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# Analysis of level shifted carrier PWM methods for 25- level Cascaded H Bridge Inverter in Matlab/Simulink

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***Abstract***

*The solar energy is replacing all other conventional energy sources because of environmental concerns and depletion of coal. But tapping of solar energy and converting it into required form that is alternating nature includes some bottlenecks. The multi-level inverters are taking lead role in converting DC in to AC. Out of these MLI's, Cascaded H-bridge MLI is very much suitable for solar energy applications. This paper includes the survey of different PWM methods and presents Simulink results of the Cascaded H-bridge MLI for several levels multiple carrier based PWM techniques. These days MLIs are in the limelight due to their advantages like handling high voltages and currents, dealing with higher switching frequencies and producing lower THDs. So in this paper the authors tried their best to prove these advantages with Simulink results.*

***Keywords***—*Multilevel Inverter (MLI), Flying Capacitor (FC), Pulse width modulation (PWM), Phase disposition (PD)*

## I. INTRODUCTION

In recent years due to the evolution of power electronics and advanced research in the area of inverters the more number of topologies available in the market. But ultimate destination of the power electronic engineer is to get the optimum THD value during the conversion of electricity from DC to AC. So he/she will go for a multilevel inverter, but the market is glutted with various topologies of these diode clamped, FC and cascaded H-bridge are popular amongst other. However NPC & FC MLI are been ostracized by engineers because of their drawbacks and not able to compete with the H-bridge inverter in the area of solar energy conversion [1]. Unlike NPC and FC MLI's the cascaded H-bridge does not require any auxiliary elements such as capacitors and diodes in its circuit topology. There is no complexity involved in the control circuit of cascaded H-bridge like other topologies going for advanced levels. However cascaded inverter usage is confined to the area of solar cells because it demands individual DC source for each bridge. Because of all the above mentioned advantages the cascaded H-Bridge MLI is undoubtedly used in the solar energy conversion systems.

## II. CASCADED MULTILEVEL INVERTER TOPOLOGY

Multi-level inverters are basically of three types, which are diode clamped, FC and cascaded inverters. Of these topologies cascaded inverter is popular because of its features like packaging and equal distribution of voltage stresses. However cascaded bridge inverters require individual dc source for each bridge, but it is going to be fitted perfectly in solar industry, and perhaps in future the market will be surprised about PV panel along with these H-bridge structures. Cascaded H-bridge inverters are again two types based on the magnitude of the individual DC source, which are: symmetric and



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asymmetric [2]. Symmetric bridge inverters are conventional requires many switches moreover can be easily extended for higher levels, whereas asymmetric multilevel inverters requires less number of switches but involves complex control. In this paper IGBT's are used because their switching frequencies are higher, if at all lower switching frequencies GTO can be used.

## III. PHASE DISPOSITION PULSE WIDTH MODULATION

As we know harmonics in the inverter output is inevitable but we can reduce these by going for MLI's or PWM techniques [3] - [5]. If we go with the first one i.e. multi-level inverter which requires more number of devices so there should be a trade-off between these two. The other option available is PWM, which is highly beneficial and yielding better results up to some extent; however consumers and designers of power converters are not satisfied with the outcomes of PWM with conventional inverter that is why multi-level inverter along with PWM method is the best choice. There are various PWM Methods available which are listed below. Out of these SHE is used for lower switching frequencies only, whereas SPWM is more popular and convenient in the perspective of control circuit design. In SVPWM we can get fine tuning of the inverter states and switches can be on/off as per switching table; however the control circuit involved is complex in nature, that is why in this paper Modulation techniques used for MLI is multi carrier modulation. It is more often reported in papers that going for higher switching frequency gives us lower THD values but the cost of IGBT's will be higher. Multi carrier PWM is broadly categorized in to two types, these are level shift and phase shift, however phase shift PWM method is suitable for lower switching frequencies so level shifted carrier PWM methods are more popular. Again level shifted carrier PWM methods are classified as below

1. Phase Disposition PWM (PD-PWM)
2. Phase opposition Disposition PWM(POD-PWM)
3. Alternative Phase opposition & Disposition PWM(APOD-PWM)
4. Carrier overlapping PWM
5. Variable frequency carrier PWM

In cascaded MLI, Level shifted PWM technique is the most commonly used method for obtaining reduced THD. In this paper, the fixed frequency PWM is employed since it enables the use of both the Triangular carriers signals and the conventional sinusoidal reference signals which are in same phase i.e. Phase Disposition PWM (PDPWM) [7]. However in Phase opposition Disposition PWM the carriers in positive side of modulating signal are in same phase and carriers on negative side of modulating signal are out of phase to the above carriers. In Alternative Phase opposition & Disposition PWM (APOD-PWM) the alternative carriers are out of phase.

