THD Analysis of Three Phase Cascaded Multilevel Inverter with Different PWM Techniques

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Abstract- *A multilevel inverter is a popular inverter for solar based high power applications. Multilevel inverter is a power electronic device that is used for high voltage and high power applications such as facts, ups and their performance is better to that of conventional H-bridge inverter. This project focus on phase shift and level shift PWM based cascaded multilevel inverter. The proposed method has been designed a 7-level cascaded multilevel inverter by using phase shifted and level shifted PWM technique and compare the THD. A detailed study of the techniques was carried out through MATLAB/SIMULINK for THD.*

Keywords- cascaded multilevel inverter (CMLI), phase shifted pulse width modulation (PSPWM), level shifted pulse width modulation (LSPWM), total harmonic distortion (THD), phase disposition (PD), phase opposition disposition (POD), alternate phase opposition disposition (APOD).

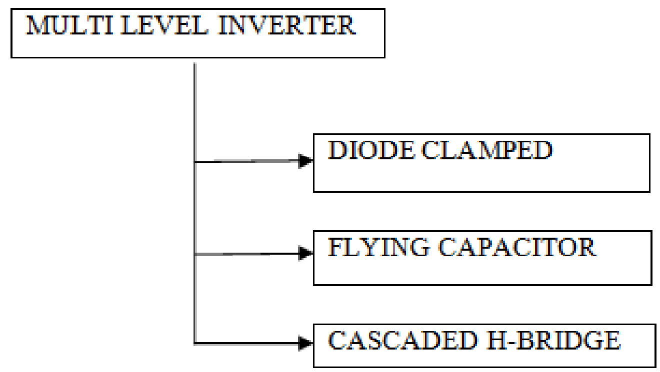
I. INTRODUCTION

Renewable energy sources have gained wide importance due to the depletion of fossil fuels [1]. Also the problem of pollution caused by fossil fuels can be solved by using clean and freely available renewable energy. Solar energy is the one of the renewable energy.

In case of solar energy system, voltage generated from solar array is needed to be converted into ac signal for high power ac applications. Conventional H-bridge inverter is not a practical solution for DC-AC conversion because of large harmonic distortion and switching losses. Later, the drawbacks of conventional inverter are overcome by MLI. The increased number of levels reduces the harmonic content and brings the output voltage waveform closer to sinusoidal. [1]-[2].

The basic concept of a multi level inverter is to achieve high power by using a series of power semi conductor switches with several lower DC voltage sources to perform the power conversion by synthesizing a stair case voltage wave form [1]-[9].

II. MAIN TOPOLOGIES OF MLI



DIODE CLAMPED INVERTER:

The main concept of this inverter is to use diodes and provides the multiple voltage levels through the different phases to the capacitor banks which are in series. A diode transfers a limited amount of voltage, thereby reducing the stress on other electrical devices. The maximum output voltage is half of the input DC voltage. It is the main drawback of the diode clamped MLI. In diode clamped inverter, when the number of levels increases more clamping diodes are required [3].

FLYING CAPACITOR MLI:

It is also known as capacitor clamped inverter. The main concept of this inverter is to use capacitors. It is of series connection of capacitor clamped switching cells. The capacitors transfer the limited amount of voltage to electrical devices.

The output is half of the input DC voltage. It is the drawback of flying capacitor MLI. It can control both active and reactive power flow. But due to the high frequency switching, switching losses will take place and control can be complicated.

CASCADED H-BRIDGE MULTILEVEL INVERTER:

It is better than diode clamped inverter and flying capacitor inverter, it requires less number of components in each switching levels and reduces THD. This topology consists of series of power conversion cells and power can be easily scaled. It consists of H-bridge cells and each cell can provide the three different voltages like zero, positive DC and negative DC voltages. One of the advantages of this type of MLI is that it needs less number of components compared with diode clamped and flying capacitor inverters. The price and weight of the inverter are less than those of the above two inverters.

In cascaded H-bridge MLI multiple DC sources can be used, whereas in diode clamped inverter and flying capacitor inverter only single DC source is used [4].

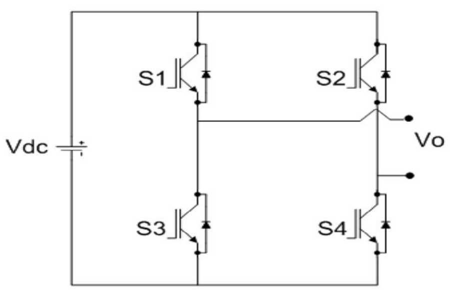


FIGURE: 3 level H-bridge inverter

TABLE: switching pattern of 3 level H-bridge inverter

Output Voltage $V_o = V_{AN}$	Switch states			
	S_1	S_2	S_3	S_4
V_{dc}	1	0	0	1
0	1	1	0	0
	0	0	1	1
$-V_{dc}$	0	1	1	0

The number level in phase voltage is 2N+1, where N is the number of H-bridges [5].

