

Comparative Analysis of Flying Capacitor and Diode Clamped Multilevel Inverters Using SPWM

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Abstract

Multilevel inverters are considered as an alternative in the field of high power, medium voltage and power quality applications due to their minimum harmonic distortion, reduced dv/dt stresses, reduced EMI and EMC issues etc. This paper presents the analysis and comparison of three level Diode Clamped or Neutral Point Clamped (NPC) and Flying Capacitor (FC) or Capacitor Clamped multilevel inverter topologies. For the topologies mentioned above the simulations were carried out for resistive load. The PWM used here is Sinusoidal Pulse Width Modulation (SPWM) and the multicarrier modulation used here is Phase shifted PWM. By comparing the THDs the advantages of Flying Capacitor Multilevel inverter over the Diode Clamped Multilevel inverter is confirmed. The simulations are performed using MATLAB/SIMULINK software and the results are presented.

Keywords: Flying Capacitor(FC), Multilevel inverters (MLI), Phase Shifted PWM, SPWM, THD, Neutral Point Clamped (NPC).

1. Introduction

Inverter is a device which converts DC power to AC power at desired voltage and frequency level. They are mainly classified into:

- Voltage source
- Current source inverters.

The voltage source inverters are again classified into: (a) Single level inverters, (b) Multilevel inverters

On the basis of single and multiple DC sources the multilevel inverters are broadly classified into [1]-[3]:

- Diode clamped or Neutral clamped
- Flying capacitor or Capacitor clamped
- Cascaded multilevel inverters.

The main function of multilevel inverters is to synthesize a desired voltages from several levels of DC voltages [5]. The multilevel inverters draw input with low distortion. They can operate with lower switching frequency with

lesser harmonics and reduced dv/dt stresses. In the multilevel inverters a sine wave can be approximated to a stepped waveform having larger number of steps so that the harmonic distortion reduces. That is as the number of levels increases the harmonic reduces. They can operate at both fundamental and high switching frequency PWM. The advantages of multilevel inverters over the conventional two level inverters are:

- Reduction in switching losses.
- Staircase waveform quality.
- Can draw input current with low distortion.
- Low THD in output voltage.
- Generate smaller common mode voltages

The various applications of multilevel inverters are in industrial medium voltage motor drives, traction drive systems, FACTS, utility interface for renewable energy systems etc. Among the various multilevel inverter topologies mentioned above this paper presents the analysis and comparison of the Diode Clamped and Flying Capacitor multilevel inverters. The research and analysis of the other topologies namely Cascaded multilevel inverter, Modular Multilevel Converter is going on.

The multicarrier PWM technique used in the Flying capacitor and Diode Clamped multilevel inverters mentioned here is the Phase Shifted PWM. In this technique all the (m-1) carriers are having the same peak to peak voltage and same frequency but the phase shift will vary depending upon the number of levels and the corresponding pulses are fed to the switching devices required. The phase shift may vary according to the level of the inverter. Let ϕ_s be the phase shift and is given by:

$$\phi_s = \frac{360}{m-1} \dots \dots \dots (1)$$

where m is the level of inverter. Since the topologies mentioned here are three level the phase shift between the

carriers are 180° apart. Fig.1 shows the phase shifted PWM for three level inverter.

