Comparative Analysis of Modular Multilevel Converter with Cascaded H Bridge Inverter using Five, Seven and Nine levels

Jahangeer Soomro, Farah Shah, Sohail A. Soomro, Faheem A. Chachar, Sadaqat Ali

Abstract--- Inverters are power electronic converter that converts DC input to an AC output waveform. These inverters are used to operate sensitive loads so they require better power quality and lower harmonic content. As all the power electronic converters are considered as switches so suitable PWM technique plays a vital role in powering these inverters. This paper attempts to compare the two very popular topologies of inverters like Cascaded H-Bridge Multilevel inverter and Modular Multilevel converter. Performance of Cascaded H-Bridge Multilevel Inverter is viewed by using modulation techniques like In-phase deposition (IPD), Phase opposite deposition (POD) and Alternate Phase opposite deposition (APOD) while Modular Multilevel Converter is viewed under nearest level Modulation (NLM) technique. These are compared in order to have lesser switching losses and lower total harmonic distortion by using MATLAB/SIMULINK simulations.

Keywords: MMC, Cascaded H Bridge Inverter, THD and MATLAB/Simulink

1. INTRODUCTION

Modern inverters, that are usually multilevel, are nowadays heart and soul of many current applications like Flexible Alternating Current Transmission System (FACTS), Variable Speed Drives, HVDC system and many more. There can be various types of inverters depending upon the output waveform produced. They can be square wave inverter, quasi square wave inverter and sine wave inverter. Each type of inverter produces some harmonic distortion which is the result of switching operation. These harmonics are also the cause of nonlinearities that is very detrimental to the system as it has ability to distort the supply voltages, power factor, heating of conductors, overloading of transformers etc. So before using any converter it is imperative to reduce its harmonic content.

Cascaded H-Bridge Inverter uses n-1/2 H-bridges in order to produce n level output voltages. They are considered as medium voltage but high-power inverters. The H-bridges are attached in a cascaded manner in order to get medium voltage output. Separate isolated DC supplies are needed to power the H-bridge network. The benefit of using this arrangement is that it eliminates the use of capacitor and diode so overall there will be lesser switching losses and the filter used will be cheaper and smaller. So the system cost will be minimized.

Modular multilevel converter have the ability to manage high voltages without the connection of series-switching devices. They can achieve higher number of output levels with greater efficiency and lesser harmonic content by providing quality power and lower common-mode voltages. Its operation is transformer less as it provides high modularity and this results in lesser switching losses and elimination of the need of filtering.

2. MODULAR MULTILEVEL CONVERTER

Modular multilevel inverters consists of two arms i.e. lower and upper arm, each having submodules connected in series. These submodules are consisted of half bridges and a diode in parallel in order to control the current flow. Both the arms are connected to inductor and resistor in order to limit fault current due to voltage difference in the arm. Capacitor is inserted and not inserted in each submodule depending on the state it is in. There can be three operating states of MMC:

1. Blocking State
2. Cut-in State
3. Cut-off State

In blocking state both the submodules are off and any of the two diode is on so it has either capacitor inserted state or not inserted state. In cut-in state, regardless of the diodes submodule-1 is on and the capacitor is inserted. While in the third state submodule-2 is on regardless of the diodes and capacitor is not inserted. The summarized operation of submodules is mentioned in the table below:

Table 1: Summary of the operation of Submodules

States	SM1	SM2	D1	D2	Capacitor
Blocking State	OFF	OFF	ON OFF	OFF ON	Inserted Not Inserted
Cut-in State	ON	OFF	-	-	Inserted
Cut-off State	OFF	ON	-	-	Not Inserted

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The basic working can be understood by these equations of upper and lower arm:

For upper arm:

$$\mathbf{Vo} = \frac{\mathbf{Vdc}}{\mathbf{2}} - \mathbf{Vm1} - \mathbf{Vm2}$$

For lower arm:

$$\mathbf{Vo} = -\frac{\mathbf{Vdc}}{\mathbf{2}} + \mathbf{Vm3} + \mathbf{Vm4}$$

Here Vo is the output voltage, Vdc is the supplied DC voltage and Vm(1-4) are the voltages across the submodules. The desired potential is achieved by connecting and disconnecting various submodules at upper and lower arm. Figure 1 shows the circuit diagram of MMC.