III. MODULATION TECHNIQUES

- **PHASE SHIFT ED**
- **LEVEL SHIFTED**

    I. PHASE DISPOSITION PWM
    II. PHASE OPPOSITION DISPOSITION PWM
    III. ALTERNATE PHASE OPPOSITION DISPOSITION PWM

PHASE SHIFT PWM:

Most of the modulation methods developed for MLI is based on carrier arrangement. The carriers arranged in horizontal displacement are phase shift carrier PWM. In phase shift PWM we compare reference wave (sine wave) with carrier wave (repeated sequence). When reference wave is greater than carrier wave then pulses are generated [6].
The carrier is shifted by an angle 360/n-1, where n represents the number of levels [7].

Carrier frequency = odd multiplier * fundamental frequency

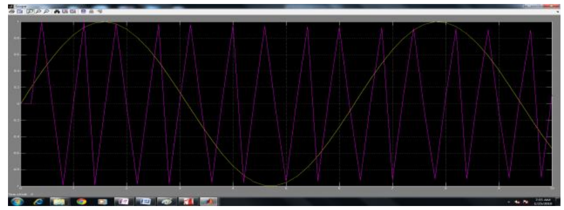


Figure: Sine PWM technique

LEVEL SHIFT PWM:

The carriers arranged in vertical displacement forms level shift PWM. In LSPWM only one reference wave is used whereas in PSPWM number of reference waves used is equal to number of carrier waves. Number of carriers require for m levels are m-1, where m is the number of levels [8].

Level shift PWM has three strategies:

PD PWM:

In PD PWM strategy all carrier wave forms are in same phase with same frequency and amplitude which is based on a comparison of reference wave form to vertically shifted carrier wave form [9]

In this technique for 7 level six carrier waves are required, which are triangular in nature and the reference signal is of sinusoidal.

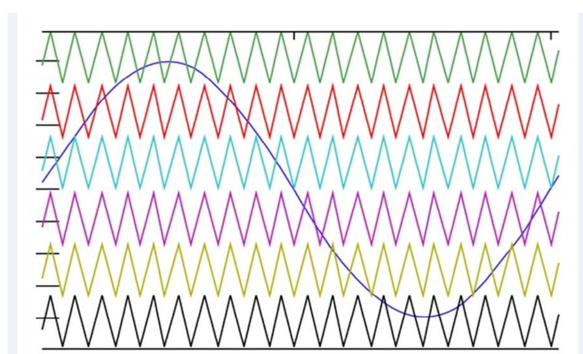


Figure: In phase disposition PWM

POD PWM:

In POD PWM strategy, where all carrier waveforms above zero reference are in phase and below zero reference are 180 degrees out of phase with same frequency and amplitude.

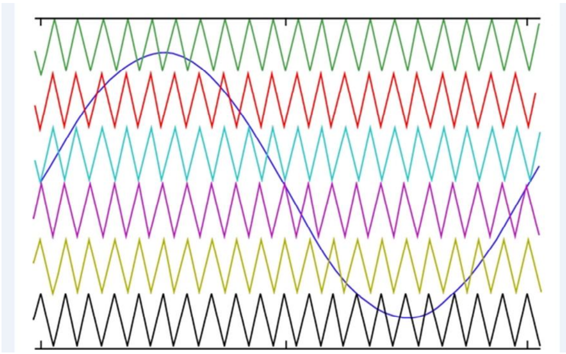


Figure: phase opposition disposition PWM

<u>APOD PWM:</u>

In APOD PWM scheme, where every carrier wave form is in out of phase with its

Neighbor carrier by 180 degrees has same frequency and amplitude [8].

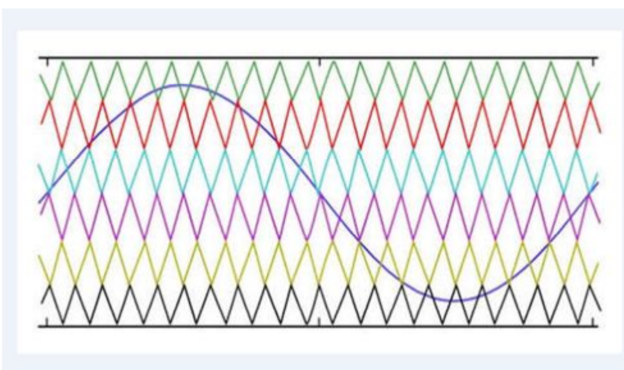


Figure: Alternate phase opposition disposition PWM

IV. SIMULATION AND RESULTS

PHASE SHIFTED PWM

The total harmonic distortion (THD) of phase shifted three phase 7-level cascaded H-bridge multi level inverter is 41.72%.