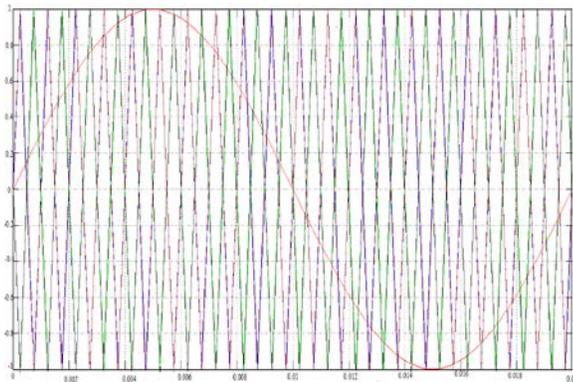


Fig.1 Phase shifted PWM for three level inverter

2.Review of Diode Clamped and Flying Capacitor Multilevel Inverters

2.1 Diode Clamped Multilevel Inverter

The topology of three phase three level diode clamped multilevel inverter is shown in Fig.2. The diode clamped converter is composed of two traditional two level voltage source converters stacked one over the other with some modifications [4]. The three level converter consists of twelve switches, four switches per phase. Considering A phase the switches Sa1 and Sa3 are complementary and the switches Sa2 and Sa4 are complementary. And for B phase the complementary pairs are Sb1, Sb3 and Sb2, Sb4. And for C phase the complementary pairs are Sc1, Sc3 and Sc2, Sc4. For an m level (m-1) capacitors, 2(m-1) switches and parallel diodes and (m-1)(m-2) clamping diodes are required. Considering

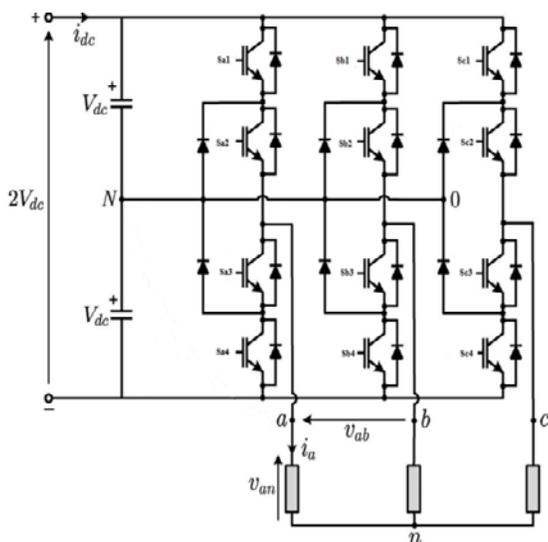


Fig.2 Three level diode clamped multilevel inverter

A phase for obtaining positive voltage the upper switches Sa1 and Sa2 are ON, for obtaining negative voltage the lower switches Sa3 and Sa4 are ON and for obtaining zero level the middle switches Sa2 and Sa3 are operated.

For the PWM the reference voltages V_a , V_b and V_c are displaced at 120° apart.

$$V_a = V_m \sin(\omega t) \dots \dots \dots (2)$$

$$V_b = V_m \sin\left(\omega t - \frac{2\pi}{3}\right) \dots \dots \dots (3)$$

$$V_c = V_m \sin\left(\omega t + \frac{2\pi}{3}\right) \dots \dots \dots (4)$$

The triangular wave is used as the carrier wave. The reference signal is having a frequency of 50Hz and the carrier signal is having a frequency of 10KHz. Both the signals have the same amplitude of 1V. The switching pulses is in such a way that in each phase the first and the third switches are complementary and the second and the fourth switches are complementary. The carriers for the first and second switches are 180° out of phase and the third and fourth switches are having a phase shift of 180°.

The advantages of diode clamped multilevel converters are [5]:

- Reactive power flow can be controlled
- Efficiency is high because all the devices are switched at fundamental frequency.
- As the number of levels is high the distortion level is low and the use of filters is unnecessary.

2.2 Flying Capacitor Multilevel Inverter

The topology of three phase three level flying capacitor multilevel inverter is shown in Fig.3 [8]. It is also called as Capacitor Clamped or Imprecated cell inverter. It is similar to that of diode clamped multilevel inverter. The