To design an N-level inverter with phase Disposition PWM (PDPWM), (N-1) carriers required. The frequency modulation index is given by $M_f = f_c / f_m$

Where $f_c$ = carrier signal frequency

$f_m$ = Frequency of modulating signal

Whereas the amplitude modulation index is defined as $M_a = A_m/(N-1)A_c$ (or ) the ratio of $V_r/V_c$

Where $A_m$=Amplitude of the modulating signal

$A_c$ = Amplitude of the carrier signal

N = Number of levels

$V_r$ = peak value of modulating waveform

$V_c$ = peak value of carrier waveform

Figure 1, 2 and 3 shows the level shifted multicarrier modulation for 5 Level, 15 Level and 25 Level Inverters.



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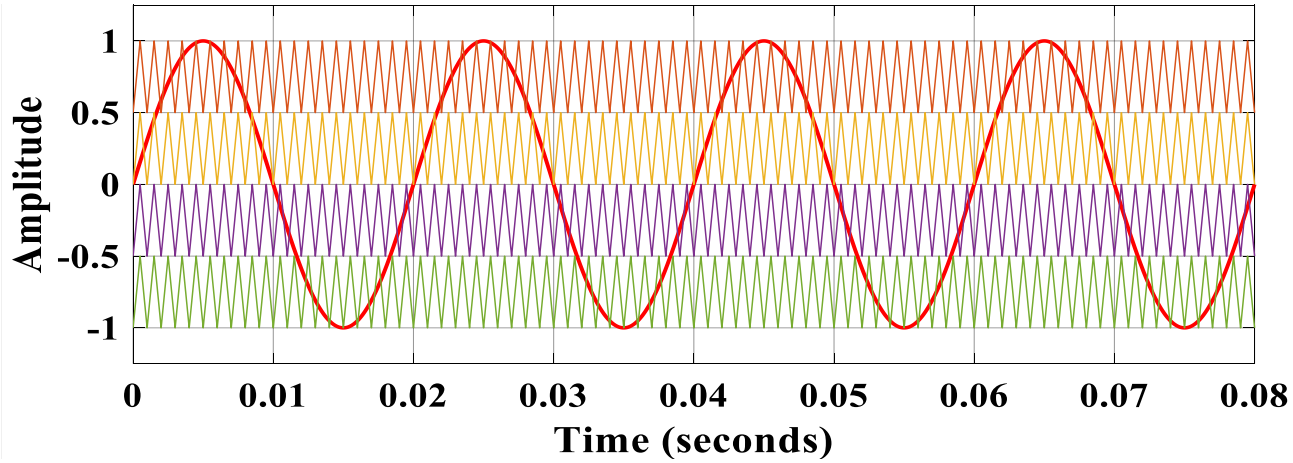


