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Research Article

Comparative Analysis of Different SPWM Techniques for Modular Multilevel Inverter

Ankita Pande†*, Palak Sharma† and Shivpal Verma†

†Electrical Engineering, RTMNU, R.G.C.E.R Nagpur India

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Abstract

In this paper, the comparison is shown between three different techniques of sinusoidal pulse width modulation i.e., phase disposition PWM, phase opposition PWM and alternate phase opposition disposition PWM used for modular multilevel inverter. The simulation of single phase three, five and seven level modular multilevel inverter has been carried out in MATLAB/Simulink and output waveforms of the same are included along with its FFT analysis.

Keyword: *Modular Multilevel Inverter, PDPWM, PODPWM, APODPWM*

1. Introduction

An inverter is a device that converts DC to AC at desired output voltage and frequency. Demerits of inverter are less efficiency, high THD, and high switching losses. To overcome these demerits, multilevel inverter is introduced (J. Rodriguez, Jih-Sheng Lai, Fang Zheng Peng, 2002).

The concept of multilevel converters has been introduced since 1975. The modular multilevel inverter which is also a type of multilevel inverter was first proposed in 2002. In recent years modular multilevel inverters are used for high power and high voltage applications. Modular multilevel inverter output are staircase output waveforms, which is closer to the sinusoidal waveform. The voltage output of modular multilevel inverter gives less number of harmonics than the conventional two level inverters. MMI consist of set of sub modules (A. Lesnicar, R.Marquardt, 2003), which can be connected or bypassed to generate the output voltage.

The SPWM methods are mainly used in multilevel inverter control strategy. The SPWM is most used for the multilevel inverter, because it is very simple technique and easy to implement. Different SPWM control techniques based on carrier disposition are there (Siemaszko D, Antonopoulos A, Ilves K, Vasiladiotis M, Angquist L, Nee H, 2010; D. Mohan, Shreejith B. Kurub ,2012), i.e. phase disposition PWM, phase opposition PWM and alternate phase opposition disposition PWM to analyse the performance of modular multilevel inverter and harmonic analysis of the output waveforms.

*Corresponding author: **Ankita Pande**

2. Modular Multilevel Inverter

The Modular Multilevel Inverter (MMI) is a newer topology first introduced in 2002. It uses a modularized set up of sub module, essentially half bridges which are connected or bypassed to generate a certain output voltage level. Every phase leg is composed of two arms where each arm has a no. of sub modules. With a suitable no. of sub modules connected in series, the valve can synthesis a stepped voltage waveforms that approximates very closely to a sine wave & contains very low levels of harmonic distortions. Modular Multilevel topology instead offers advantages such as higher voltage levels, modular construction, longer maintenance intervals & improved reliability.

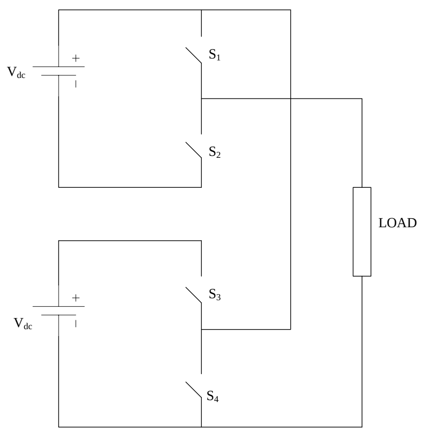

Fig.1 Circuit diagram of a modular half-bridge 3 level inverter

Fig.1shows the circuit diagram of half bridge 3 level modular multilevel inverter. The output V_o can take three possible values i.e. +Vdc, 0 and -Vdc. It can be extended further. The number of possible outputs represents the level of the inverter. With the increase in number of levels, the output has more number of steps leading to sinusoidal waveform. This is the basic idea behind various topologies of multilevel inverters.