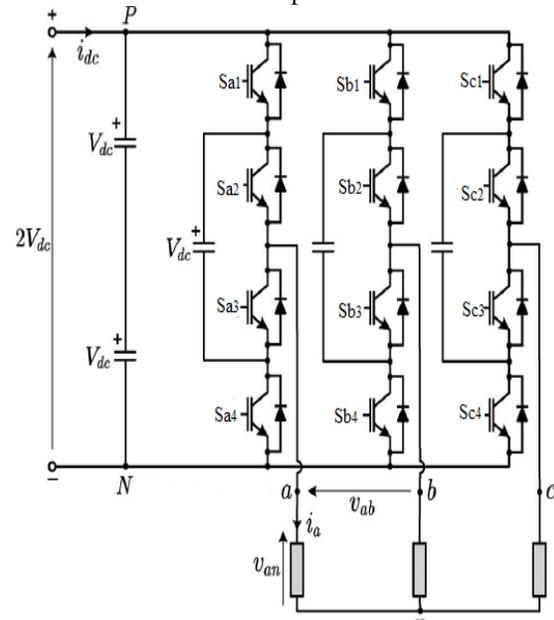


Fig.3 Three level Flying capacitor multilevel inverter

only difference is that here the clamping diodes are replaced by flying capacitors. The flying capacitor is also called as imprecated cell inverter. The flying capacitor is so called because the capacitors float with respect to earth's potential. In flying capacitor multilevel inverters the switching combination or states which produce the same phase voltage level will be referred to as a redundant

switching state. This topology consists of twelve switches. Each leg consists of four switches that is (m-1) switches where m is the number of levels. Considering A phase the switches Sa₁ and Sa₄ are complementary, and the other complementary pairs are Sa₂ and Sa₃. For m levels 2(m-1) switches (m-1) dc bus capacitance and (m-1)(m-2)/2 balancing capacitors per phase are required. Considering A phase for obtaining a positive voltage switches Sa₁ and Sa₂ are ON and for negative voltages switches Sa₃ and Sa₄ are ON. As compared to the Diode clamped multilevel inverter here an extra switching state is possible, that is the zero level can be obtained in two ways. Either switches Sa₁ and Sa₃ are operated or switches Sa₂ and Sa₄ are operated.

The PWM used here is Sinusoidal PWM. Let Va, Vb and Vc be the three phase reference voltages which are displaced at 120° apart.

$$V_a = V_m \sin(\omega t) \dots \dots \dots (2)$$

$$V_b = V_m \sin(\omega t - \frac{2\pi}{3}) \dots \dots \dots (3)$$

$$V_c = V_m \sin(\omega t + \frac{2\pi}{3}) \dots \dots \dots (4)$$

The frequency of carrier is 10 kHz. The carriers for the first and second switches, second and fourth switches are 180° out of phase. Figure 2 shows the three level flying capacitor multilevel inverter. The switching pulses are in such a way that the complementary pairs are switches (Sa₁, Sa₄) and (Sa₂, Sa₃).

The advantages of Flying Capacitor multilevel inverters are:

- For a high m level the use of filters is unnecessary.
- Use of active and reactive power flow is possible.
- It eliminates the clamping diode problems present in the diode clamped multilevel topologies
- It limits the dv/dt stresses across the devices.

3. Results and Discussion

The comparison of three level flying capacitor and diode clamped multilevel inverters are conducted for resistive loads using MATLAB/SIMULINK. Here the sinusoidal pulse width modulation (SPWM) with switching frequency of 10 KHz is used as the basic modulation for

both the inverters and the multi carrier PWM used here is the Phase Shifted PWM. The input to both the inverters are 800V.

