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# Comparative Study of THD Characteristics in Different Cascaded H-Bridge Configurations for Multilevel Multicarrier Modulation

**[1]Balwinder Kumar, [2]Sikander Hans**

[1]Principal, Department of Electrical Engineering, KC Polytechnic, Pandoga, Una

[2]Principal, Department of Electrical Engineering, KC group of Research & professional institute, Pandoga, Una

[1]er.bkumar1985@gmail.com, [2]dr.sikanderhans@gmail.com

**Abstract:** This paper presents a comprehensive comparative study investigating the Total Harmonic Distortion (THD) characteristics of various Cascaded H-Bridge (CHB) configurations utilized in Multilevel Multicarrier Modulation (MMCM) systems. The research examines different CHB topologies, focusing on their impact on THD performance in MMCM applications. Through theoretical analysis and simulation, this study evaluates THD levels under varying operating conditions, including different modulation schemes and switching strategies. A discussion on main topologies of multilevel inverter namely H-bridge, NCP(neutral point clamped),NCP- H and flying capacitor is carried out utilizing carrier based PWM methods. Comparison is done on basis of harmonic component, THD and nu of component used by 3, 5 and7 level cascaded H-bridge topology respectively. To support the result a detailed study is carried out using MATLAB Simulink software.

***Keywords***- Multilevel inverter, PWM, THD, NCP, NCP-H.

## 1. INTRODUCTION

Over past decade, multilevel inverter (MLI) come as revolution in field of inverter technology [1,2], as their application to medium and high level voltage is remarkable(2-13kV) which includes ac drives [3],power distribution[4],PV application[5],electric vehicle[6]etc. Main advantages of MLI: (a) reduction of input voltage stress on component thereby reducing voltage rating of device (b) decrease in conduction time, (c) lower device switching frequency for same number of output voltage level ultimately reducing the THD. Apart of these advantages its disadvantage are (a) complex circuit, (b) problem of voltage balance, (c)high cost etc. This paper helps in understanding the output voltage characteristics of 3, 5 and 7 level cascaded H Bridge subjected to different carrier PWM techniques[7-8].

In this contest, significant contribution by research work contributed towards dual three- phase induction motor modeling, control aspect, and modulation techniques. But insignificant articles by research related to the power balancing with symmetrical and asymmetrical voltage and/or current contributions for six-phase asymmetrical induction motor, deliberating keeping stator winding open-end configuration[9]. In this dissertation devoted towards minimizing THD by increasing number of level for different modulation index is shown for multilevel ac motor drive system and keeping renewable energy in mind dc power is extracted from sun[10-11].

In view of later, to retrieve the demerits of classical inverters we should know about the multilevel technology and the merits it offer[12]. Multilevel inverters are a good alternative for power applications due to the fact that, they can achieve high power using mature medium-power semiconductor technology. Practically, multilevel inverters present great advantages compared with conventional and very well-known two-level converter. These advantages are fundamentally focused on improvements in the output signal quality (Voltage & Current) and a nominal power increase in the converter[13].

## 2. RELATED WORKS

***Some of the recent workings related to the research paper is described below,***

Recent research articles mostly addressing towards multiphase induction motors due to their redundant structure, and reliability with high fault tolerant capabilities. Increasing phase becomes more predominant factor to have additional degree of freedom[14]. On another hand multilevel inverter widely replaces the conventional two-level three-phase voltage source inverter (VSI) by their performance toward lower THD and lower *dv/dt* stresses in output. Combing multiphase motor with multilevel inverter technologies could be good solution for low-voltage high-current application more suitable for industries[15]. Several power conversion structures addressing towards multiphase-multilevel ac motors are proposed last decades for its reliability and performance. In this thesis work proposes a comparative study of THD of 3,5,7 level of cascaded H-bridge has been performed, in particular vital optimum solution for multiphase machines with respect to cost and performances[16].

Proposed a set of techniques for improving the output waveform quality from an Isolated H-Bridge Multi-Level power converter by the introduction of unequal H-Bridge Cell voltages and the use of a high performance PWM H-Bridge cell[17]. The waveform quality improvements are quantified in terms of frequency weighted THD for a series of six circuit configurations[18].

Presented a Reduced Switching-Frequency-Modulation Algorithm for High-Power Multilevel Inverters as Multilevel inverters which are mainly controlled with high-frequency pulse width-modulation is not suitable for very high-power application due to significant switching losses[19]. So they presented an adaptive duty-cycle modulation algorithm that reduces the switching frequency to a minimum necessary to fulfill the dynamic requirements of the system. This is achieved by using the slope of the voltage reference to adapt the modulation period to ensure that only one-step change between two voltage levels[20].

Gave a technology review of voltage-source-converter topologies for industrial medium-voltage drives[21]. In this paper they cover the high-power voltage-source inverter and the most used multilevel-inverter topologies, including the neutral-point clamped, cascaded H-bridge, and flying-capacitor converters and the operating principle of each topology and review of the most relevant modulation methods, which focused mainly on those used by industry. In addition, the latest advances and future trends of the technology were discussed[22]. Their paper concluded that the topology and modulation-method selection are closely related to each particular application, leaving a space on the market for all the different solutions, depending on their unique features and limitations like power or voltage level, dynamic performance, reliability, costs, and other technical specifications[23].

## 3. VARIOUS CARRIER BASED PWM TECHNIQUES

### A. Phase Shift Modulation

In general, a MLI with m-level need(m-1) triangular carriers[25]. All the triangular carriers have the same frequency and same peak to peak amplitude in phase shifted multicarrier modulation but the carriers have a phase shift as follows

$Øcr = 360°/(m – 1)$

The modulating signal is usually 3-phase sinusoidal wave with adjustable amplitude and frequency. By comparing carrier waves with modulating wave gate signals are generated

-for 3 level

$Øcr = 360°/(m–1)$

$= 360°/(3–1)$ $= 360°/2$

$= 180^0$

-for 5 level

$Øcr = 360°/(m–1)$

$= 360°/(5–1)$ $= 360°/4$

$= 90^0$

The inverter phase voltage is given as

$vAN = vH1 + vH2 + vH3$

### B. Level Shifted

It requires (m-1) carriers for m level inverter which are vertically disposed[26]. Amplitude modulation index is defined as

$ma = Vm / Vcr(m – 1)$ for $0 <= ma <= 1$

Where

$Vm$ is the peak amplitude of the modulating wave

$Vcr$ is the peak amplitude of each carrier wave.

Three scheme for level shifted are

(A) Phase disposition (PD), this scheme employs all carriers in phase.

(B) Phase opposite disposition (POD), this scheme employs carrier above and below zero point with phase shift of 180.

(C) Alternate phase opposite disposition (APOD), this scheme employs carrier phase shifted by 180 from its adjacent carrier[27].

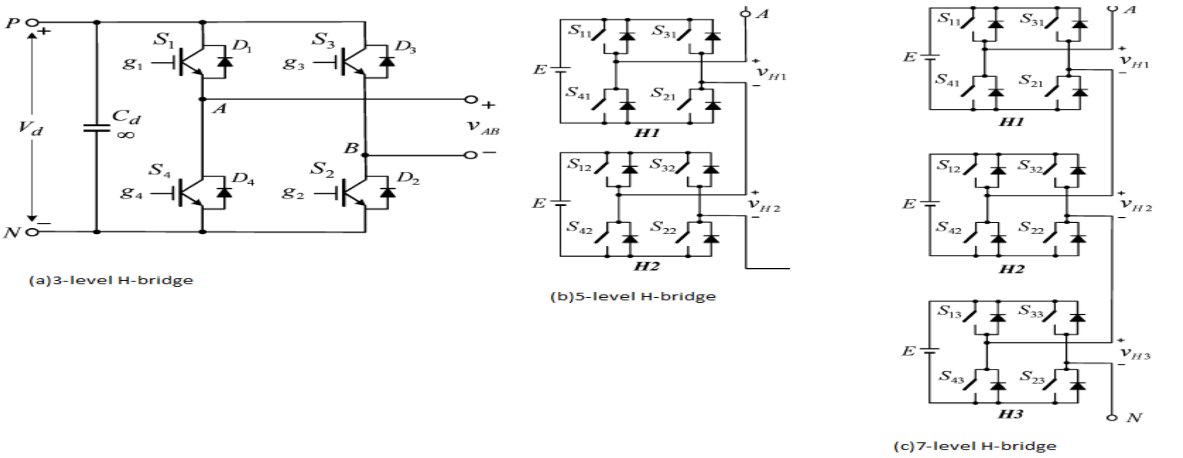


Figure1. 3,5,7-Level H-bridge inverter

## 4. MODELING AND SIMULATION RESULTS

To verify the performance of the proposed cascaded inverter, an induction motor drive is studied[28]. The proposed inverter generates the switching sequence by comparing main reference sine wave with triangular carrier wave thus generating signals for IGBTs as discussed in earlier chapter. The MATLAB simulink is used is used to simulate 3, 5 and7- level inverters induction motor drives[29].

