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# Harmonic Analysis of Three level Flying Capacitor Inverter

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**Abstract –***The aim of this paper is to determine the Total harmonic distortion (THD) of three phase three level flying capacitor inverter fed star connected R-L load. The modulation Techniques used is Phase Disposition Sinusoidal pulse width modulation (PD-SPWM) and Phase Opposition Disposition Sinusoidal pulse width modulation (POD-SPWM).The Modulation index is varied to analyze its effect on Current THD and Voltage THD.This paper also presents the comparison of PD-SPWM and POD-SPWM controlled Flying capacitor Inverter in terms of THD. The simulation result shows that PD-SPWM has better performance when compared to POD-SPWM. The simulation of circuit is done by using MATLAB/Simulink.*

***Key Words*: *PD-SPWM, POD-PWM, THD, Modulation Index.***

## 1. INTRODUCTION

### 1.1 Multilevel Inverters

Multilevel inverters have drawn tremendous interest in power industry owing to their advantages such as higher efficiency, lower common mode voltage, lower voltage stress on power switches, lower dv/dt ratio, no EMI problems & its suitability for high voltage and high current applications [1].There are three types of multilevel inverters. They are Diode clamped or Neutral clamped, Flying capacitor or Capacitor clamped &. Cascaded H bridge multilevel inverters [2]-[3].During the 1980s the development of the Multilevel Converters did not move much forward. Only after ten years, at the turn of the decade, finally appeared articles about new applications, e.g. nuclear fusion, and new control methods. The next turning point came at the beginning of the 1990s when Meynard and Foch (1992) presented the flying capacitor converter as a multilevel chopper and a multilevel inverter.

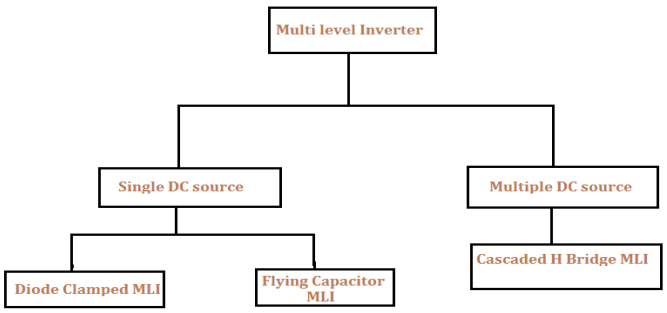


**Fig-1.1.1:** Classification of Multilevel Inverter

The FCMLI is considered For THD analysis in this paper because it is easier to increase number of levels in this inverter than the diode clamped multilevel inverters. The advantage of FCMLI is that it can control both real and reactive power flow.

### 1.2 Multilevel Inverter PWM Strategies

PWM control strategies are development to reduce the Total Harmonic Distortion [4].PWM strategies used in conventional inverters can be modified to use in MLI.The advent of multilevel inverter PWM modulation methodologies can be classified according to switching frequency as shown in figure 1.2.1

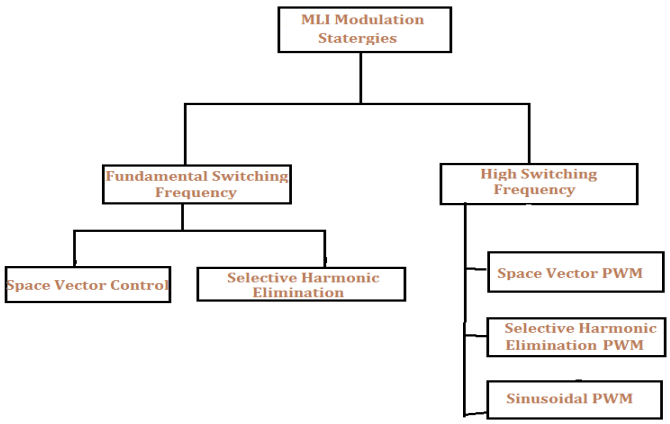


**Fig-1.2.1:** Classification of Multilevel Inverter PWM Strategies

There are several Multi carrier based High frequency techniques such as i) Phase disposition PWM (PDPWM) ii) Phase Opposition Disposition PWM (PODPWM) iii) Alternate Phase Opposition Disposition PWM (APODPWM) iv) Phase Shift PWM (PSPWM) v) Alternate Phase Shift PWM (APSPWM) vi) Carrier Over Lap PWM (COPWM) vii) Variable Frequency PWM (VFPWM) viii) Alternate Variable Frequency PWM (AVFPWM).In multilevel Inverters modulation index is defined as follows