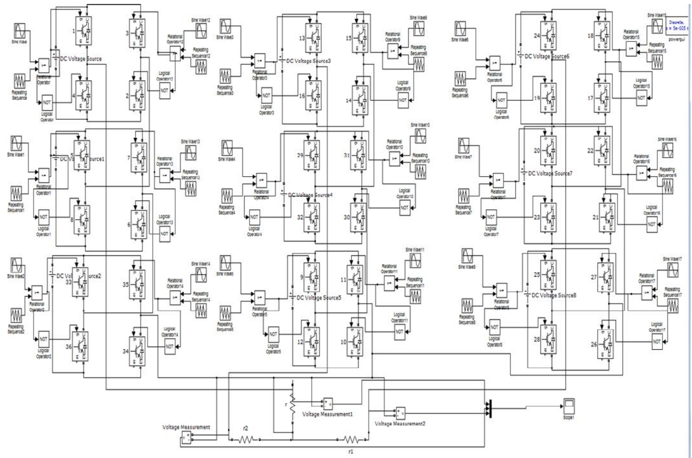


Figure: 3 phase 7-level cascaded H-bridge MLI using phase shift PWM technique

Three phase 7-level cascaded H-bridge multi level inverter circuit consists of 3 h-bridges in each phase. In PS PWM technique the phase angle delay to obtain 7-level output is 60 degrees for single phase. In case of three phase 120 degrees is added for the next phase. When reference signal is greater than the carrier signal then the pulses are generated and they are given to the switches to obtain required output.

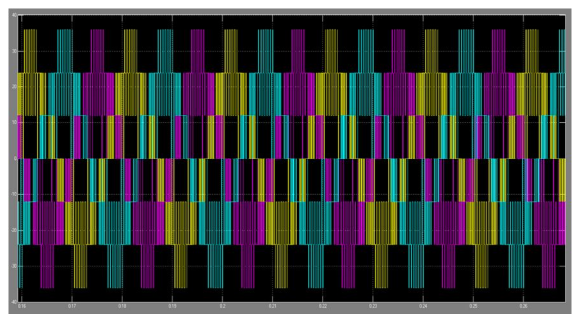


Figure: 3 phase output wave form of CMLI

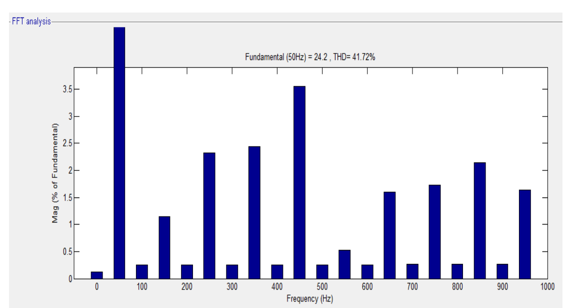


Figure: FFT analysis

LEVEL SHIFTED PWM

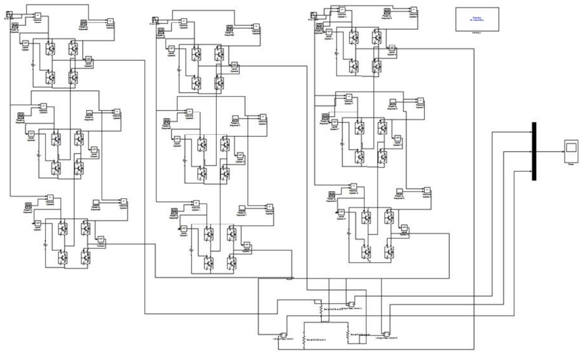


Figure: 3 phase 7-level CMI using LSPWM

Three phase 7-level cascaded H-bridge multi level inverter circuit consists of 3 h-bridges in each phase. In LS PWM the reference signal is sinusoidal and for different switches triangular carrier signals with different amplitudes are given to obtain required output.

PHASE DISPOSITION:

The total harmonic distortion (THD) of level shifted phase disposition is improved compared to phase shifted type and is 18.01%.

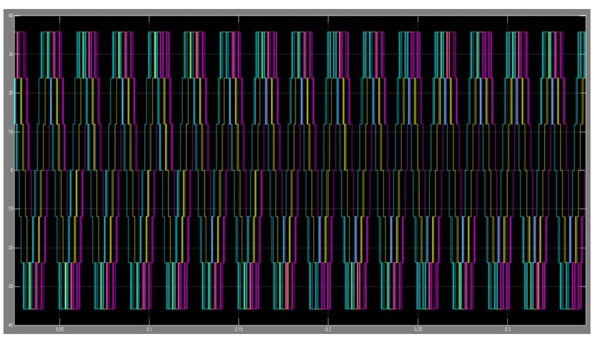


Figure: 3 phase 7-level output wave form of PDPWM

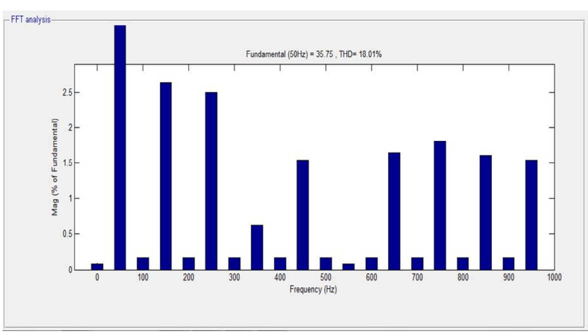


Figure: FFT analysis

PHASE OPPOSITION DISPOSITION:

The total harmonic distortion (THD) of level shifted POD PWM is 17.98%.

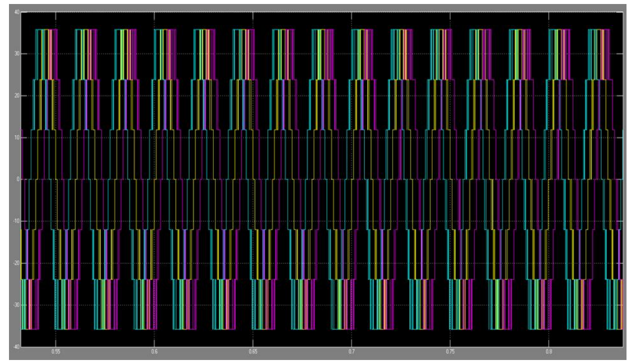


Figure: 3 phase 7-level output waveform of PODML

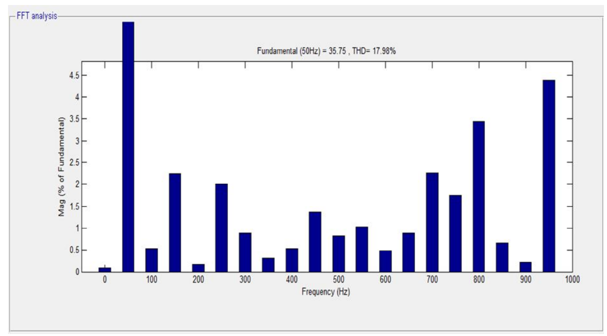


Figure: FFT analysis

ALTERNATE PHASE OPPOSITION DISPOSITION:

The total harmonic distortion (THD) of level shifted APOD PWM is less compared to other types of pulse width modulation techniques and it is 17.90%.

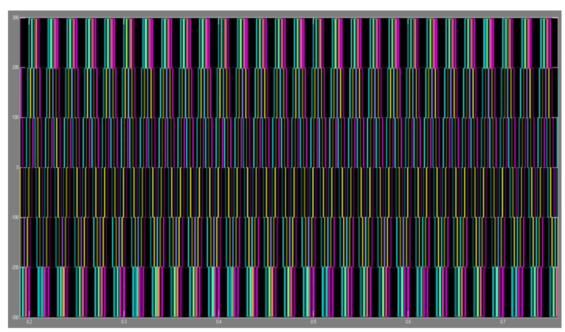


Figure: 3 phase 7-level output waveform of APODPWM

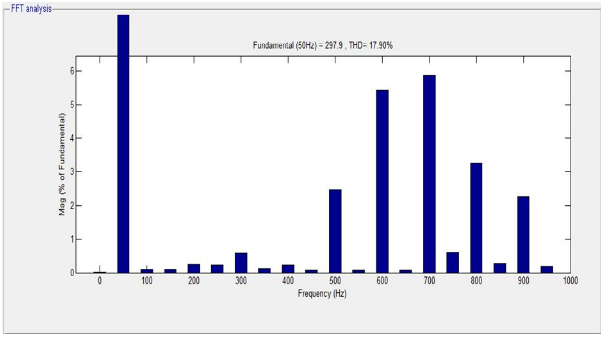


Figure: FFT analysis

V. COMPARISION OF THD

S.NO	PWM TECHNIQUES	NO.OF LEVELS	THD%
1	PHASE SHIFT PWM	7-LEVEL	41.72%
2	PD PWM	7-LEVEL	18.01%
3	POD PWM	7-LEVEL	17.98%
4	APOD PWM	7-LEVEL	17.90%

VI. CONCLUSION

In this paper, MLI is designed for solar applications which overcome the drawbacks of the conventional multilevel inverter. It has been discussed that the cascaded H-bridge topology using phase shift PWM, PDPWM, PODPWM, APODPWM are compared. It can be concluded that APOD technique is better among the four topologies. Simulation results shows that, if the number of levels increases then the harmonic content will be reduced and the proposed MLI has the characteristics which are desirable for solar based high power applications. The proposed LSPWM technique with low THD that is APOD can be extended by connecting it to the grid for future applications.

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