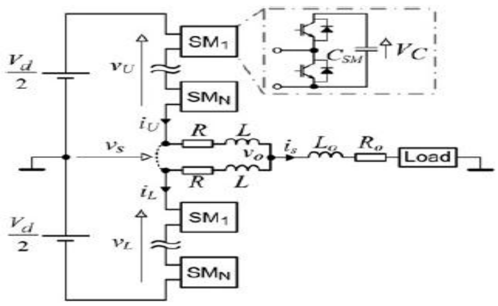

Figure 1: Circuit diagram of MMC

MMC is implemented by using nearest level modulation technique which is an alternate of carrier based modulation techniques. This scheme have the advantage of being simple and easy to implement. It was primarily introduced for large-drive multilevel systems but due to the fact that it is flexible and provides easy digital implementation while operating at higher levels, it can also be used for MMC in HVDC systems and other sort of similar application. It escapes the use of multiple carrier waves and directly computes the switching states and duty cycles. The main idea behind this approach is that the reference wave is sampled at frequency fs and then it is approximated to its nearest integer level. Now the reference waveform becomes a staircase, so for n-levels of MMC, NLM produces N+1 level. Higher the frequency of converter, better will be the approximation. Figure 2 and 3 shows the block diagram and working principle of NLM.

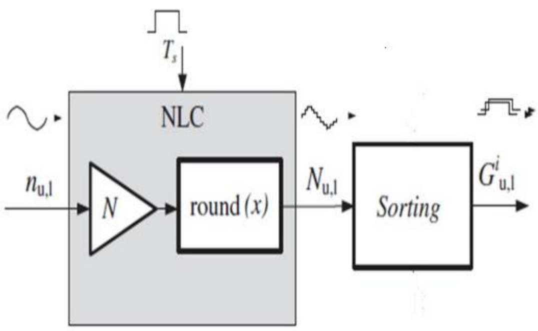

Figure 2: Block diagram of NLM

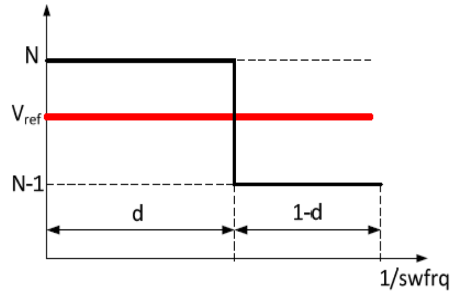

Figure 3: Working principle of NLM

3. CASCADED H-BRIDGE MULTILEVEL INVERTER

Cascaded H-bridge inverter is one of the three types of multilevel inverter. Other types include diode clamped inverters and flying capacitor inverters. The major benefit of using cascaded H-bridge is that it doesn't require a diode and flying capacitor. It is made up of series connected H-bridges powered by separate isolated DC sources. For a 5-level cascaded H-bridge inverter the output voltages vary from 2Vdc to -2Vdc by creating 5 intermediate levels in between. These voltages are achieved by using different combinations of the switches. It produces its output by combining several isolated voltage levels. A series of full H-bridges makes up the phase of inverter which can generate different levels of output voltage and offers phase balancing of Ac systems. This configuration can also be used for high-power inversion and high voltage application because by using this topology the load on the switch is reduced as compared to other unipolar and bipolar inverters. Also we can increase the power and voltages in safer limits as it is attuned to lesser noise and other interferences. Figure 4 shows the circuit diagram of cascaded H-bridge inverter. The figure shows that for a five level output, 2 series-connected h-bridges supplied by 2 DC supplies are used. The output voltage is the sum of the voltages of 2 H-bridges.

$$\mathbf{Vo = V_{1} + V_{2}}$$

Where V1 is the voltage across the first H-bridge while V2 is the voltage across second H-bridge.