### 4.1 Simulation of Three-Level Cascade Inverter Induction Motor Drive

A three level h bridge employs 4 IGBT and two triangular wave are compared with one sine wave to generate 2 IGBT signals (and their complementary) i.e. 4 gate signals[30].

(A) Taking upper triangular wave, If sine signal is greater than triangular wave magnitude output is given to upper IGBT and its complementary is given to lower IGBT in the same leg[31].
(B) Taking lower triangular wave, If sine signal is greater than triangular wave magnitude output is given to lower IGBT and its complementary is given to upper IGBT in the same leg[32].
Thus, 4 IGBT are gated with 4 suitable signals.

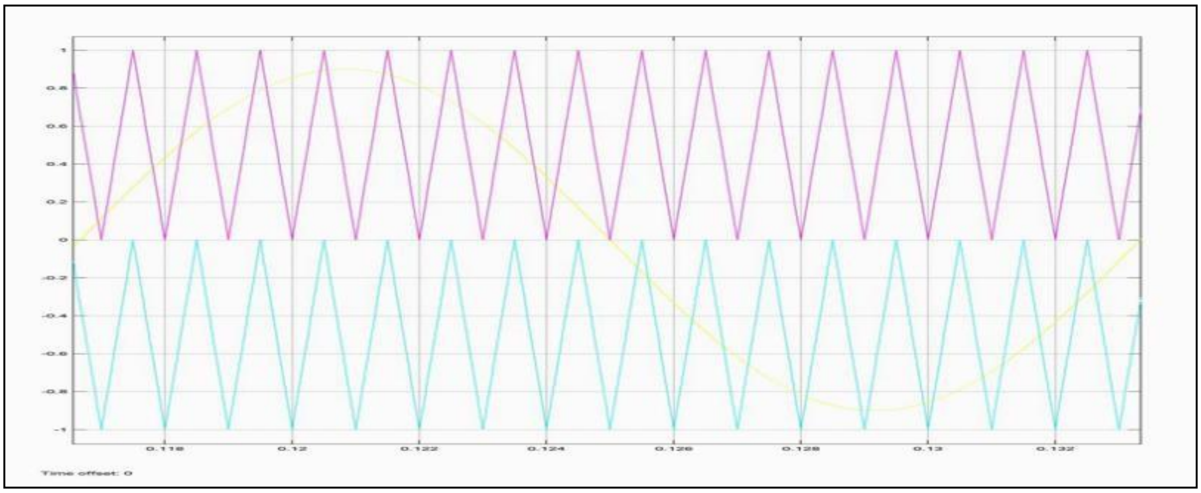

**Fig.2** Carrier-Modulation Signals of 3-Level Inverter

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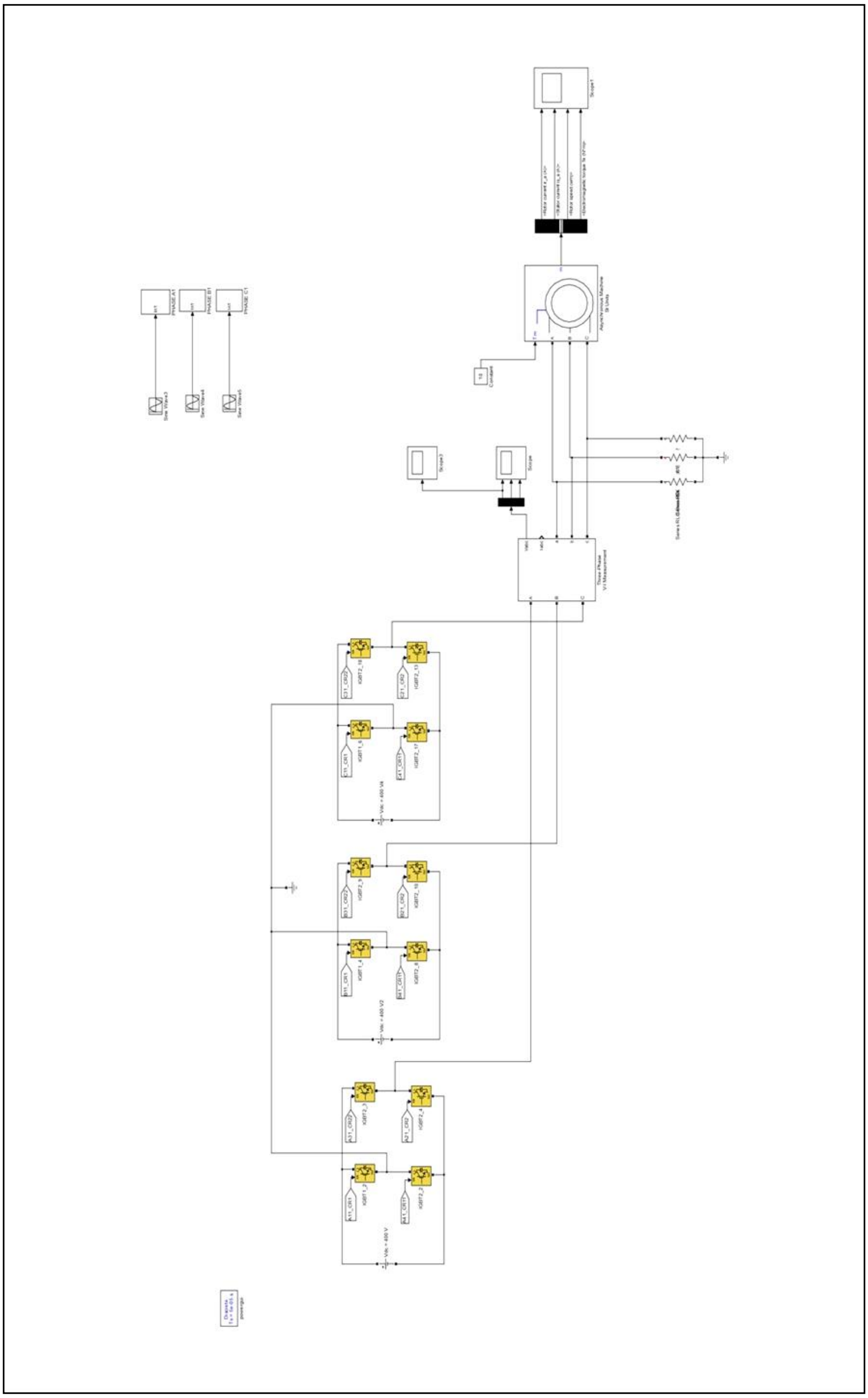

**Fig.3** Three-Level Cascaded Inverter

### 4.1.1. Simulation Results

Figs. 4-6 shows the line voltage, switching scheme of phase A, Waveforms of rotor current, stator current, rotor speed and electromagnetic torque & THD (pd, pod, apod) of a 3-level inverter[33]. Table 1 represents THD at different modulation indices. In steady state, a small-speed ripple is introduced due to the harmonics of the output voltage, specifically the fifth and seventh harmonics. Similarly the torque shown in contents some ripples because of harmonics[34]. The THD for modulation index 1 for PD (phase disposition) scheme is 66.57% and for different values of modulation index (PD and POD) it is tabulated in table 1.