Fig. 1: Carrier waveform and Reference waveform for 5-level inverter

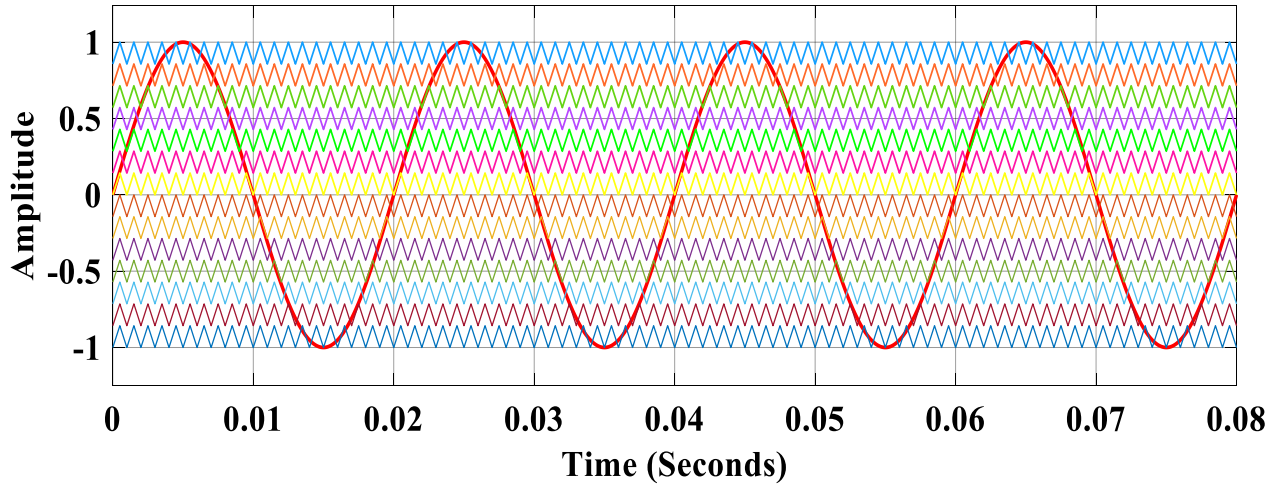


Fig. 2: Carrier waveform and Reference waveform for 15-level inverter

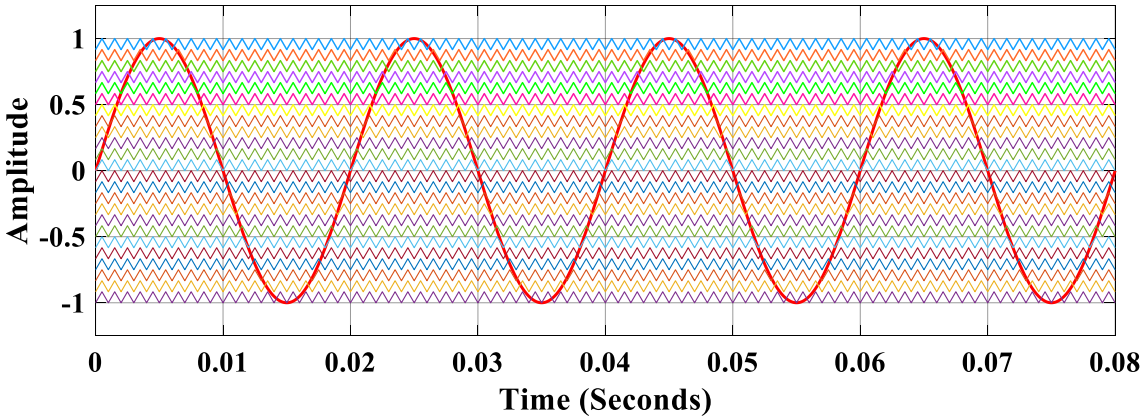


Fig. 3: Carrier waveform and Reference waveform for 25-level inverter

## IV. MATLAB-SIMULINK IMPLEMENTATION

The simulation of cascaded MLI is processed using MATLAB based SIMULINK and the developed models are shown in the fig.4.and fig-5.