Table 1 Switching pattern for 3 level MMI

Switches	+Vdc	0	-Vdc
S1	ON	OFF	OFF
S2	OFF	ON	ON
S3	ON	ON	OFF
S4	OFF	OFF	ON

3. SPWM Techniques

The gate pulses are generated by utilizing the simplicity of multi carrier sine PWM. In this technique sine wave is taken as reference wave of amplitude A_r and frequency f_r and it is continuously compared with triangular carrier wave of amplitude A_c and frequency f_c. If sine wave is greater than triangular wave, switch is turned on otherwise off. For N level N-1 carrier wave with same frequency f_c and same amplitude A_c are disposed such that the bands they occupy are continuous. The reference waveform has peak-to-peak amplitude A_r, the frequency f_r and it is zero centered in the middle of the carrier set. The reference is continuously compared with each of the carrier signals. If the reference is greater than a carrier signal, then the device corresponding to that carrier is switched on otherwise off.

In multilevel inverters, the amplitude modulation index (M) is the ratio of reference amplitude (A_r) to carrier amplitude (A_c).

$$M = A_r/(N-1)A_c$$

3.1 Phase Disposition Pulse Width Modulation Method (PDPWM)

In phase disposition method all the carriers have the same frequency and amplitude. Moreover all the N-1 carriers are in phase with each other.

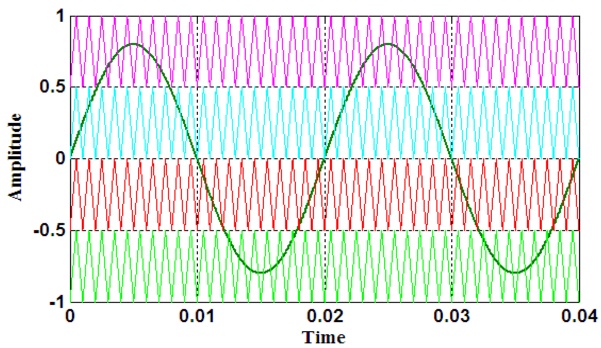

Fig 2: Phase Disposition PWM

It is based on a comparison of a sinusoidal reference waveform with vertically shifted carrier waveform as shown in Fig. 2. This method uses N – 1 carrier signals to generate N level inverter output voltage. All the carrier signals have the same amplitude, same frequency and are in phase. In this method four triangular carrier waves have been compared with the one sinusoidal reference wave.

3.2 Phase Opposition Disposition (PODPWM)

In Phase Opposition Disposition (POD), the carrier signal above the zero axis all the carrier wave have same frequency, same amplitude and in phase each other (Fig. 3). But the below the zero axis all the carrier wave have same frequency, same amplitude and in phase but all carrier wave have phase shifted 180 degree compare to the above zero axis carrier waveform.

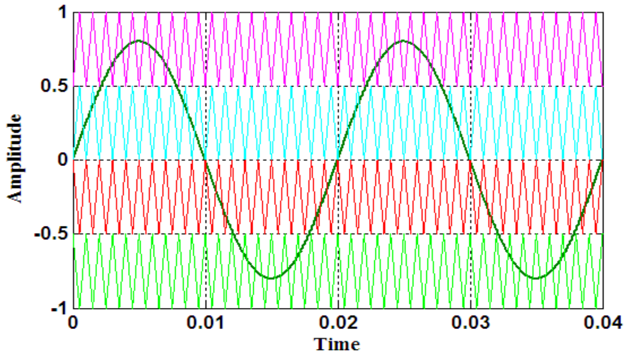

Fig 3: Phase Opposition Disposition PWM

3.3 Alternate Phase Opposition Disposition (APODPWM)

In Alternate Phase Opposition Disposition PWM (APOD), every carrier waveform is out phase with its neighbouring carrier wave by 180 degree as shown in fig. 4. All the carrier waveform have same frequency, same amplitude and but compare one carrier waveform to neighbour carrier waveform is phase shifted 180 degree. Odd carrier waveforms are in phase but compare to even carrier waveform are out of phase shift 180 degree in odd carrier waveform.