**Fig.4** Line Voltage Waveform for 3 Level

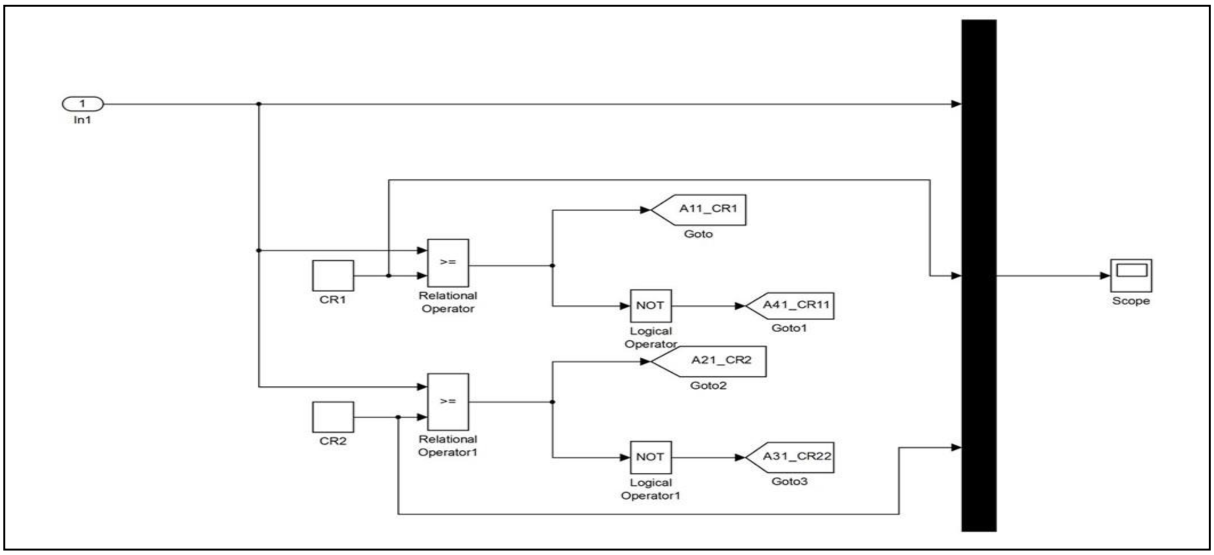


**Fig.5** Switching Scheme of Phase A for 3 Level

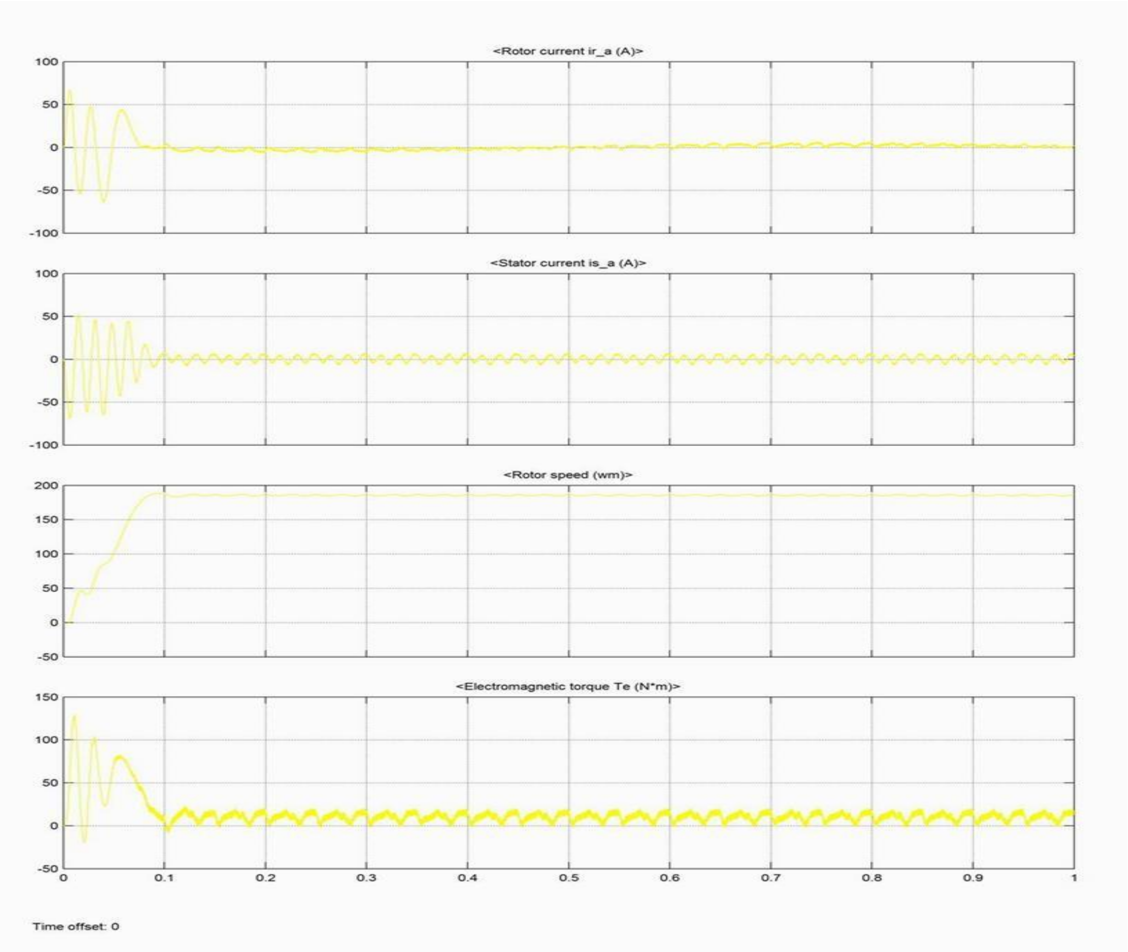


Fig.6 Waveforms of Rotor Current, Stator Current, Rotor Speed and ElectromagneticTorque for 3 Level

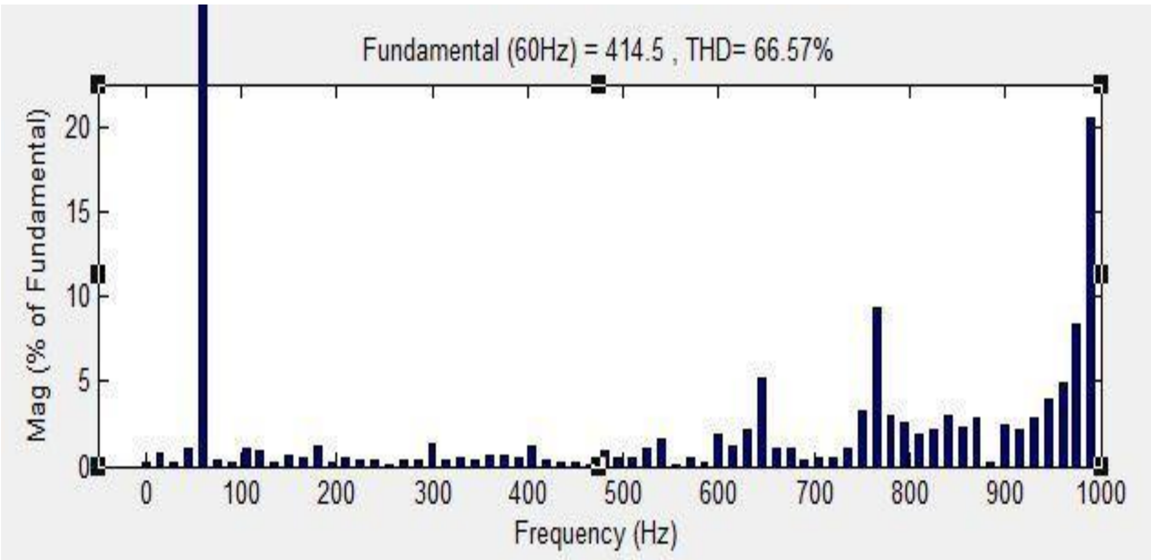


Fig.7 THD of 3 Level with PD

**Table 1:** THD for Different Values of Modulation Index (PD and POD) For 3 level

| MODULATION INDEX | PD(PHASE DISPOSITION) | POD(PHASE OPPOSITE DISPOSITION) |
|---|---|---|
| 0.9 | 66.57 | 65.97 |
| 0.85 | 70.03 | 69.56 |
| 0.8 | 79.65 | 78.84 |

### 4.2 Simulation of Five-Level Cascade Inverter Induction Motor Drive

Five level inverter is modeled in the same way as the three level inverter. The difference here is the number of carrier signals. Here we are taking four carrier signals. Two of them are applied across the positive half cycle of the modulating signal, remaining two of them are applied across the negative half cycle of the modulating signal[35]. From these signals eight PWM signals are generated and then given to the eight switches of a leg. Similarly the pulses are generated for remaining phases. Figure 9 shows the model of a 5-level cascaded inverter. Figure 8 shows the carrier modulation signals of a five-level cascaded H bridge inverter.