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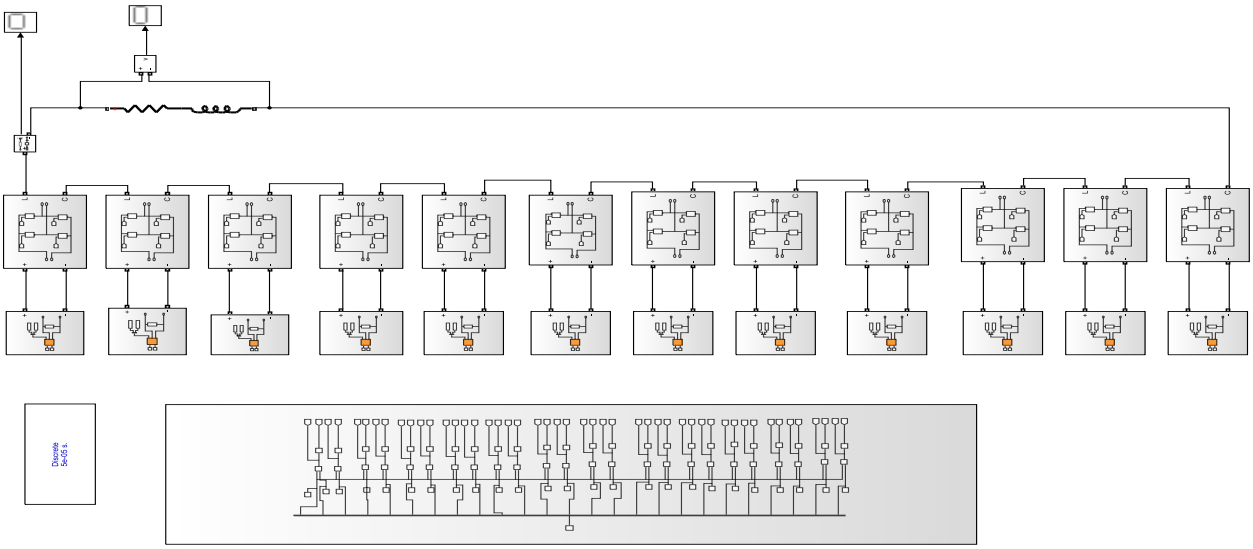

Fig.4: Simulink model for 1-Φ Twenty-five level Inverter

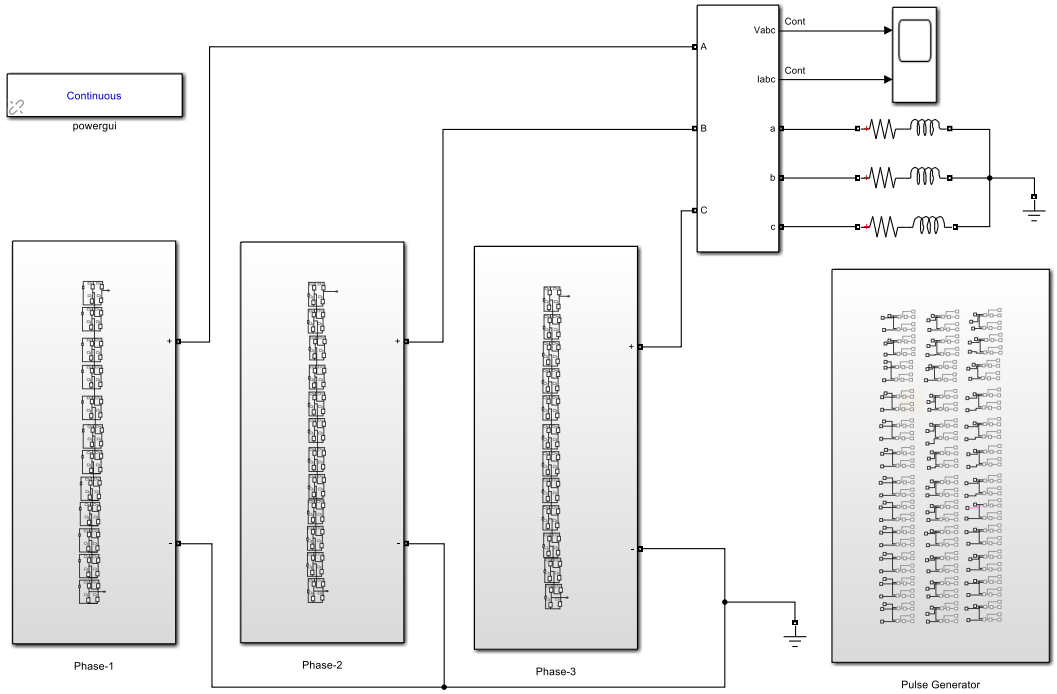


Fig.5: Simulink model for 3-Φ Twenty-five level Inverter

Both the single phase MLI and three phase MLI possess the same type of control circuit of cascaded MLI. The DC source (PV System) that employed possess different voltages which is due to asymmetrical cascaded H bridge MLI and voltage is obtained using Voltage measurement scope and it is represented in the form of pulses showing 25 Level Inverter. In the circuit, IGBT's are employed for the purpose of fast switching and only one switch is kept in on state at a time, i.e., in one H-bridge two switches are in on state and two switches are in off state.