3.1 Diode Clamped Multilevel Inverter

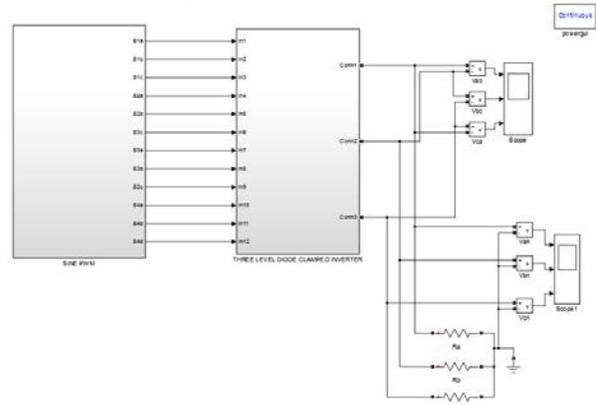


Fig.4. Diode clamped multilevel inverter Simulink model

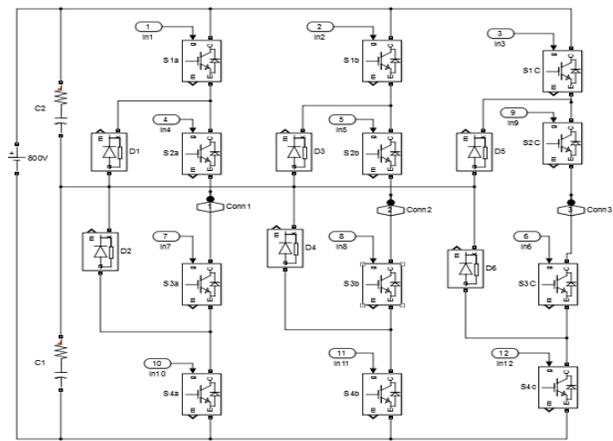


Fig.5. Schematic of Three level Diode clamped MLI

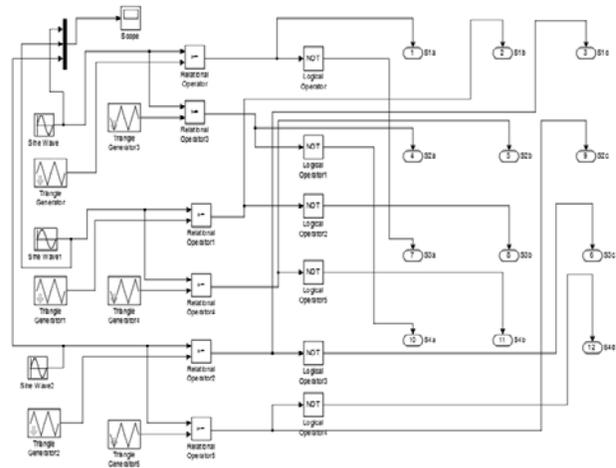


Fig 6.Sinusoidal PWM

Fig.4 shows the simulation circuit of Diode clamped multilevel inverter for resistive load. Fig.5 shows the schematic of three level diode clamped multilevel inverter. Fig.6 shows the sinusoidal PWM.Fig.7 and Fig.8 shows the PWM input and output for A phase respectively.Fig.9 and Fig.10 shows the line and phase voltages respectively.