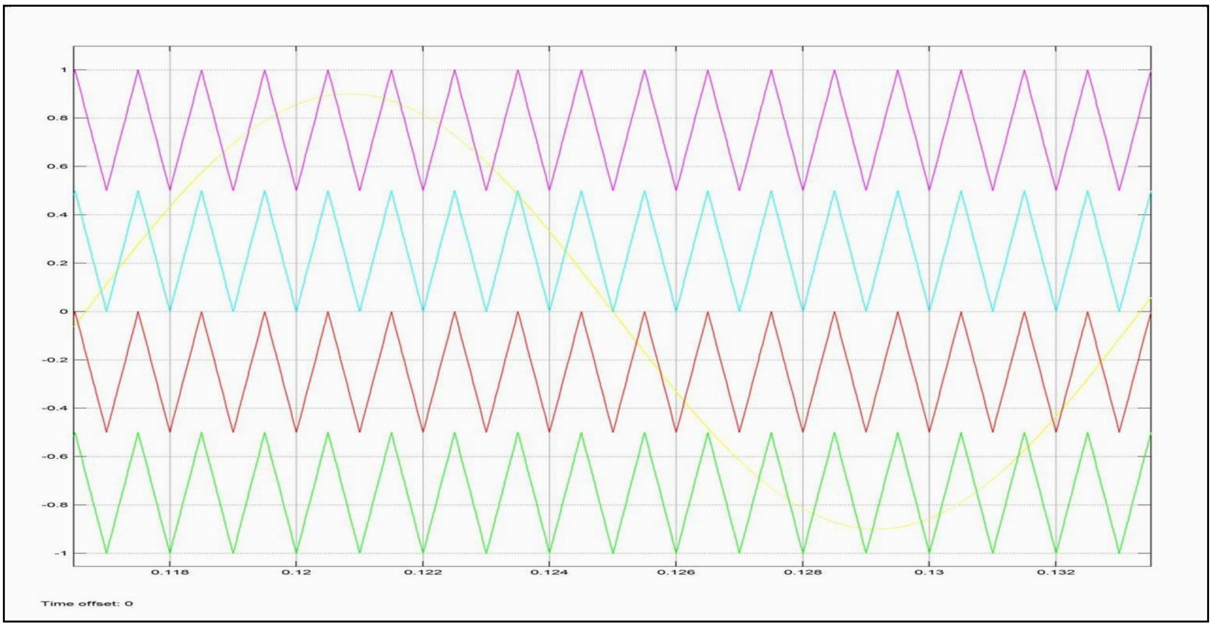


**Fig.8** Shows the Carrier Modulation Signal of a 5-Level Cascaded Inverter

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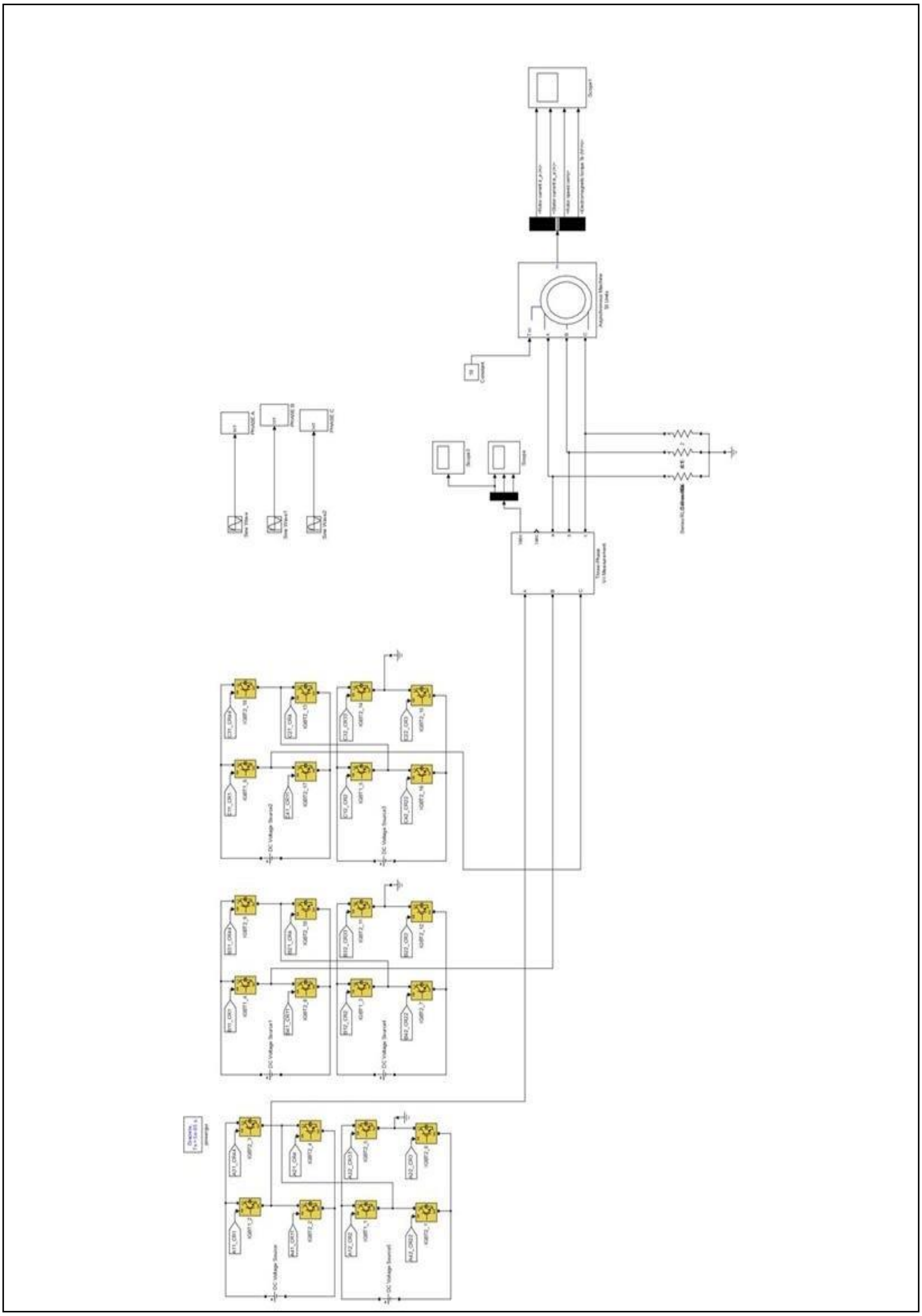

**Fig. 9** Shows the Model of a 5-Level Cascaded Inverter

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### 4.2. 1. Simulation Results

Figs. 10-12 shows the line voltage, switching scheme of phase A, Waveforms of rotor current, stator current, rotor speed and electromagnetic torque & THD (pd, pod , apod) of a 3-level inverter. Table 2 represents THD at different modulation indices. In steady state, a small-speed ripple is introduced due to the harmonics of the output voltage, specifically the fifth and seventh harmonics.By comparing the three level inverter and the five level inverter we can say that the distortion in five level inverter voltage is less. The current waveforms are closed to sinusoidal. The speed and torque ripples are very less as compared to three level inverter. Dynamic response is also better for fivelevel inverter, which can be observed from the speed and torque waveforms. The THD for modulation index 1 for PD (phase disposition) scheme is 33.78% and for different values of modulation index (PD, POD and APOD) it is tabulated in table 2.