Same switching pattern is followed and for realization of SPWM, one sinusoidal wave form and twenty four carrier wave forms are taken in to consideration. Here a sine reference wave Vr of the required frequency is taken to compare with a fast moving triangle carrier wave Vc. The switching instant is obtained from the intersecting point of those two wave forms and modulated pulse commutation, the self commutation is done without the help of any commutating elements, if a high



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power rated MLI required then usage of SCR's is unavoidable and nexus of commutating elements with the SCR makes power circuit complex and bulky. The Comparator is used to mix the sinusoidal reference wave form and the high frequency carrier wave form. The comparator is used to match up to the signal in the outward appearance of 0 or 1. The output of comparator is fed to XOR gate followed by a NOT gate and by keeping the switch in ON state, the voltage flow in circuit gives twenty five level multi-level inverter[8].

## V. SIMULATION RESULTS

The inverter output waveforms of 1-Φ and 3-Φ five level, fifteen level and twenty five level asymmetric cascaded MLI with RL load using level shifted carrier PWM schemes and their FFT analysis are shown in Fig.6, Fig.7, Fig.8, Fig.9, Fig.10 and Fig.11. From the results, it is clear that the THD is less than 5% in both 1-Φ MLI and 3-Φ MLI.

### A. THD analysis of 1-Φ MLI are given below

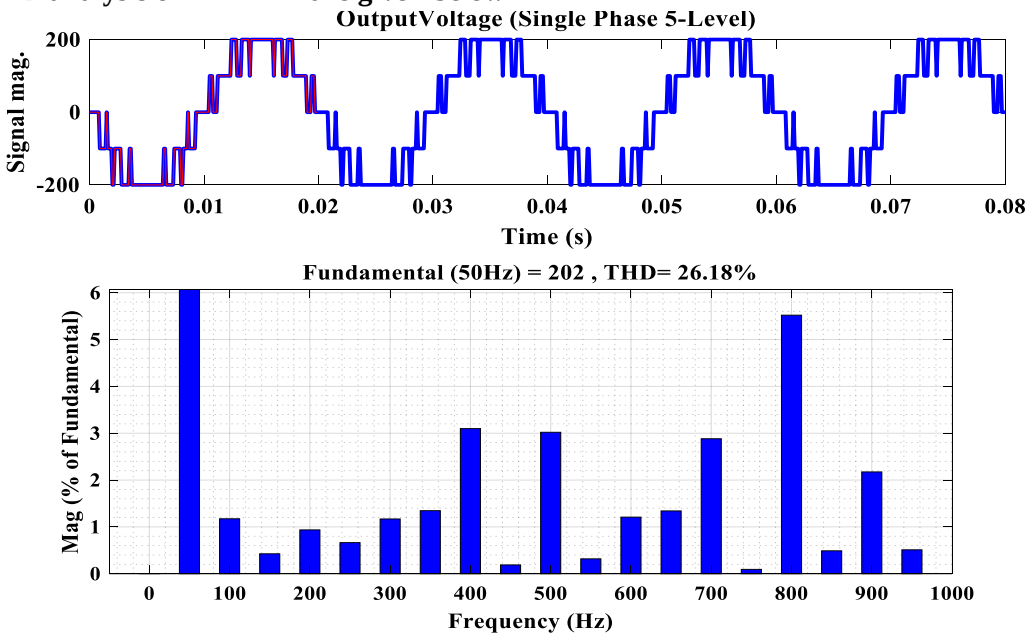
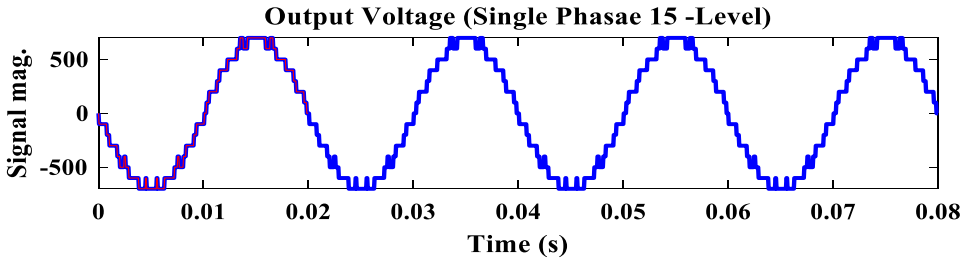