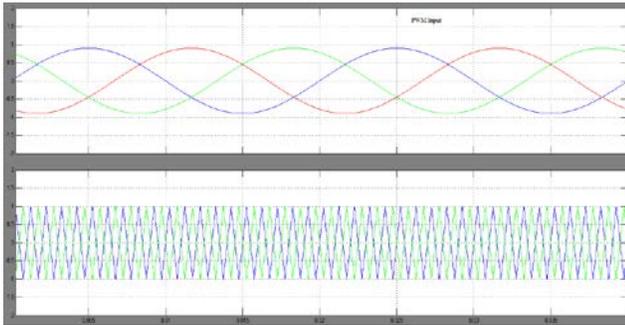


Fig.7 PWM inputs

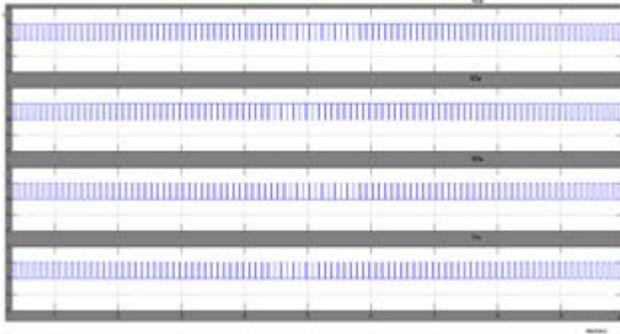


Fig.8 PWM output signal for A phase

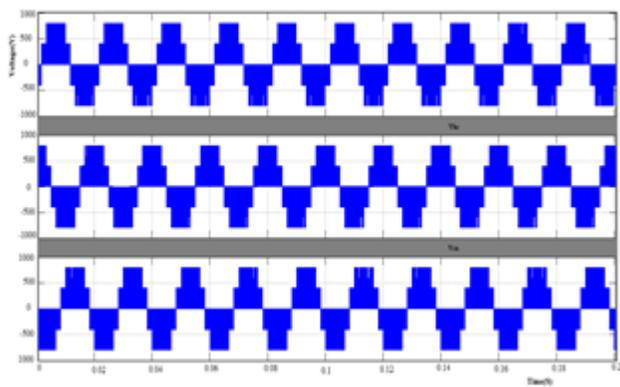


Fig 9. Line voltage

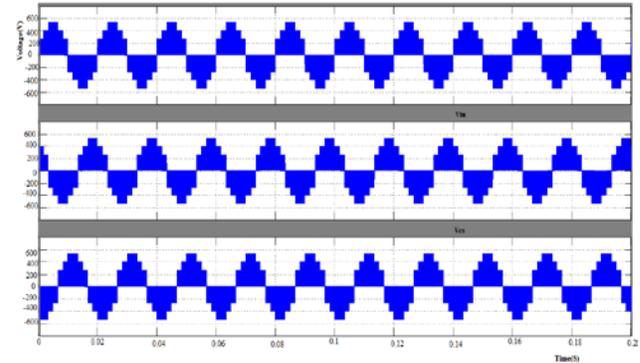


Fig 10.Phase voltage

Fig.11 shows the line voltage THD and Fig.12 shows the phase voltage THD of three level diode clamped multilevel inverter.