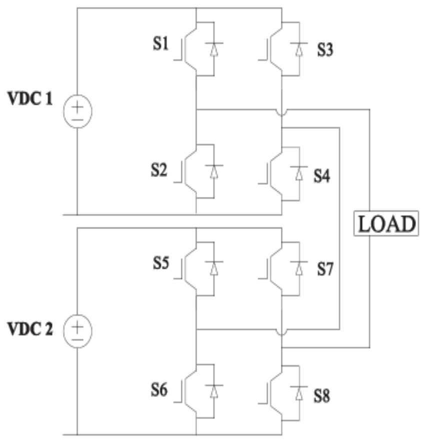

Figure 4: Circuit diagram of 5-level cascaded H-bridge inverter

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In this paper, the modulation technique used to power this inverter is Carrier deposition SPWM. Its different variants are In-phase deposition (IPD), Phase opposite deposition (POD) and Alternate Phase opposite deposition (APOD).

A-In-phase deposition (IPD)

In this type of carrier deposition, all triangular carriers are in phase to each other. Figure 5 shows the waveform of IPD scheme.

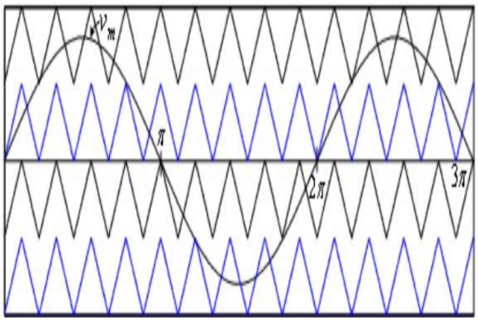

Figure 5: IPD Scheme

B- Phase opposite deposition (POD)

This type of carrier deposition uses in-phase carriers above the reference line and out of phase carrier below the reference line. Figure 6 shows POD scheme.

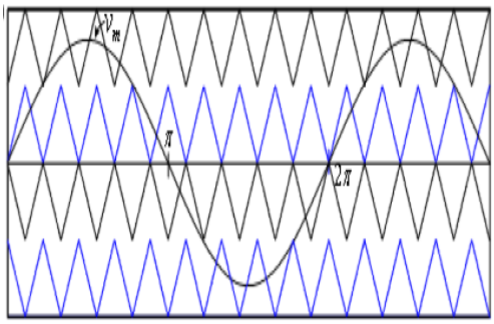

Figure 6: POD Scheme

C- Alternate Phase opposite deposition (APOD)

This scheme uses in-phase and out of phase carrier waveforms alternatively. Figure 7 shows APOD scheme.

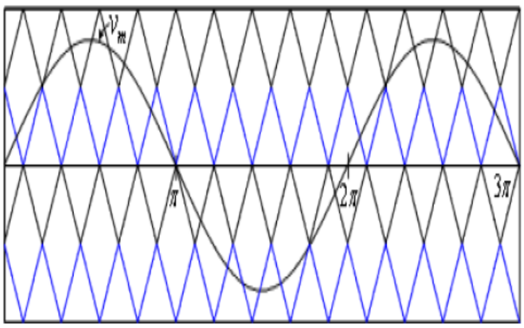

Figure 7: APOD scheme

4. COMPARATIVE ANALYSIS OF CASCADED H-BRIDGE INVERTER AND MODULAR MULTILEVEL CONVERTER

Comparative analysis of both the inverters in done by using MATLAB/Simulink software. These are compared in terms of total harmonic distortion for 5, 7 and 9 levels.

A-For 5 levels

- For 5 level MMC the output voltage and THD are shown in figure 8 and 9.