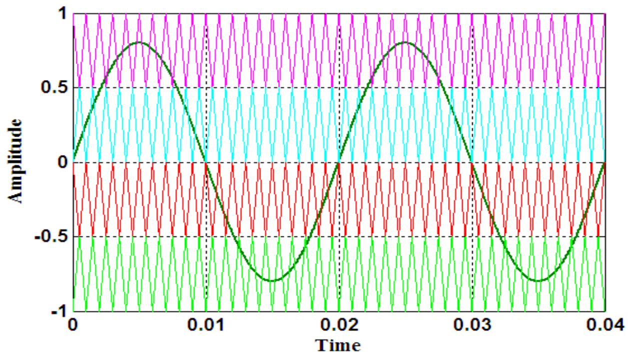

Fig 4: Alternate Phase Opposition Disposition PWM

4. Simulation Results

The simulation of Modular Multilevel inverter using different SPWM techniques has been carried out. Simulation parameters are given below:

Table 2 Simulation Parameters

Parameters	Values
DC Bus Voltage	100 V
Carrier frequency	2.0 kHz
Fundamental frequency	50Hz
Load	R=10Ω

The simulation result for 3 level MMI is shown in fig 5. The output voltage and current waveforms will be same for PD, POD and APOD pulse width modulation. The harmonic analysis for different techniques is shown in fig 6 and fig 7.

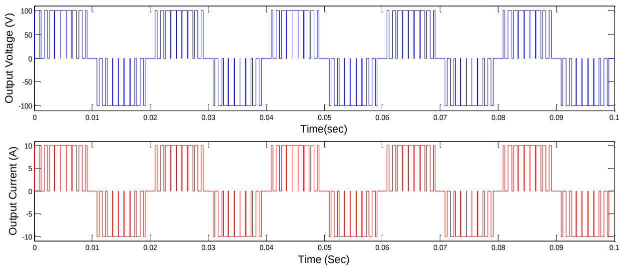

Fig. 5: Simulation result for single phase 3 level MMI

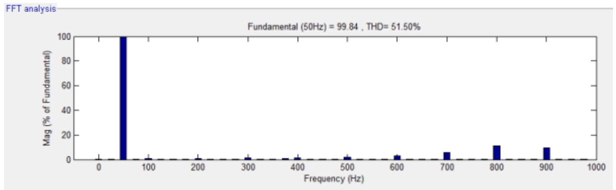

Fig. 6: FFT analysis for 3 level MMI using PDPWM

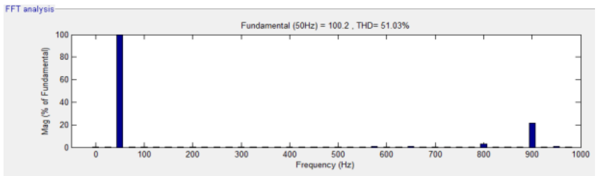

Fig. 7: FFT analysis for 3 level MMI using PODPWM

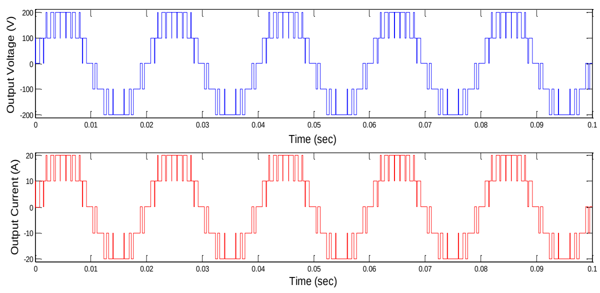

Fig. 8: Simulation result for single phase 5 level MMI

The simulation result for 5 level MMI is shown in fig 8. The output voltage and current waveforms will be same for PD, POD and APOD pulse width modulation. The harmonic analysis for different techniques is shown in fig 9, fig.10 and fig.11.