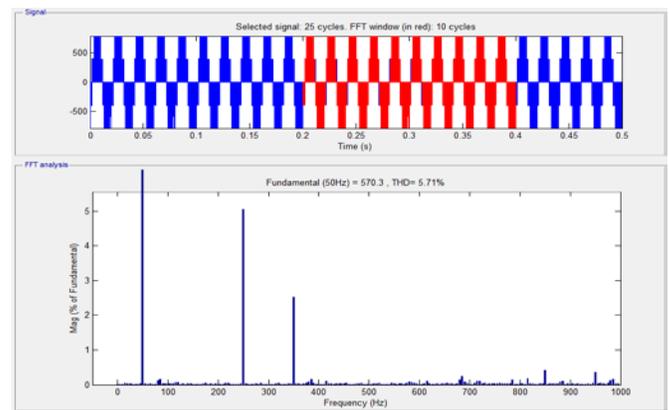


Fig.11.Inverter Line voltage THD

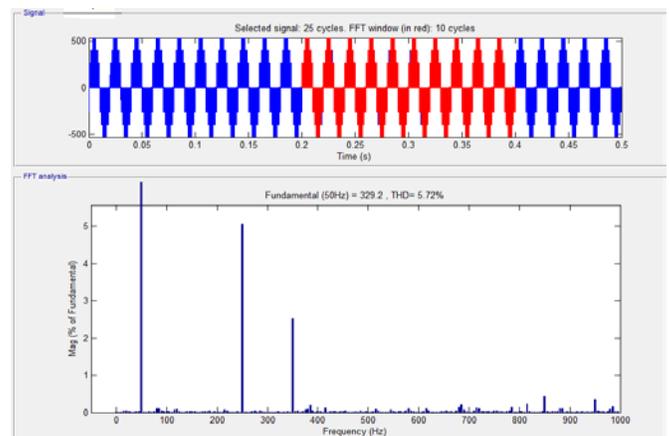


Fig.12.Inverter Phase voltage THD

3.2 Flying Capacitor Multilevel Inverter.

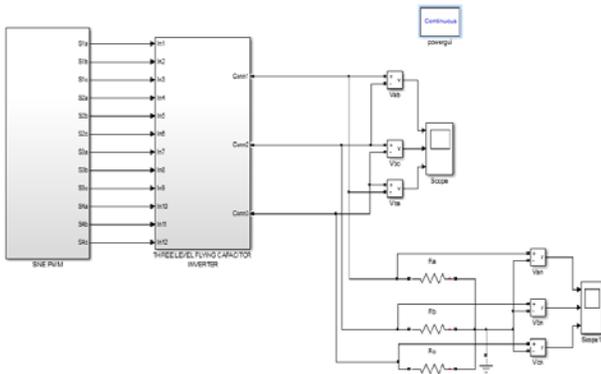


Fig.13 Simulation circuit of flying capacitor multilevel inverter

Fig.13 shows the simulation circuit of flying capacitor multilevel inverter. Fig.14 shows the simulink model of three level flying capacitor multilevel inverter. Fig.15 shows the Sinusoidal PWM. Fig.16 shows the PWM input and switching

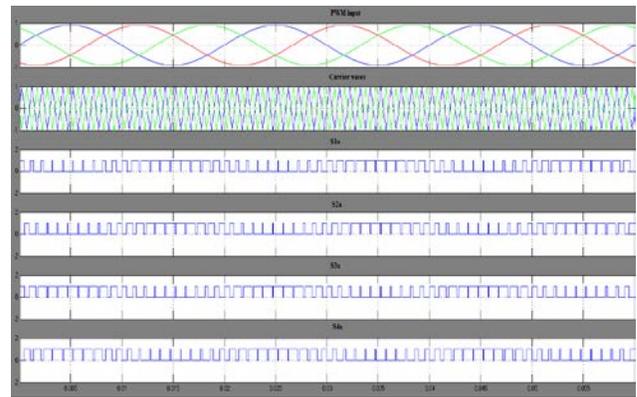


Fig.16 PWM input and switching pulses for A phase. Fig.17 and Fig.18 shows the line and phase voltages respectively. Fig.19 shows the line voltage THD and Fig.20 shows the phase voltage THD of three level Flying capacitor multilevel inverter.

Table 1 shows the comparison of THD values of Diode Clamped and Flying capacitor multilevel inverter topologies and from the table given above it is clear that