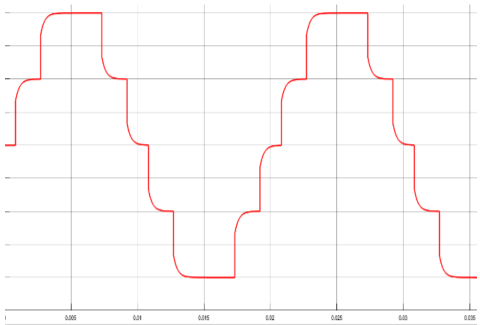

Figure 8: Output levels for MMC

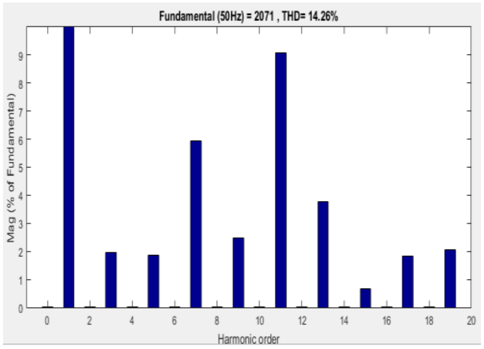

Figure 9: THD for 5-levels of MMC

- For 5 level cascaded H-bridge the output voltage and THD for POD, IPD and APOD are shown in figures 10, 11, 12, 13, 14 and 15.

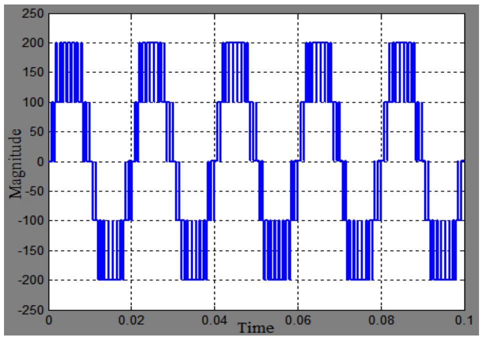

Figure 10: Output voltage for 5 level POD Scheme

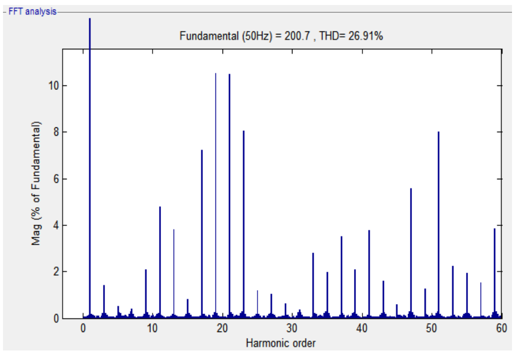

Figure 11: THD for POD Scheme

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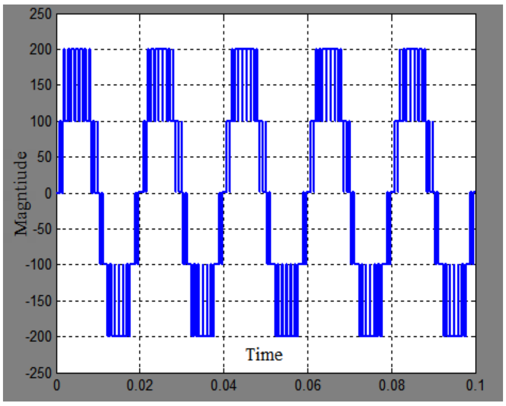