$$M.I = \frac{A_m}{(m-1)A_c}$$

In this Paper, PD and POD SPWM strategies are considered for triggering switches of three level flying capacitor inverter.

## 2. FLYING CAPACITOR MULTI LEVEL INVERTER

The three phase three level flying capacitor inverter is shown in Fig.2.1. This inverter is called so because the capacitor's floats with respect to earth potential. Flying capacitor Multi level inverter is also known as Capacitor clamped MLI.For m level flying capacitor inverter consists of 2(m-1) switches, (m-1) main capacitors and (m-1)*(m-2)/2 auxiliary capacitors are required in each phase leg. Thus a three level flying capacitor inverter consists of four switches, two main capacitors & one auxiliary capacitor in each leg.

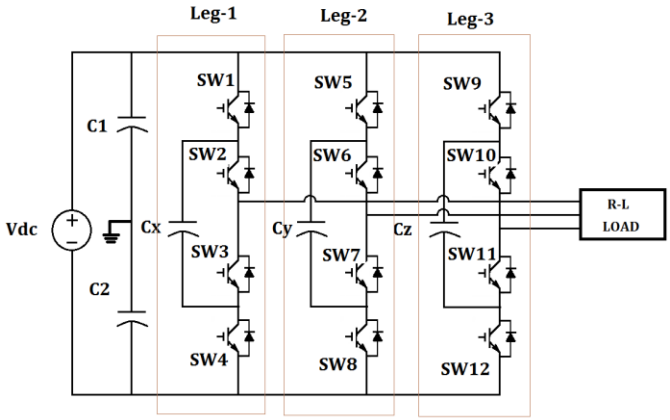


**Fig-2.1:** Three phase three level flying capacitor inverter

The possible switching states are four in 3 level FCMLI. When the switches SW1, SW2 are ON and SW3, SW4 are OFF the output voltage is positive. When switches SW3, SW4 are ON and SW1, SW2 are OFF the output voltage is negative. Zero level can be obtained in two ways that is either SW1, SW3 are ON or SW2, SW4 are ON.

**Table -2.1**: Switching states and Output voltage of leg1 of three level flying capacitor inverter

| Switching state | S1 | S2 | S3 | S4 | Vout |
|---|---|---|---|---|---|
| **1** | 0 | 0 | 1 | 1 | **-Vdc/2** |
| **2** | 1 | 0 | 1 | 0 | **0** |
| **3** | 0 | 1 | 0 | 1 | **0** |
| **4** | 1 | 1 | 0 | 0 | **+Vdc/2** |

## 3. PD-SPWM & POD-SPWM CONTROL TECHNIQUES

### 3.1.Phase disposition sinusoidal pulse width modulation

In SPWM technique , sinusoidal reference wave is compared with triangular carrier waveform to generate pulses to switches of inverter. This traditional SPWM technique is applied to multilevel inverter by using multiple carriers. For m level inverter (m-1) carriers are required. Phase disposition SPWM has carriers in same phase above and below zero reference line. All the carrier signals are of same frequency and same amplitude in PD-SPWM. It is most widely used method as it provides low harmonic distortion in load voltage and current.

