmonics and switching losses.

Multilevel inverters placed big role in high power high voltage applications of electric motor drives [4], which provides stair case or stepped/PWM output voltage which is approximately sinusoidal ac output voltage with less distortion. MLIs provide better harmonic profile, reduced stress on semiconductor power electronic devices. With advancement in power semiconductor devices and converter topology, the issue of power quality becomes more significant multilevel inverters have a solution problems faced by the conventional two level inverters.

II. MULTILEVEL INVERTERS

There are mainly three types of MLI topologies:

1. Diode clamped multilevel inverter [3]
2. Flying capacitor multilevel inverter
3. Cascaded H- bridge multilevel inverter [9]

A. Diode clamped MLI:

The advantages of DCMLI are:

- i. More number of levels leads to less harmonic distortion.
- ii. Reactive power flow is controlled.
- iii. High efficiency for fundamental switching frequency.
- iv. Control method is easy.

The disadvantages of DCMLI are:

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- i. More number of clamping diodes.
- ii. Real power flow is difficult because of imbalance capacitances.
- iii. Different current ratings required for switches.

B. Flying capacitor MLI:

The advantages of FCMLI are:

- i. Flexible switch redundancy for balancing the voltage.
- ii. Lower harmonic distortion when levels are more.
- iii. Both real and reactive power is controlled.

The disadvantages of FCMLI are:

- i. Excess number of storage capacitors.
- ii. Inverter control is complicated.
- iii. Switching frequency and losses are more.

C. Cascade H-bridge MLI:

The advantages of H-bridge MLI are [5]:

- i. Switching losses and device stress is less.
- ii. Least number of components are required.
- iii. Potential of electric shock is less.

The disadvantages of H-bridge MLI:

It is limited to certain applications because separate DC sources are required

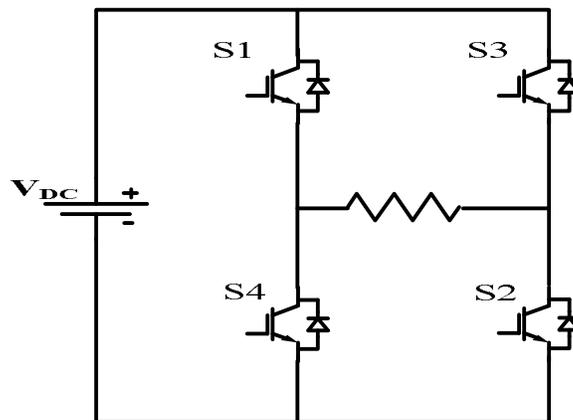


Fig.1. H-Bridge inverter

TABLE I
SWITCHING STATES OF THREE LEVEL CHB

Voltage (Vo)	S1	S2	S3	S4
0	1	0	1	0
+Vdc	1	1	0	0
-Vdc	0	0	1	1
0	0	1	0	1



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TABLE II
 TOTAL NUMBER OF COMPONENTS REQUIRED FOR DIFFERENT TYPES OF MLIs

Converter type	Main switching devices	Main diodes	DC bus capacitors	Clamping diodes	Balancing capacitors
Diode clamp	$(m-1)*2$	$(m-1)*2$	$(m-1)$	$(m-1)*(m-2)$	0
Flying capacitor	$(m-1)*2$	$(m-1)*2$	$(m-1)$	0	$(m-1)*(m-2)/2$
Cascaded inverter	$(m-1)*2$	$(m-1)*2$	$(m-1)/2$	0	0

From above all discussion we can conclude that in all these topologies CHB topology is advantageous because of individual dc voltage sources which are available like batteries and fuel cells. In diode clamped MLI excess clamping diodes are required as number of levels increases clamping diodes requirement increases rapidly and it is difficult to control the power flow in flying capacitor MLI excess numbers of storage capacitors are required and it is difficult to maintain voltage balance in between capacitors. Now coming to required total number of switches for same level are more in diode clamped and flying capacitor because of clamping diodes and storage capacitors. This paper deals with different levels like three, five, seven, nine level topologies of CHB MLI and comparisons of THD of each inverter. By increasing no of levels we can reduce the total harmonic distortion for power quality improvement we have to reduce the harmonic content to meet the minimum harmonic distortion level of IEEE-519 [7]. The harmonic content decreases as the number of levels increases and filtering requirement reduces. This paper presents detail enhancement of simulation results of different levels CHB inverter [6] and comparison of THD between them.