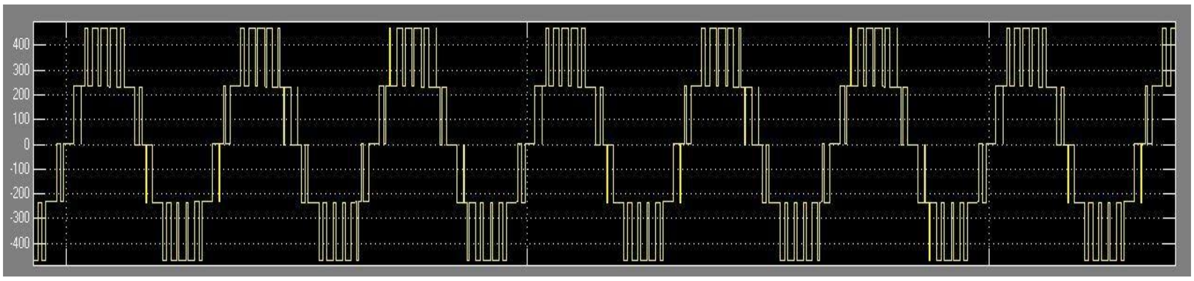



**Fig.10** Line Voltage Waveform for 5 Level

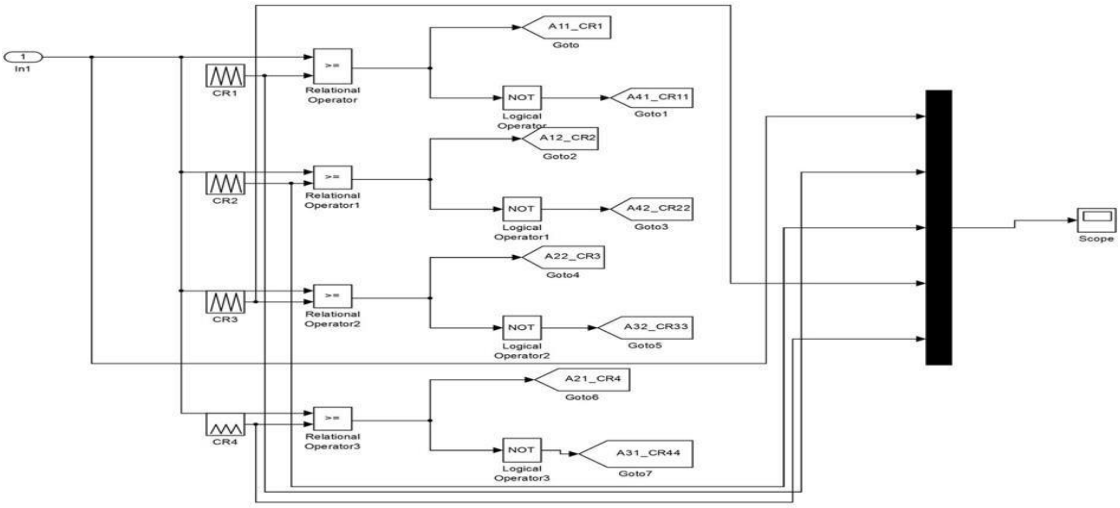



**Fig.11** Switching Scheme of Phase A for 5 Level

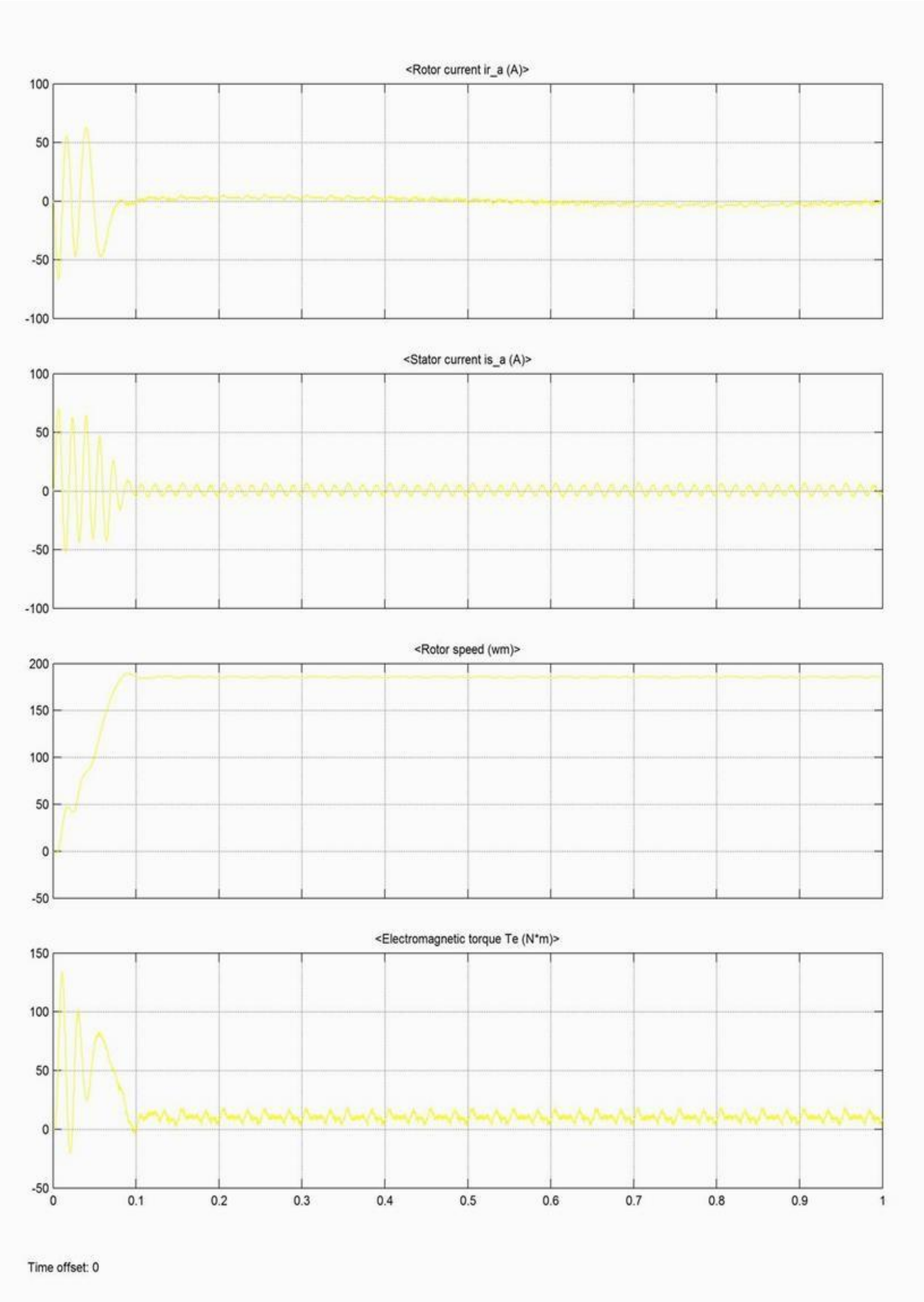



**Fig.12** Waveforms of Rotor Current, Stator Current, Rotor Speed and ElectromagneticTorque **f**or 5 Level

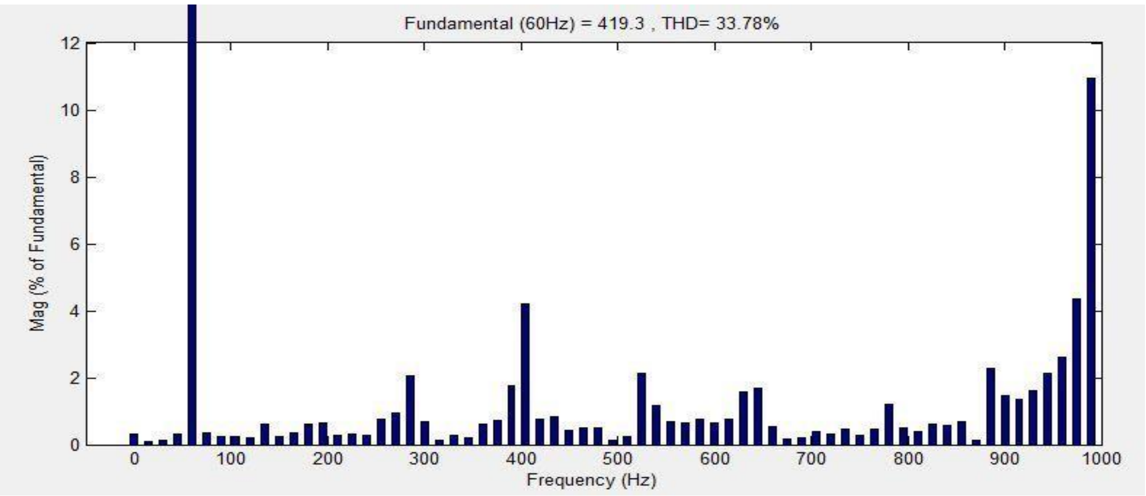



Fig.13 THD of 5 Level With PD

**Table 2:** THD for Different Values of Modulation Index (PD, POD and APOD) for 5Level

| MODULATION INDEX | PD(PHASE DISPOSITION) | POD(PHASE OPPOSITE DISPOSITION) | APOD(ALTERNATE PHASE OPPOSITE DISPOSITION) |
|---|---|---|---|