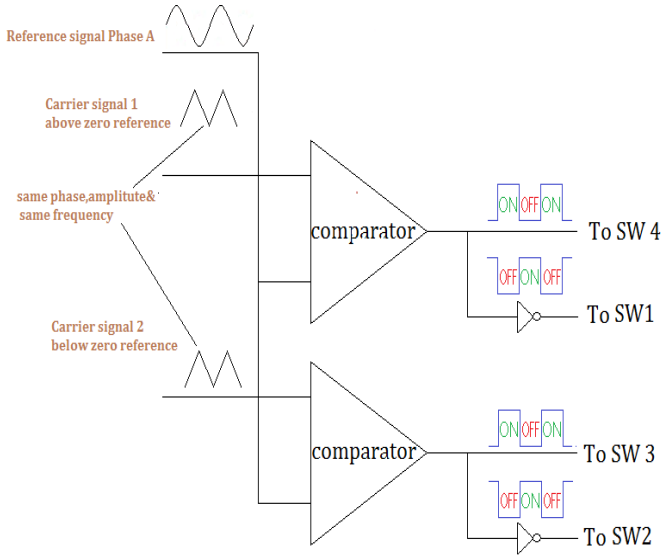


**Fig-3.1.1:** Phase disposition sinusoidal pulse width modulation (for leg-1)

### 3.2. Phase opposition disposition sinusoidal pulse width modulation

In this POD-SPWM strategy, the carrier signals above zero reference are in same phase and carrier signals below zero reference are also in same phase, but are 180° phase shifted from those above zero.

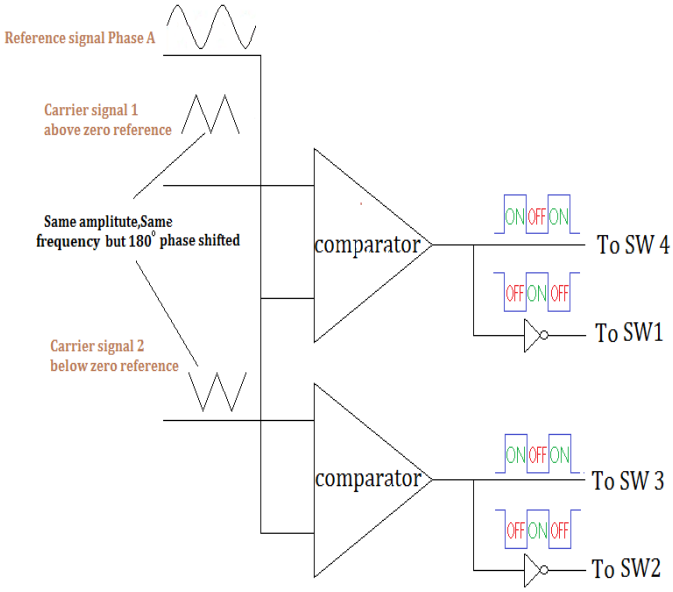


**Fig-3.2.1:** Phase Opposition disposition sinusoidal pulse width modulation (for leg-1)

## 4. SIMULATION & THD ANALYSIS OF PD-SPWM & POD-SPWM CONTROLLED THREE PHASE THREE LEVEL FLYING CAPACITOR INVERTER

A Three phase three level flying capacitor inverter using PD-SPWM & POD-SPWM Controlled Strategies is simulated in MATLAB Simulink.

MATLAB Simulation parameters are

1. Carrier Frequency=1000 Hz
2. System Frequency=50 Hz
3. Load resistance(R) =10 Ohm
4. Load Inductance (L) =50e-3 Henry
5. Input D.C voltage=440V
6. Modulating index (M.I) =0.6 to 1