III. POWER QUALITY

Power quality places a major role in electrical drives applications. This is characterized by parameters that express harmonic pollution, reactive power, poor power factor and load unbalance. Best electrical supply would be constant magnitude and frequency sinusoidal voltage, however because of non-zero impedance of supply system, transients and outages, load voltage will not be sinusoidal. If power quality is good then loads connected to it will run satisfactory and efficiently, if it is bad loads connected to it will have reduced life time, efficiency of electrical installation will reduce.

Poor power quality includes: increase system losses, equipment failure or malfunctioning, equipment over heating leading to lifetime reduction, load imbalance result in excessive voltage imbalance causing stress on other loads connected to same network electronic communication interference damage to sensitive equipments like PC's and controlling equipments

Harmonic distortion: harmonic pollution is characterized by the total harmonic distortion and its definition is the ratio of RMS harmonic content to fundamental

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + \dots + V_n^2}}{V_1}$$

Where V_1 is fundamental voltage and V_2 to V_n is harmonic components magnitude

IV. CASCADED H-BRIDGE INVERTERS

These inverters are nothing but series connection of single phase inverters with separate dc sources avoid extra clamping diodes and voltage balancing capacitors. N level cascaded H-bridge inverter consists of series connection of $(N-1)/2$ of cells in each phase. Four active devices in each cell produce three levels like +Vdc,-Vdc,0 as the number of levels M increases number of active switches required are also increases $2(M-1)$.

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A. Multi level cascaded H-bridge inverter:

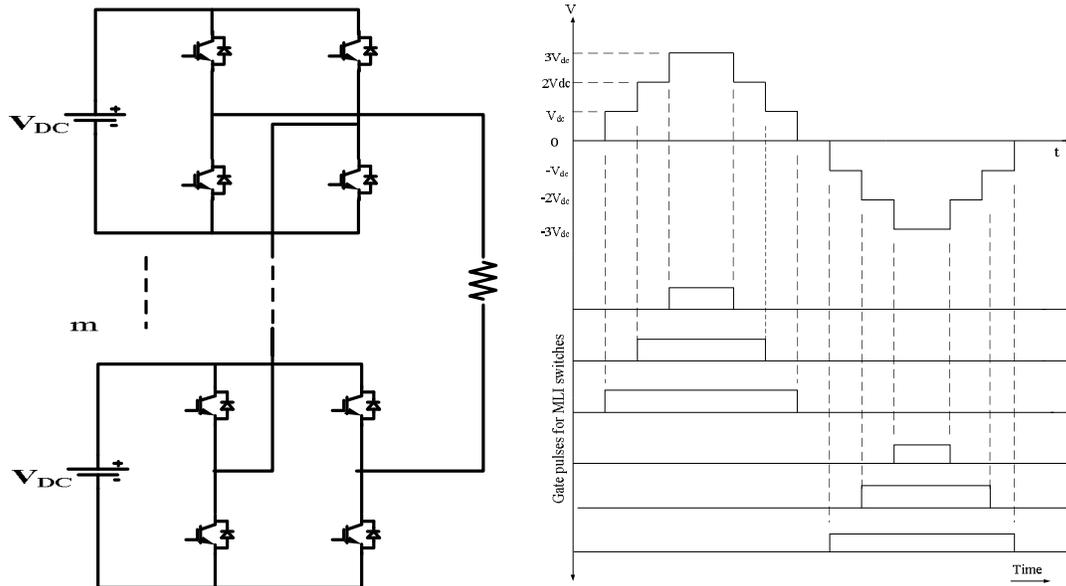


Fig.2. Multi Level CHB bridge inverter and its voltage waveform

The switching states for five level, seven level and nine level CHB inverters are shown in the following tables

TABLE. III
SWITCHING STATES OF FIVE LEVEL CHB

Voltage (Vo)	S1	S2	S3	S4	S5	S6	S7	S8
0	0	1	0	1	1	0	1	0
V_{dc}	1	0	0	1	0	1	0	1
$2 V_{dc}$	1	1	0	0	1	1	0	0
$- V_{dc}$	0	1	0	1	1	0	0	1
$-2 V_{dc}$	0	0	1	1	0	0	1	1