Fig. 6: Inverter Output voltage and FFT spectrum of 1-Φ 5 Level cascaded inverter



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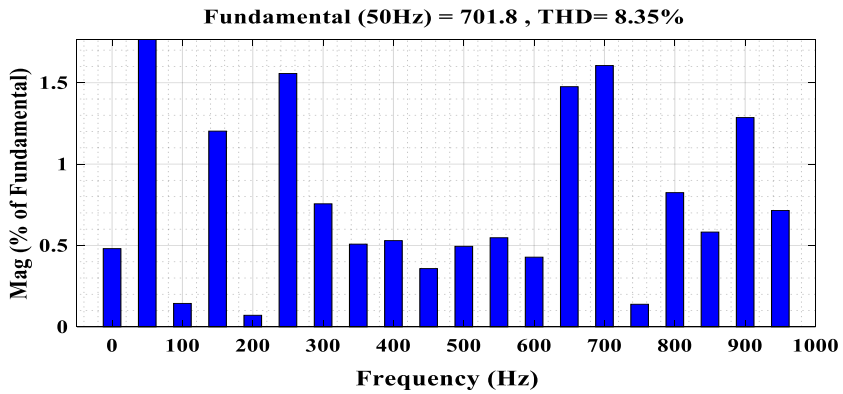


Fig. 7: Inverter Output voltage and FFT spectrum of 1-Φ 15 Level cascaded inverter

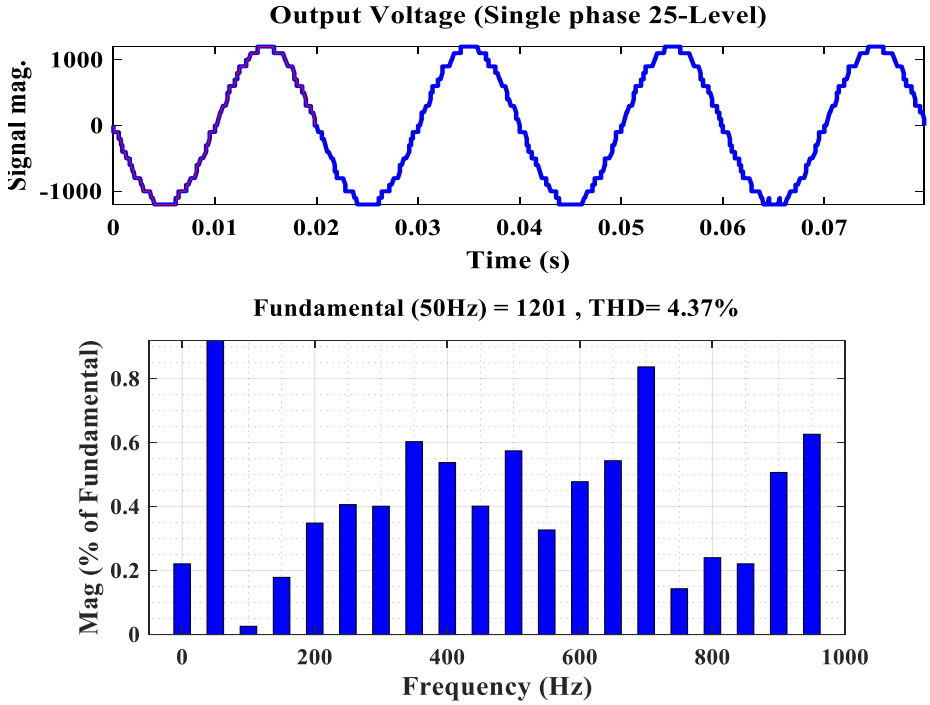


Fig. 8: Inverter Output voltage and FFT spectrum of 1-Φ 25 Level cascaded inverter

Table.1.Comparison of THD for 1-Φ MLI

| Single phase MLI | THD % | | |
|---|---|---|---|
| | **5 Level** | **15 Level** | **25 Level** |
| Phase Disposition | **26.18%** | **8.35 %** | **4.37 %** |
| Phase Opposition Disposition | 26.69% | 9.47% | 6.89% |
| Alternate Phase opposition Disposition | 36.93% | 19.56% | 16.56% |

The above table shows that as the number of level in the output waveform increases the distortion of harmonics will decrease but at the cost of more devices and complex control circuit. In the industrial sectors where inverter fed drives available less than 5% THD is not needed but in some special applications like medical and space industries the scientists and designers will least bother about cost and complexity since the perfection is highly needed. And the table also compares about different level shifted carrier PWM techniques which can be observed that PD and POD methods giving comparable



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results where as APOD inferior method is compared to others. There is another table.2 in this paper itself which compares similar things but for 3-phase inverter.