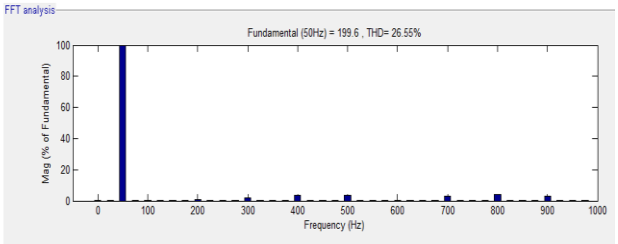

Fig. 9: FFT analysis for 5 level MMI using PDPWM

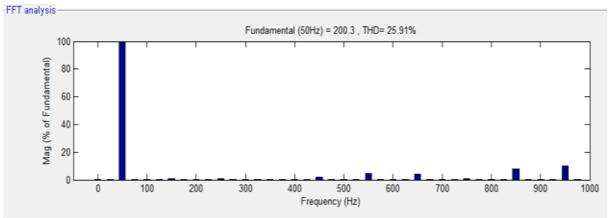

Fig. 10: FFT analysis for 5 level MMI using PODPWM

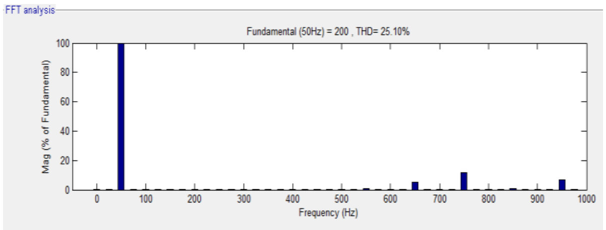

Fig. 11: FFT analysis for 5 level MMI using APODPWM

The simulation result for 7 level MMI is shown in fig 12. The output voltage and current waveforms will be same for PD, POD and APOD pulse width modulation. The harmonic analysis for different techniques is shown in fig 13, fig.14 and fig.15.

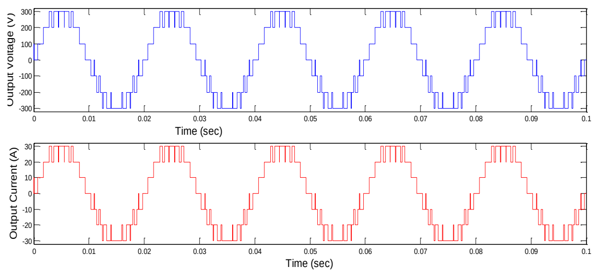

Fig. 12: Simulation result for single phase 7 level MMI

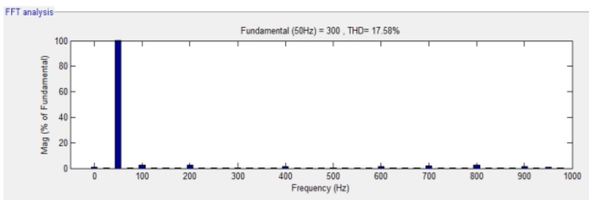

Fig. 13: FFT analysis for 7 level MMI using PDPWM

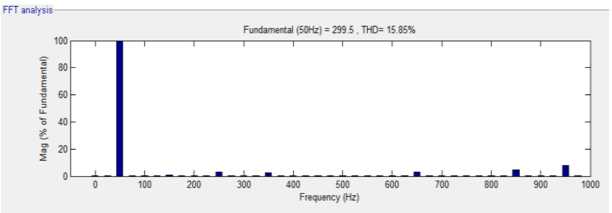

Fig. 14: FFT analysis for 7 level MMI using PODPWM

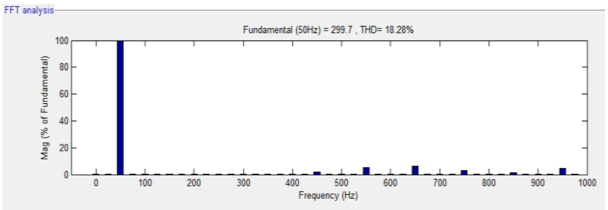

Fig. 15: FFT analysis for 7 level MMI using APODPWM

A comparison in terms of total harmonic distortion is given for all the three SPWM techniques in Table 3.

Table 3 Comparison of Harmonic Analysis for Different SPWM Techniques

No. Of Levels	THD (PDPWM)	THD (PODPWM)	THD (APODPWM)
3 level	51.5%	51.03%	51.03%
5 level	26.55%	25.91%	25.10%
7 level	17.58%	15.85%	18.28%

Conclusion

Simulation of three, five and seven level modular multilevel inverter has been done using MATLAB/Simulink. The gate pulses have been generated by using different SPWM techniques. The result of harmonic analysis shows that, Total Harmonics Distortion (THD) in phase opposition disposition pulse width modulation gives more reduction in THD as compared to other two techniques.

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