TABLE. IV
SWITCHING STATES OF SEVEN LEVEL CHB

Voltage (Vo)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
0	0	1	0	1	0	1	0	1	0	1	0	1
V_{dc}	1	1	0	0	0	1	0	1	0	1	0	1
$2V_{dc}$	1	1	0	0	1	1	0	0	0	1	0	1
$3V_{dc}$	1	1	0	0	1	1	0	0	1	1	0	0
$-V_{dc}$	0	1	0	1	0	1	0	1	1	1	0	0
$-2V_{dc}$	0	1	0	1	0	0	1	1	0	0	1	1
$-3V_{dc}$	0	0	1	1	0	0	1	1	0	0	1	1

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TABLE. V
SWITCHING STATES OF SEVEN LEVEL CHB

Voltage (Vo)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
0	0	1	0	1	0	1	0	1	0	1	0	1
V_{dc}	1	1	0	0	0	1	0	1	0	1	0	1
$2V_{dc}$	1	1	0	0	1	1	0	0	0	1	0	1
$3V_{dc}$	1	1	0	0	1	1	0	0	1	1	0	0
$-V_{dc}$	0	1	0	1	0	1	0	1	1	1	0	0
$-2V_{dc}$	0	1	0	1	0	0	1	1	0	0	1	1
$-3V_{dc}$	0	0	1	1	0	0	1	1	0	0	1	1

TABLE. VI
SWITCHING STATES OF NINE LEVEL CHB

Output voltage (Vo)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
0	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
V_{dc}	1	1	0	0	0	1	0	1	0	1	0	1	0	1	0	1
$2V_{dc}$	1	1	0	0	1	1	0	0	0	1	0	1	0	1	0	1
$3V_{dc}$	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	1
$4V_{dc}$	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0
$-V_{dc}$	0	1	0	1	0	1	0	1	0	1	0	1	0	0	1	1
$-2V_{dc}$	0	1	0	1	0	1	0	1	0	0	1	1	0	0	1	1
$-3V_{dc}$	0	1	0	1	0	0	1	1	0	0	1	1	0	0	1	1
$-4V_{dc}$	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1

B. Carrier based PWM techniques:

TABLE VII
COMPARISON OF ADVANCED MODULATION TECHNIQUES

Modulation type	Gating signal generation by comparison of
Trapezoidal	Triangular carrier wave with modulating trapezoidal wave
Staircase	Triangular carrier wave with modulating stair wave
Stepped	Triangular carrier wave with modulating Stepped wave
Delta	Triangular carrier wave oscillates above and below reference wave
Harmonic injection	Modulating signal is generated by injecting selected harmonics

Carrier based modulation schemes [8] for multilevel inverter is generally classified into two types:

1. Phase Shifted
2. Level Shifted

In m level multi carrier modulation schemes require (m-1) triangular carrier wave forms. All having same frequency and amplitude. In phase shifted carrier wave forms are horizontally disposed. In level shifted carrier wave forms are vertically disposed

Most of the level shifted carrier based PWM techniques have been derived three carrier disposition categories. The phases of carrier signals rearrange to produce three main disposition techniques known as

1. PD (Phase Disposition)
2. POD (Phase Opposition and Disposition)
3. APOD (Alternate Phase Opposition and Disposition).

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The reference wave positioned at centre of the carrier set continuously compared with carrier waves. When reference goes above all carriers a maximum output is obtained similarly when reference goes down each carrier the corresponding levels in the inverter output gets reduced. The carrier arrangements and corresponding switching patterns of five levels CHB MLI are shown in below figures