**B. THD analysis of 3-Φ MLI are given below**

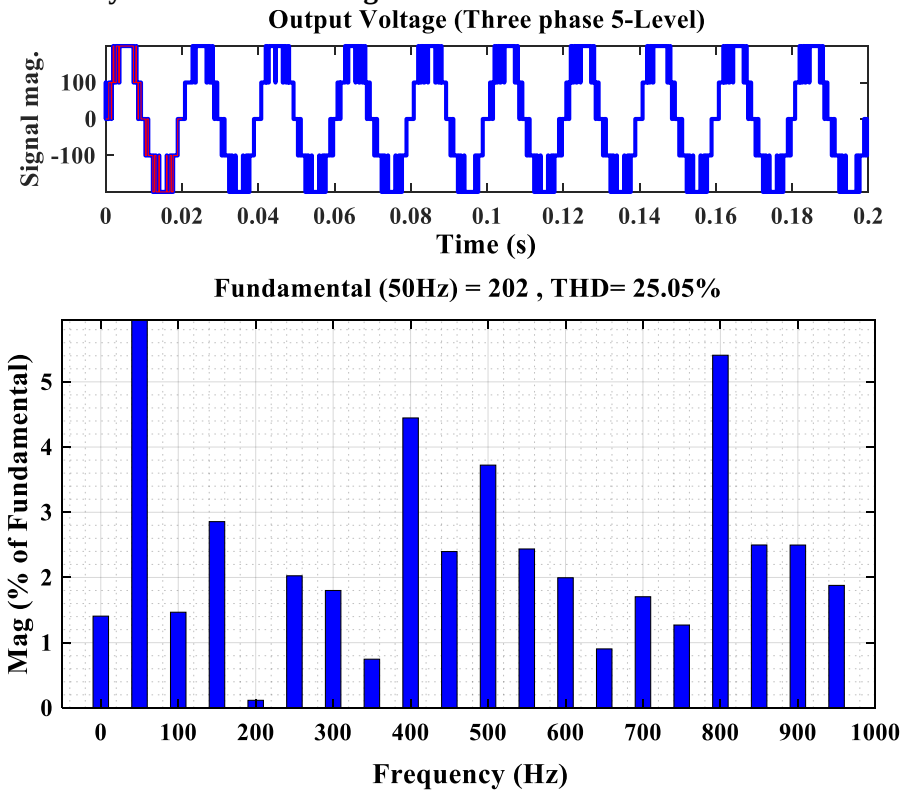
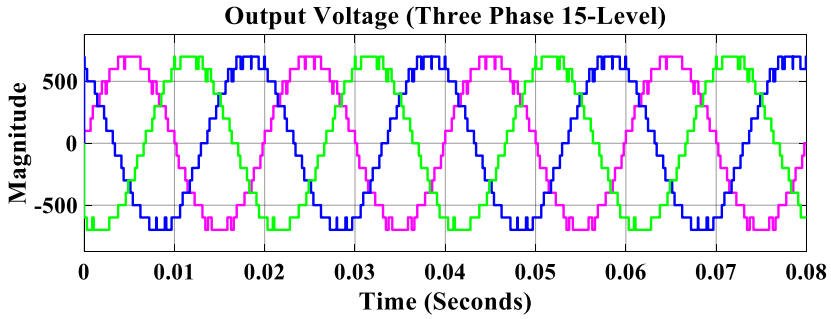



Fig. 9: Inverter Output voltage and FFT spectrum of 3-Φ 5 Level cascaded inverter