Figure 12: Output Voltage for IPD Scheme

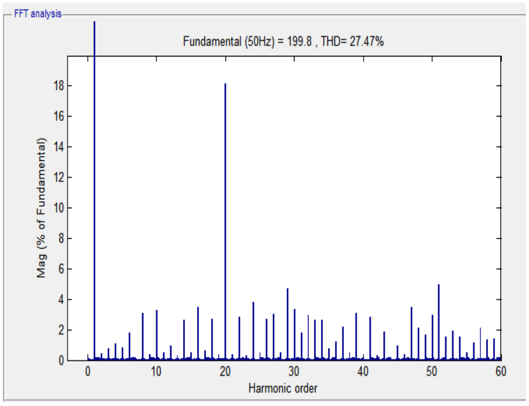

Figure 13: THD for IPD Scheme

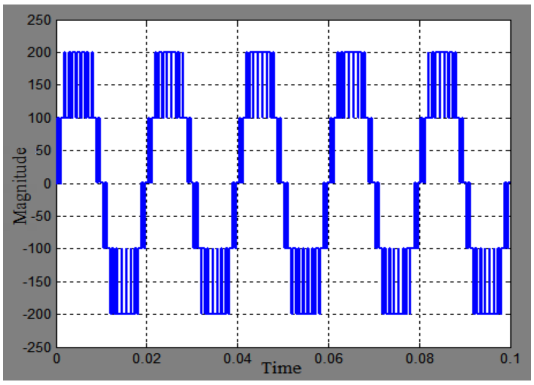

Figure 12: Output voltage for 5 level APOD Scheme

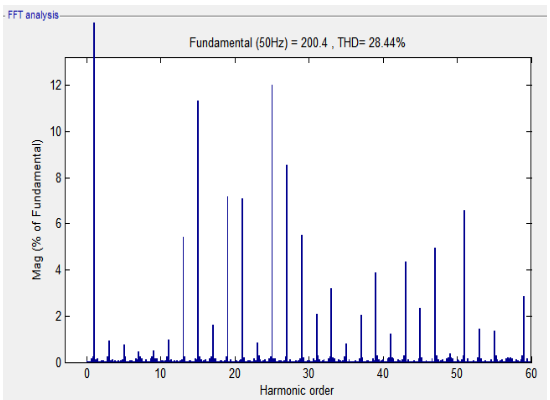

Figure 13: THD for APOD Scheme

B-For 7 levels

- For 7 level MMC the output voltage and THD is shown in figures 16 and 17.

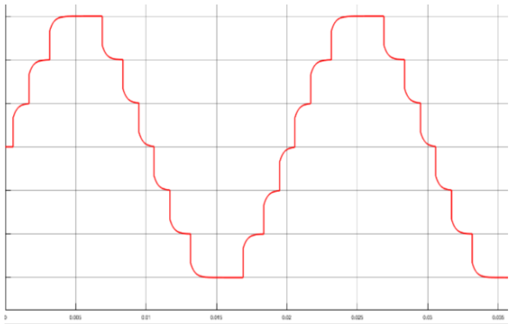

Figure 14: Output Voltage for 7-level MMC

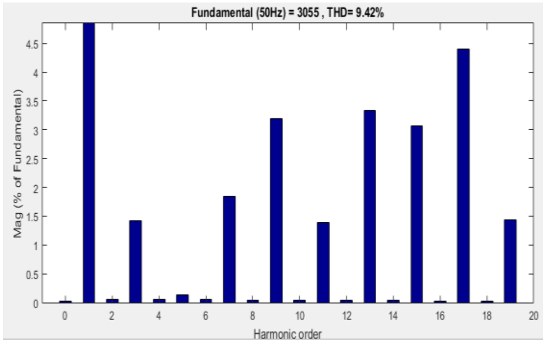

Figure 15: THF for 7-level MMC

- For 7-level Cascaded H-bridge the output voltage is shown in figure 18.

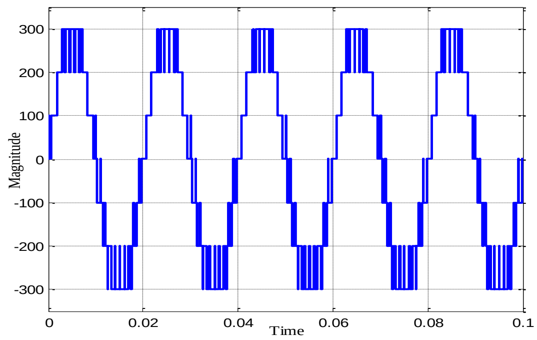

Figure 16: Output voltage for 7-levels

Table 2: THD for IPD, POD and APOD Schemes.