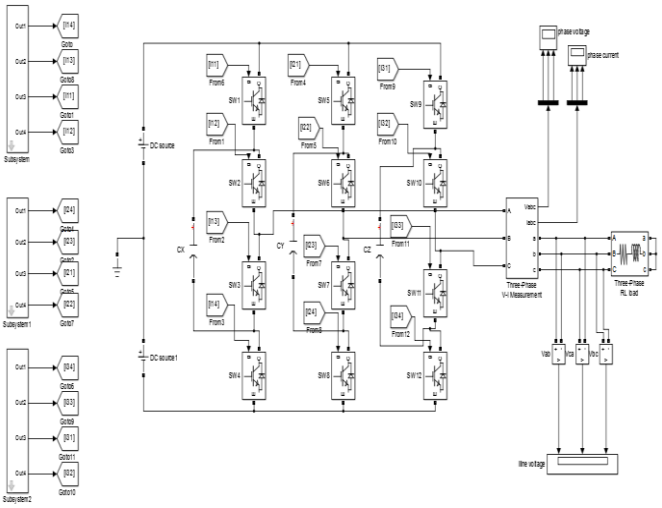

**Fig-4.1:** Simulink model for PWM based Three phase three level flying capacitor Inverter

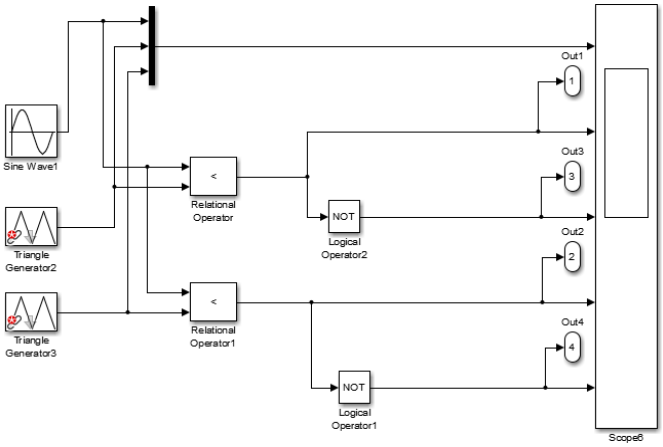


**Fig-4.2:** Simulink model for PD-SPWM switching signal generation (Phase A)

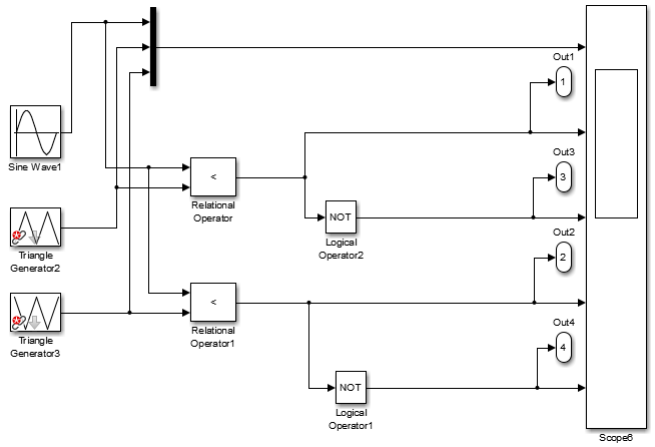


**Fig-4.3:** Simulink model for POD-SPWM switching signal generation (Phase A)

Fig 4.4 shows carrier signal, reference signal comparisons for PD-SPWM and Fig 4.5 shows pulses generated by PD-SPWM strategy for triggering switches of flying capacitor inverter circuit.