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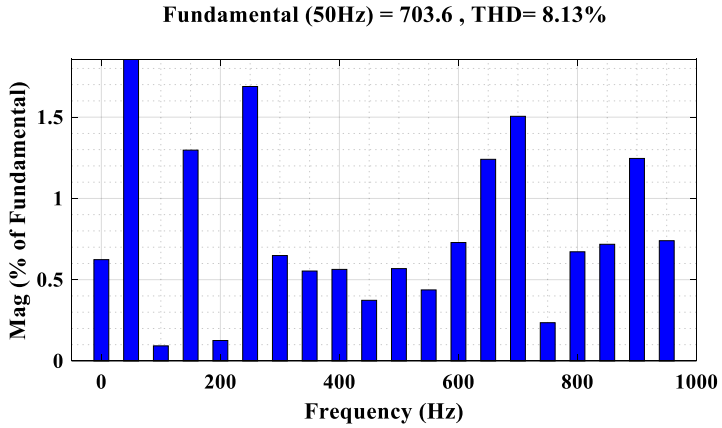


Fig. 10: Inverter Output voltage and FFT spectrum of 3-Φ 15 Level cascaded inverter

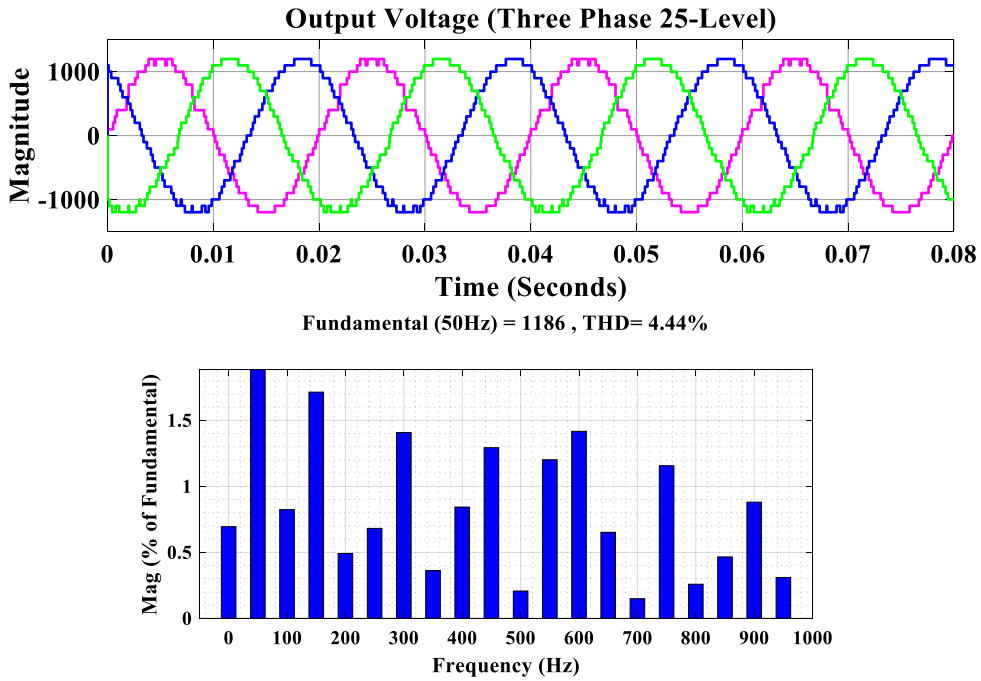


Fig. 11: Inverter Output voltage and FFT spectrum of 3-Φ 25 Level cascaded inverter

Table.2.Comparison of THD for 3-Φ MLI

| Three Phase MLI | THD % | | |
|---|---|---|---|
| | **5 Level** | **15 Level** | **25 Level** |
| Phase Disposition | **25.05%** | **8.13 %** | **4.44 %** |
| Phase Opposition Disposition | 26.69% | 9.47% | 6.89% |
| Alternate Phase opposition Disposition | 36.93% | 19.56% | 16.56% |

## VI. CONCLUSIONS

Multi level inverters are popular because of lower harmonics and device ratings; however control methods are difficult because more number of devices for higher levels, that is why different PWM methods are available, and in this paper multi carrier PWM technique are compared for cascaded H-bridge MLI. Different modulating techniques are discussed for the THD of the voltage of CMLI and found that the fewer amount of THD is observed for Phase Disposition (PD) technique.



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