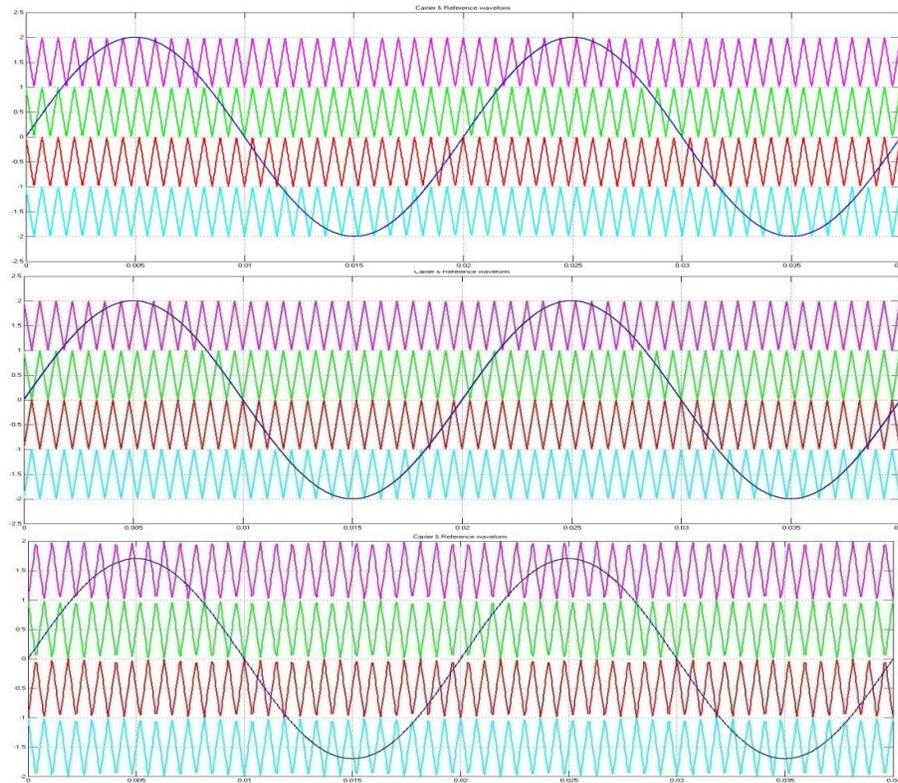


Fig.3 Five Level inverter's PD, POD, APOD carrier & reference waveforms with $m_a=0.85$

V. SIMULATION

The simulation results for different levels of CHB MLI with PD & 13th level with PD, POD, APOD are shown below:

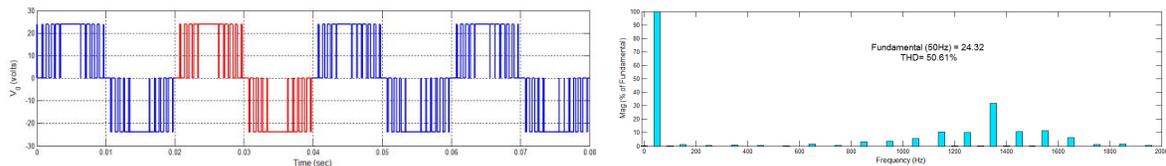


Fig. 4 Voltage and FFT analysis of 3 level PD CHB MLI

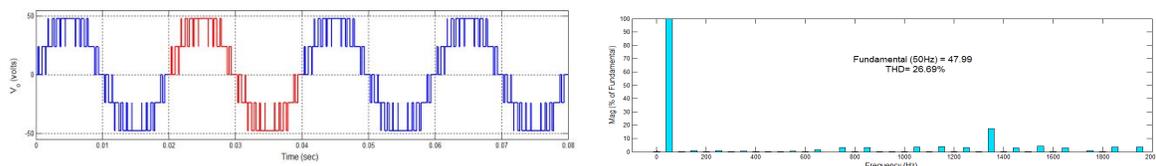


Fig.5 Voltage and FFT analysis of 5 level PD CHB MLI

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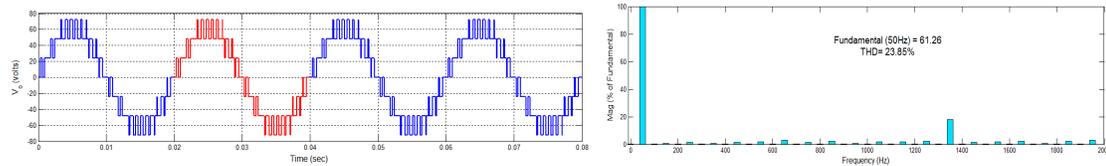