| 0.9 | 33.78 | 33.71 | 33.56 |
| 0.85 | 36.71 | 36.61 | 36.56 |
| 0.8 | 38.67 | 38.65 | 38.55 |

### 4.3 PV panel

As the energy demand is increasing and fossil fuel are coming to an end more emphasis is given to the use of renewable energy which leads us to integrate such power and cascaded H bridge is capable of from distributed renewable sources such as solar panels, bio mass, wind stations and can be added with main grid, battery, fuel cell etc. So a prototype that dc voltage can also be harnessed from Matlab solar panel is shown in figure 14.

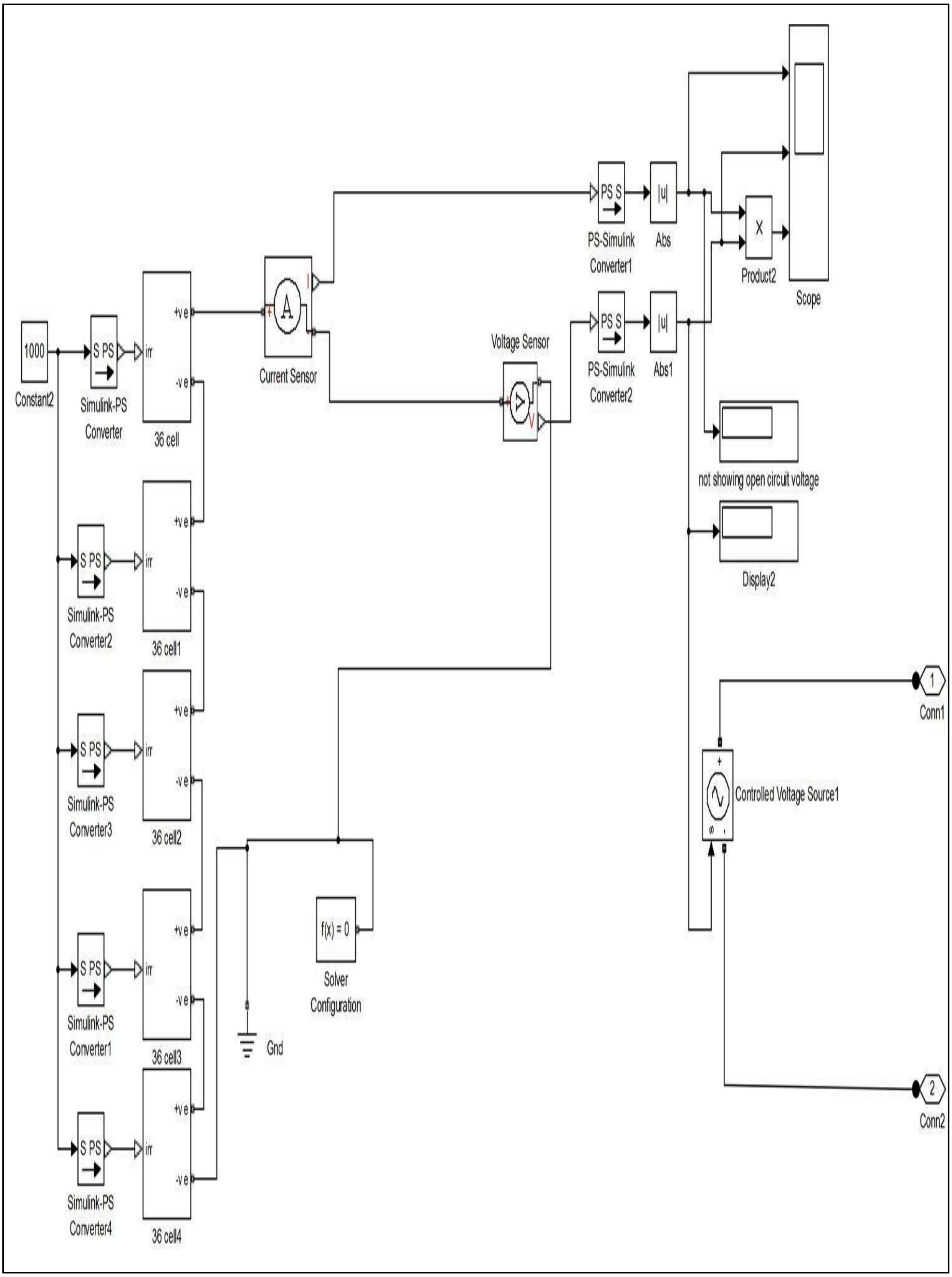
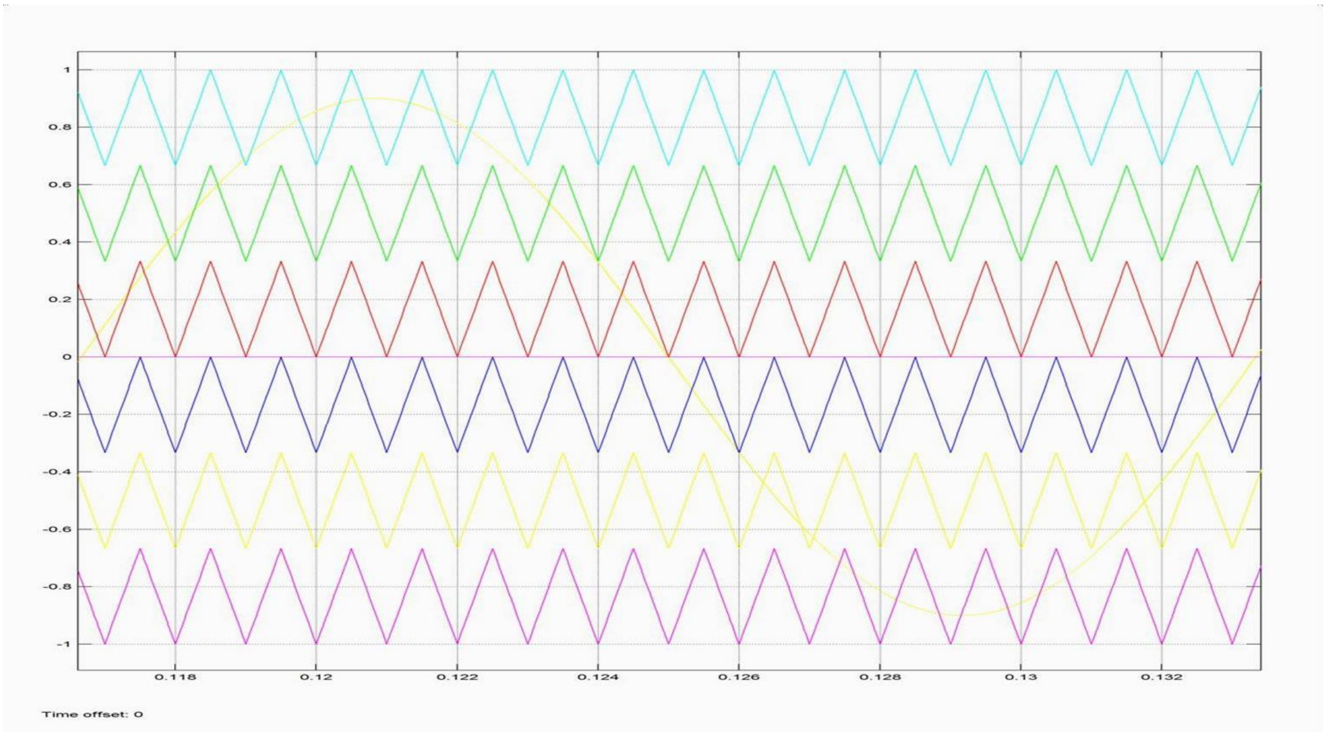