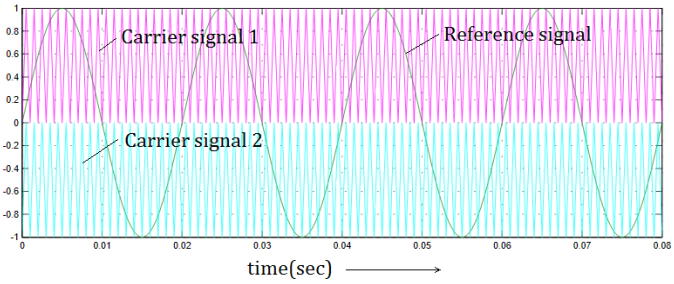


**Fig-4.4:** Comparison of carrier signals and reference for PD-SPWM generation

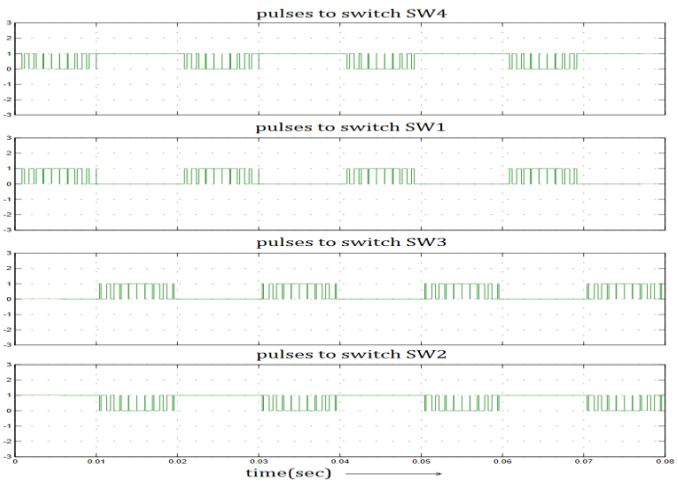


**Fig-4.5:** Pulses for triggering switches of 3 phase 3 Ievel flying capacitor inverter using PD-SPWM Strategy

Fig 4.6 shows carrier signal, reference signal comparisons for POD-SPWM and Fig 4.7 shows pulses generated by POD-SPWM strategy for triggering switches of flying capacitor inverter.

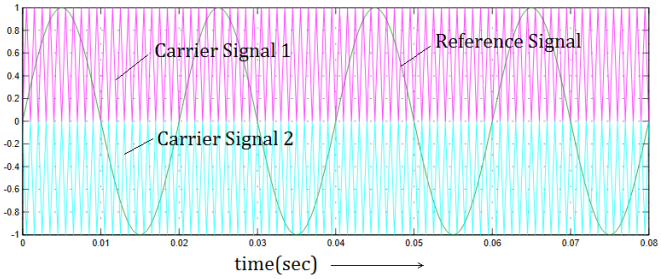


**Fig-4.6:** Comparison of carrier signals and reference for POD-SPWM generation

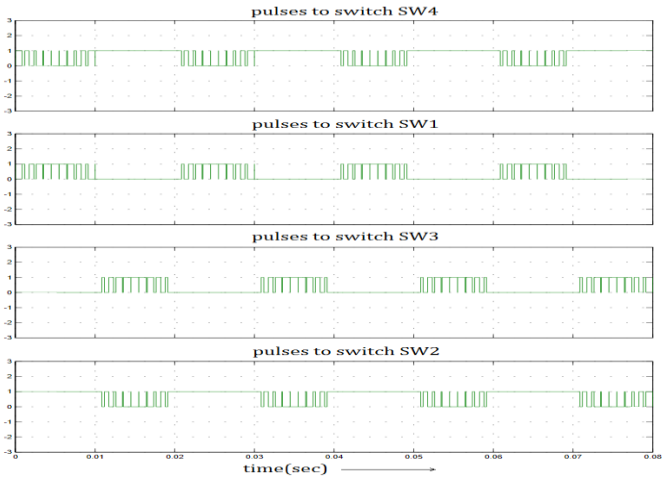


**Fig-4.7:** Pulses for triggering switches of 3 phase 3Ievel flying capacitor inverter using POD-SPWM Strategy

Fig 4.8, 4.9 & 4.10 shows phase voltage, line voltage and phase current waveforms for PD-SPWM strategy.