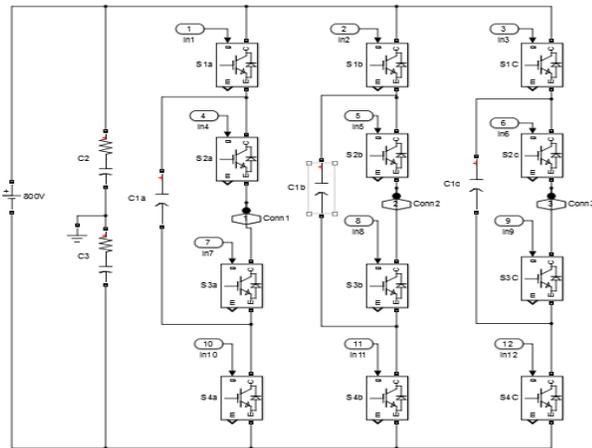


Fig.14 Simulink model of three level flying capacitor multilevel inverter

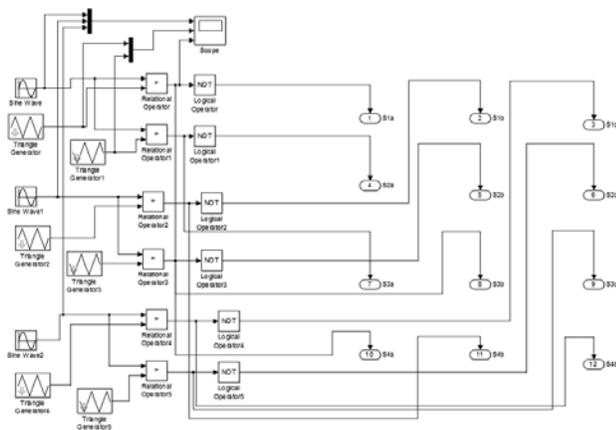


Fig.15 Sinusoidal PWM

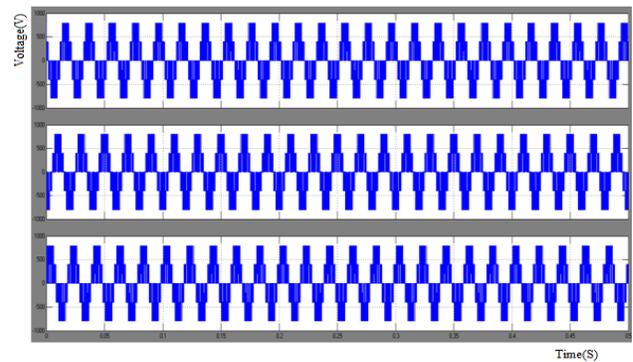


Fig. 17 Line voltage

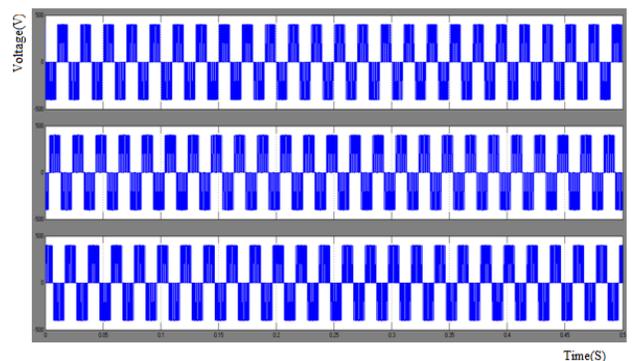


Fig.18 Phase voltage

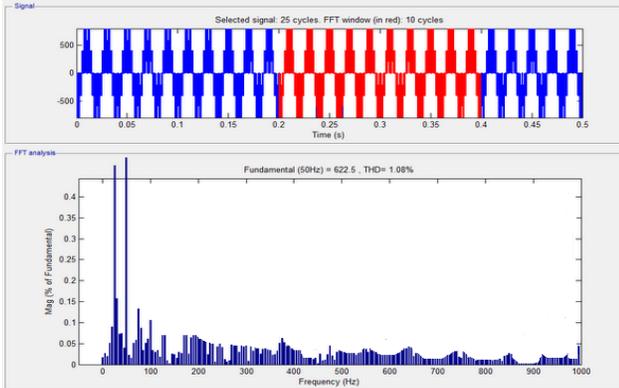


Fig.19 Line voltage THD

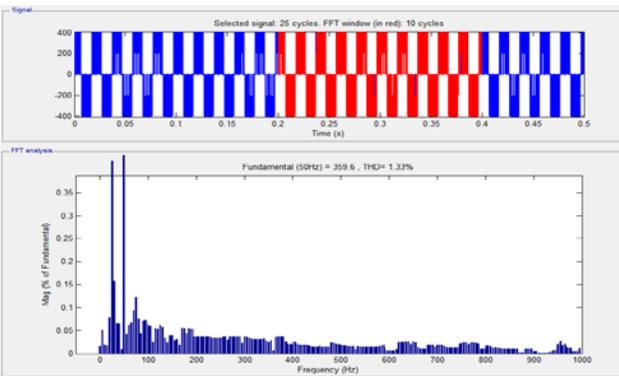


Fig.20 Phase voltage THD

Table 1: Comparison of voltage THD for various multilevel converter topologies

Sl No.	Topology	Voltage THD(%)	
		Line voltage	Phase voltage
1	Three level Diode Clamped Multilevel inverter	5.71	5.72
2	Three level Flying capacitor Multilevel inverter	1.08	1.33

the Total Harmonic Distortion decreases when moving from Diode Clamped to Flying capacitor multilevel inverter.

4. Conclusions

The simulation of three level Diode Clamped and Flying capacitor multilevel inverters was carried out using Sinusoidal PWM. It also explains the multi carrier phase shifted pulse width modulation. The performance of the

inverters was analysed using MATLAB/SIMULINK. From the above results obtained the advantages of the over the Flying capacitor multilevel inverter is confirmed

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Biographies

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