**Fig.14** PV Panel

### 4.4 Simulation of Seven Level Cascade Inverter Induction Motor Drive

Seven level inverter is modeled similar to that of the three-level and five-level inverter. The difference here is also the number of carrier signals. Here we are taking six carrier signals. Three of them are applied across the positive half cycle of the modulating signal. Remaining three of them are applied across the negative half cycle of the modulating signal. From these signals twelve PWM signals are generated and then given to the eight switches of a leg. Similarly the pulses are generated for next two phases. Fig 16 shows the model of a 7-level cascaded inverter. Fig.15 shows the carrier modulation signal of a seven-level cascaded inverter.

**Fig.15** Shows the Carrier Modulation Signal of a 7-Level Cascaded Inverter



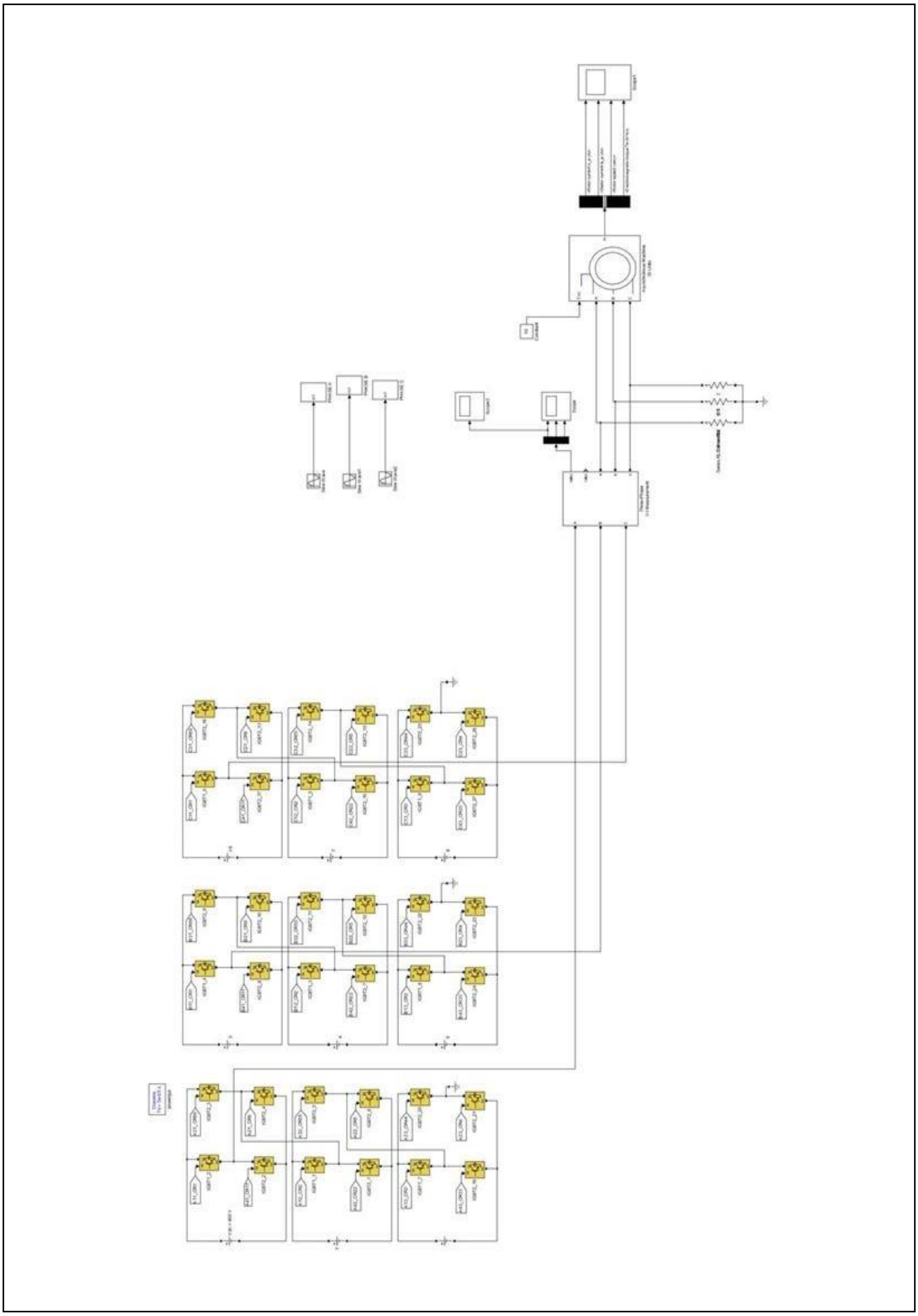


**Fig.16** Shows the Model of 7-Level Cascaded Inverter

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#### 4.4.1 Simulation Results

Figs. 17-19 shows the line voltage, switching scheme of phase A, Waveforms of rotor current, stator current, rotor speed and electromagnetic torque & THD(pd, pod , apod) of a 3-level inverter. Table 3 represents THD at different modulation indices by comparing the three, five level inverter and the seven level inverter we can say that the distortion in seven level inverter voltage is very much less. The current waveforms are closed to sinusoidal. Dynamic response is also better for seven level inverter, which can be observed from the speed and torque waveforms. The THD for modulation index 1 for PD (phase disposition) scheme is 23.23% and for different values of modulation index(PD, POD and APOD) it is tabulated in table 3.