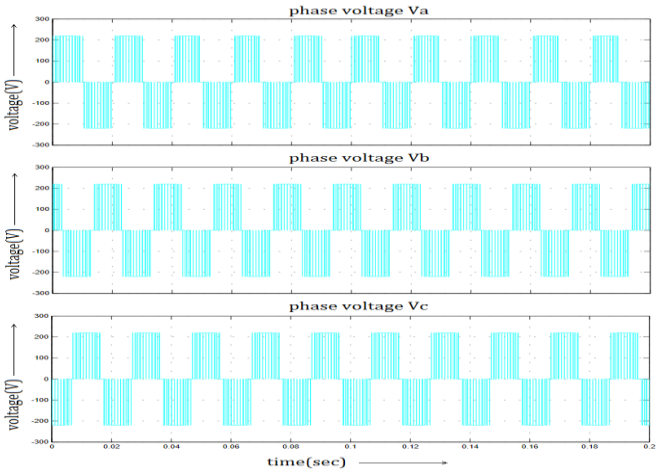


**Fig-4.8:** Phase voltage waveforms of PD-SPWM controlled 3 phase 3 level flying capacitor Inverter

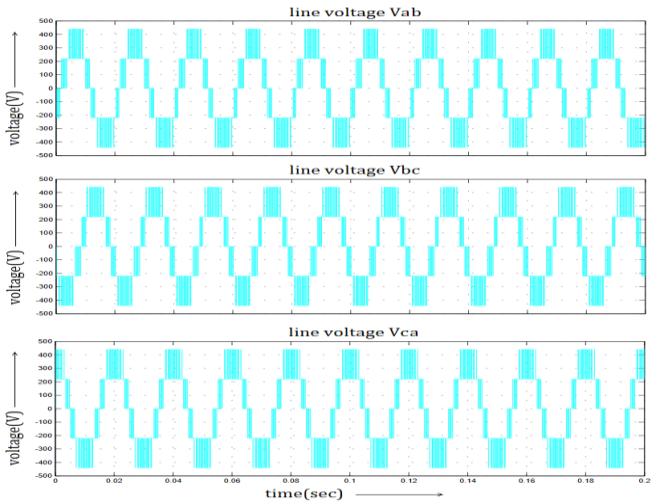


**Fig-4.9:** line voltage waveforms of PD-SPWM controlled 3 phase 3 level flying capacitor Inverter

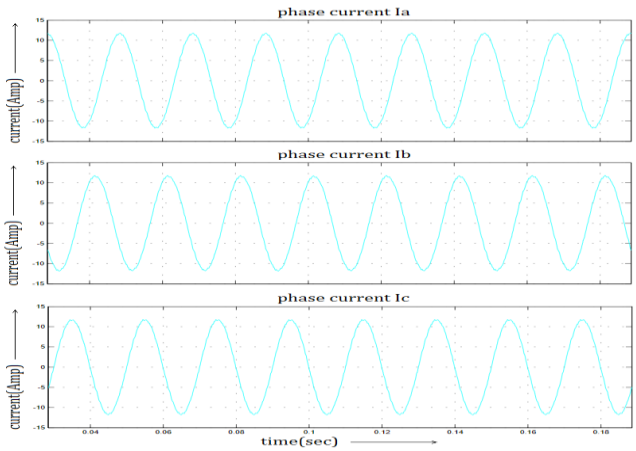


**Fig-4.10:** Phase current waveforms of PD-SPWM controlled 3 phase 3 level flying capacitor Inverter

Fig 4.11, 4.12, & 4.13 shows phase voltage, line voltage and phase current waveforms for POD-SPWM strategy.