Scheme	THD
IPD	18.26%
POD	16.45%
APOD	17.72%

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C-For 9 levels

- For 9 level MMC the output voltage and output THD are shown in figure 19 and 20.

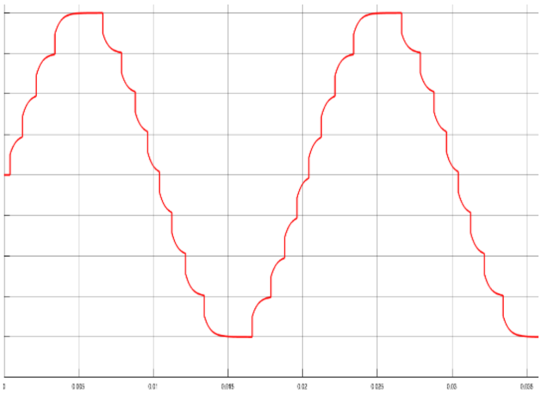

Figure 17: Output voltage for 9 level MMC

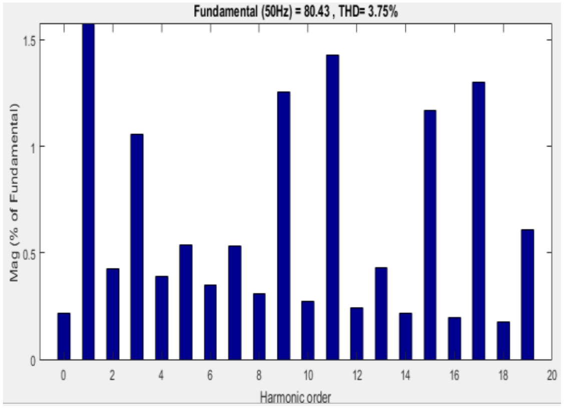

Figure 18: THD for 9 levels MMC

- For Cascaded H-bridge Inverter the output voltage for 9 levels is shown in figure 21.

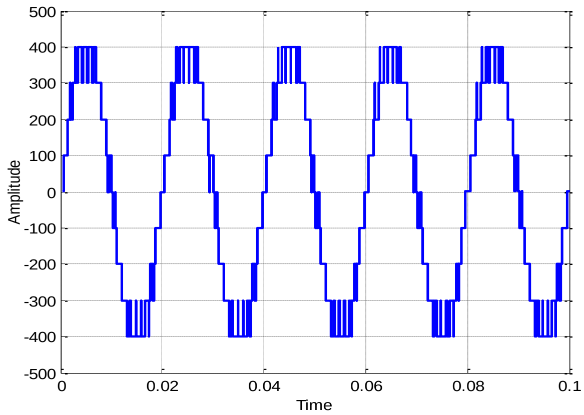

Figure 19: Output voltage of 9 levels for CHB Inverter

Table 3: THD in output for 9 levels

Scheme	THD
IPD	13.45%
POD	12.96%
APOD	13.46%

5. RESULTS

From the results of comparative analysis, it is shown that the POD scheme used in Cascaded H-bridge inverters is having lesser THD in the output than APOD and IPD Schemes. While MMC is having even THD as compared to Cascaded H-bridge inverter implemented by using POD scheme.

The summarized results of the comparative analysis are given below in table 4.

Table 4: Summarized results of analysis of THD

SR.NO	LEVELS	Cascaded H-Bridge (POD)	MMC
1	5	26.91%	14.26%
2	7	16.45%	9.42%
3	9	12.96%	3.75%

6. CONCLUSION

From the results it is concluded that Cascaded H-bridge Inverters produce lesser THD when it is used with POD scheme. When this cascaded topology is compared with the Modular Multilevel Converter by using nearest level Modulation technique then MMC is found better as the THD produced by MMC is nearly half of what is produced by cascaded H-bridge inverters.

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