Fig.6. Voltage and FFT analysis of 7 level PD CHB MLI

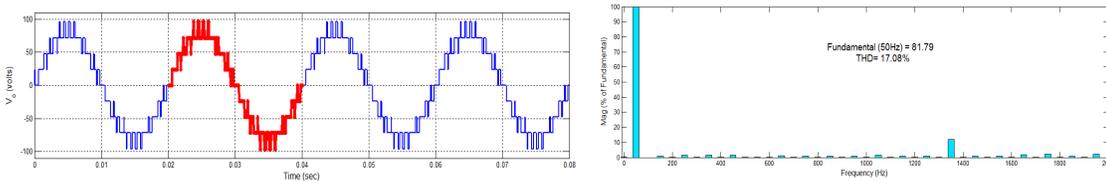


Fig.7. Voltage and FFT analysis of 9 level PD CHB MLI

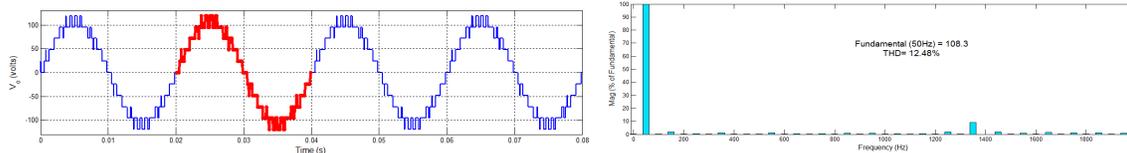


Fig.8. Voltage and FFT analysis of 11 level PD CHB MLI

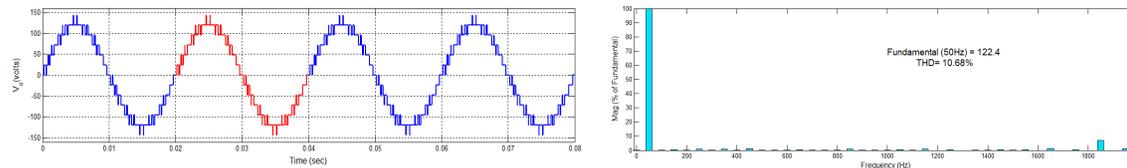


Fig.9. Voltage and FFT analysis of 13 level PD CHB MLI

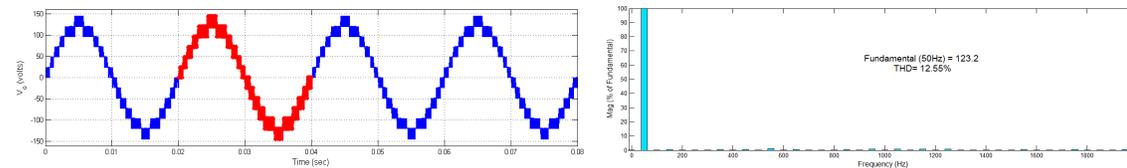


Fig.10. Voltage and FFT analysis of 13 level POD CHB MLI

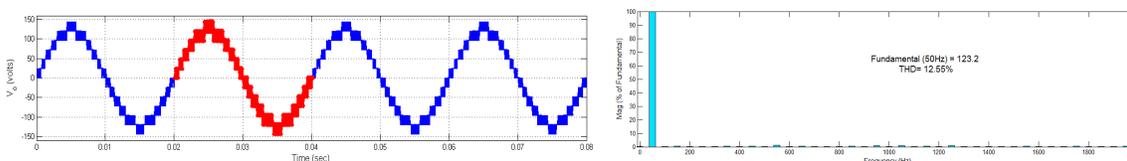


Fig.11. Voltage and FFT analysis of 13 level APOD CHB MLI

TABLE VIII
COMPARISON OF DIFFERENT LEVELS THD

No of levels	Total voltage Harmonic Distortion (THD)	Load-R (ohms)	L (milli Henry)
Three	50.61%	20	36
Five	26.69%	20	36
Seven	23.85%	20	36
Nine	17.08%	20	36



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From all the above simulation results we can say that as the number of levels increases the output voltage wave form, which is approximated to sinusoidal wave form and THD also decreases. This is most essential in power quality improvement. PD technique has low harmonic content compared to other technique as shown below

TABLE IX
COMPARISON OF DIFFERENT CARRIER WAVE BASED FOR DIFFERENT LEVELS OF MLI

No. of levels	PD	POD	APOD
5 level	26.69%	27.40%	37.13%
7 level	23.85%	24.48%	25.27%
9 level	17.08%	17.43%	17.56%
11 level	12.48%	13.24%	13.30%
13 level	10.68%	12.56%	12.55%

VI. CONCLUSION

The different techniques for generating pulses for CHB MLI are shown along with THDs. All the simulations are simulated in MATLAB/SIMULINK. The PD technique is easy and found low THD compared to other techniques up to 13th level. As the levels are increasing the voltage stress also decreases for same power and voltage rating. The power losses are reduced and there by increases the power quality, efficiency and life of the system. As it is modular, it is more reliable and robust. The developed CHB is used for electric utility applications, which avoids the use of transformer and can interface the renewable energy to grid. The applications of simulated CHB can be used for inverter power supplies, industrial drives, hybrid electric vehicles, VAR and harmonic compensators like filters, etc.

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