**Fig.17** Line Voltage Waveform For 7 Level

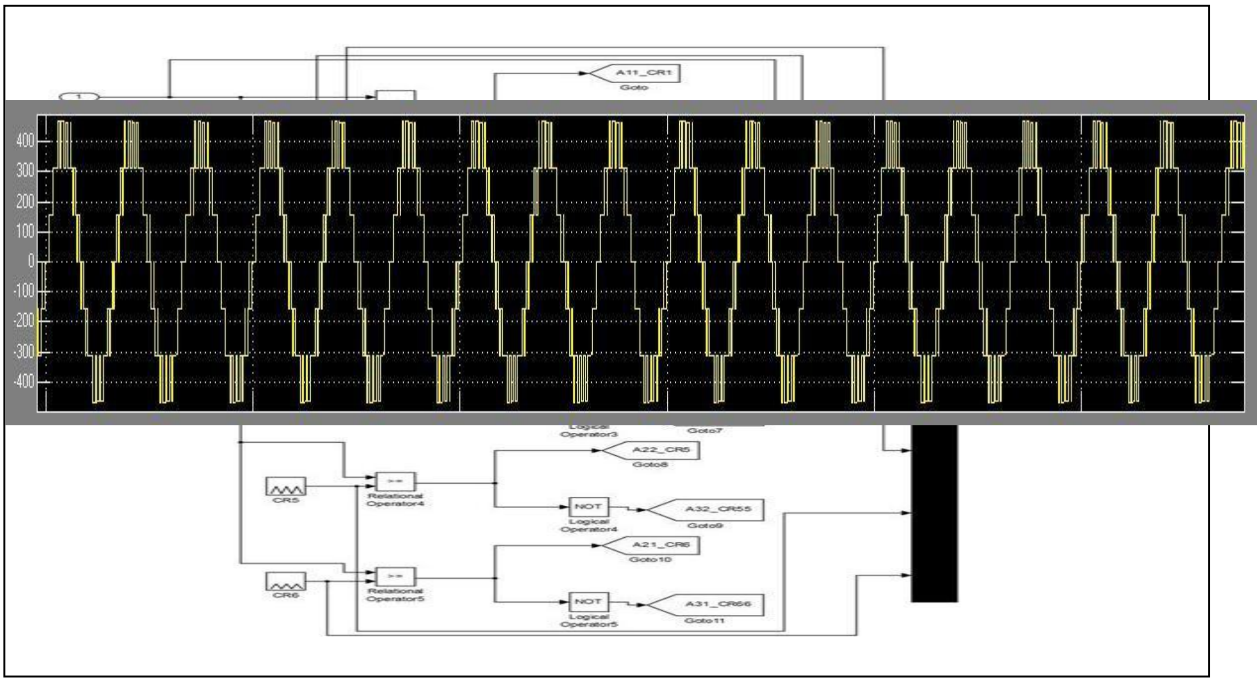


**Fig. 18** Switching scheme of phase A for 7 level

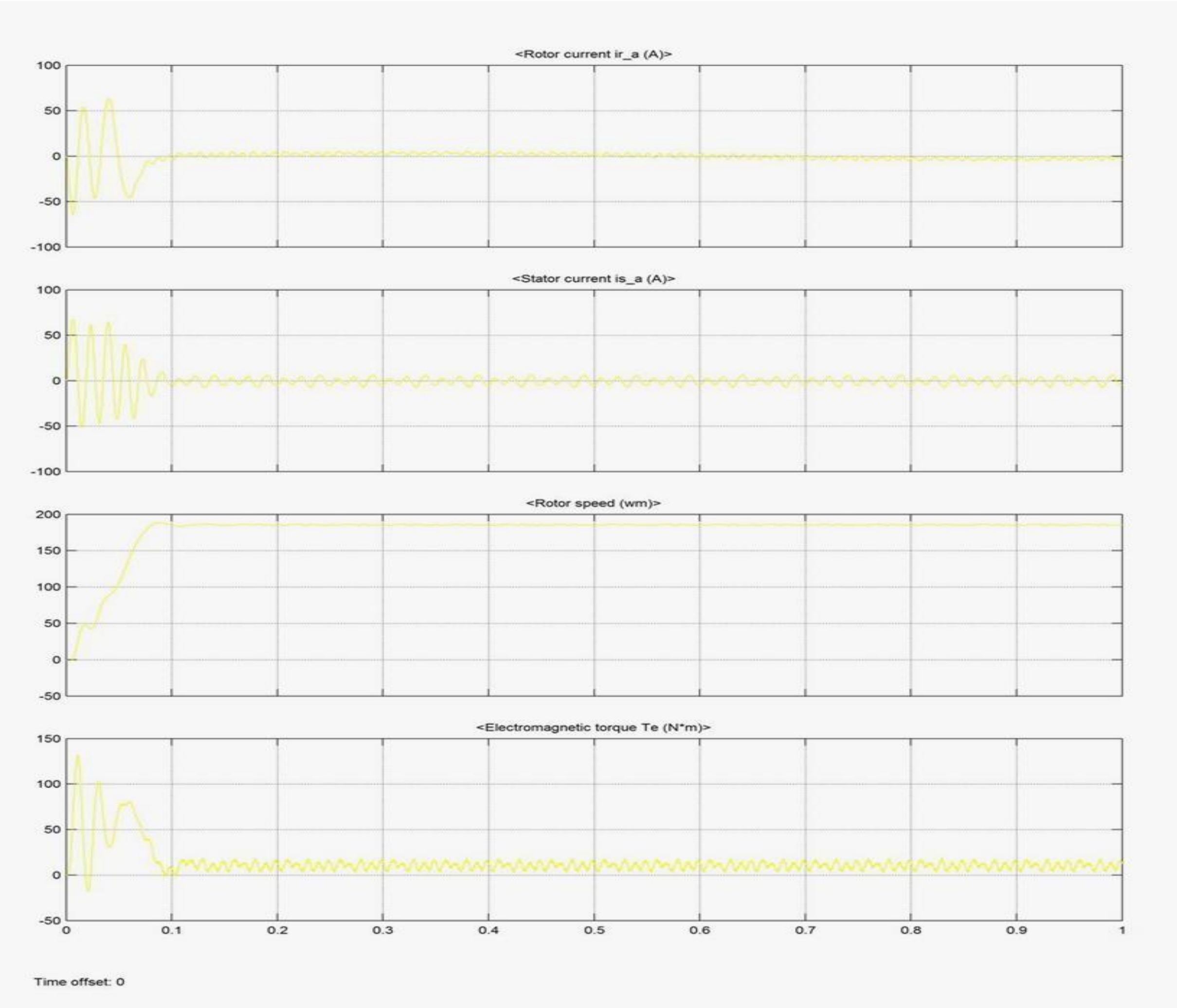


**Fig.19** Waveforms of Rotor Current, Stator Current, Rotor Speed and ElectromagneticTorque for 7 Level

**Fig.20** THD of 7 Level with PD

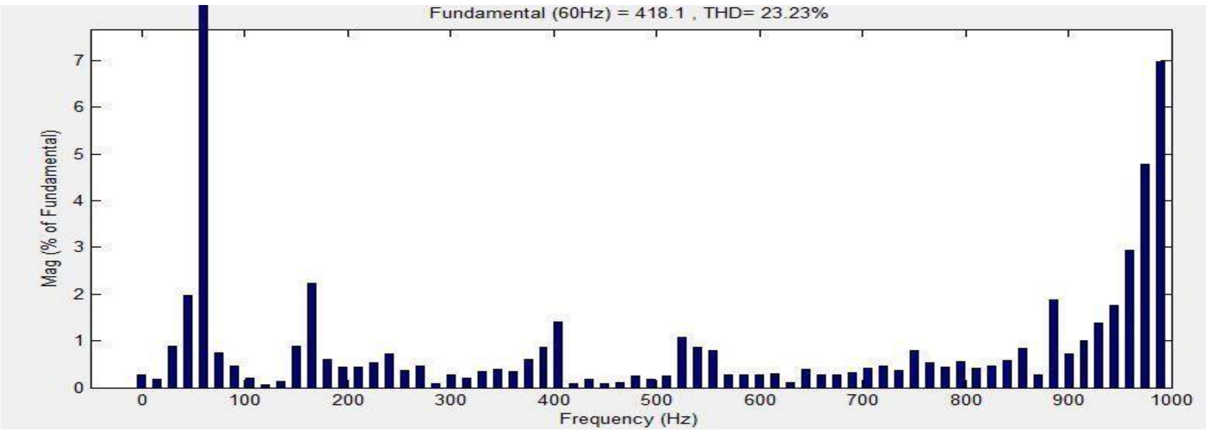


**Table 3:** THD For Different Values of Modulation Index (PD, POD and APOD) for 7Level

| MODULATION INDEX | PD(PHASE DISPOSITION) | POD(PHASE OPPOSITE DISPOSITION) | APOD(ALTERNATE PHASE OPPOSITE DISPOSITION) |
|---|---|---|---|
| 0.9 | 23.23 | 22.83 | 23.18 |
| 0.85 | 24.04 | 23.82 | 23.61 |
| 0.8 | 24.57 | 24.22 | 24.04 |

## 5. CONCLUSION

This paper discuss about performance characteristics of various cascaded H Bridge utilizing various PWM input (PD, POD, APOD). Comparison of THD level components is also tabulated which shows by increasing number of level THD reduced to a great extent and it also show that it is minimum for 7 Level using POD PWM scheme. This work was supported in part by a grant from the National Science Foundation. In conclusion, this comparative study has provided valuable insights into the Total Harmonic Distortion (THD) characteristics of various Cascaded H-Bridge (CHB) configurations in Multilevel Multicarrier Modulation (MMCM) systems. Through rigorous analysis and simulation, it was observed that the choice of CHB topology significantly influences THD performance under different operating conditions. The findings underscore the importance of careful selection and optimization of CHB designs for MMCM applications to minimize THD and enhance overall system efficiency. Future research could explore additional factors affecting THD, such as component tolerances and control strategies, to further refine CHB configurations for improved MMCM performance.

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