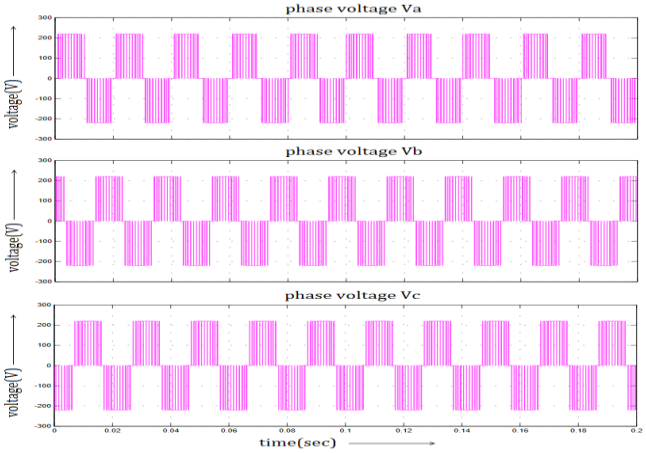


**Fig-4.11:** Phase voltage waveforms of POD-SPWM controlled 3 phase 3 level flying capacitor Inverter

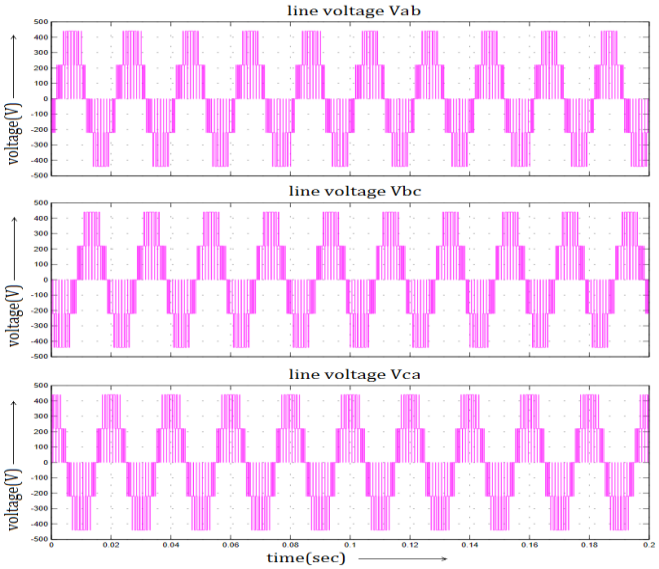


**Fig-4.12:** Line voltage waveforms of POD-SPWM controlled 3 phase 3 level flying capacitor Inverter

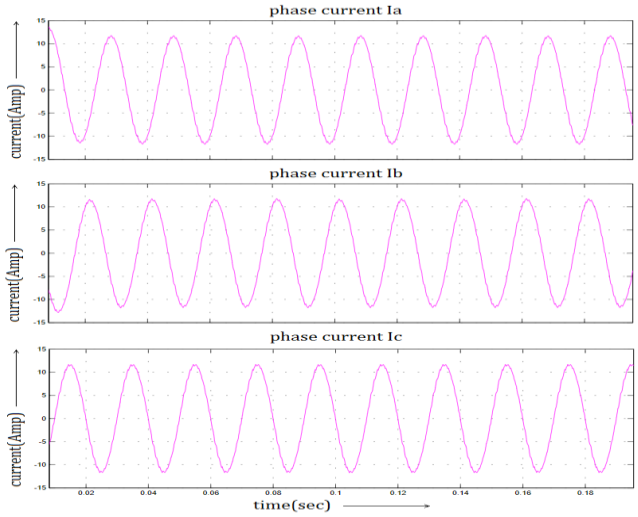


**Fig-4.13:** Phase current waveforms of POD-SPWM controlled 3 phase 3 level flying capacitor Inverter

Fig 4.14 to 4.21 shows Current THD & Voltage THD analysis at different modulation indexes for 3 phase 3 level flying capacitor Inverter

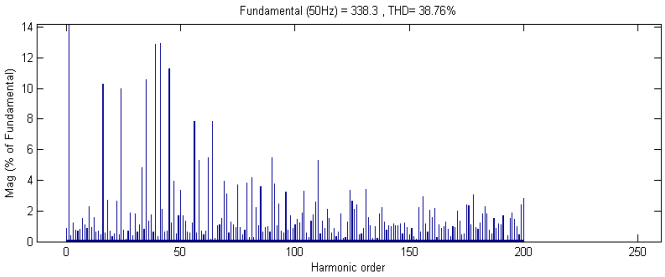


**Fig-4.14:** THD analysis of PD-SPWM controlled Flying capacitor inverter's line voltage at M.I=0.9

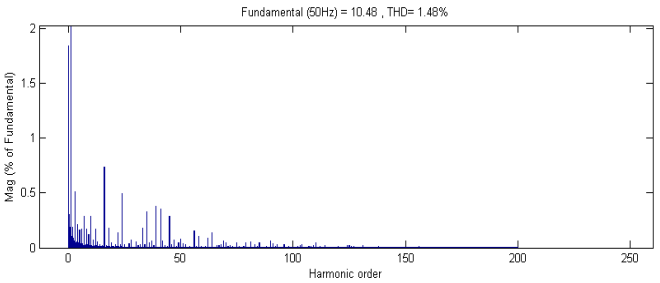


**Fig-4.15:** THD analysis of PD-SPWM controlled Flying capacitor inverter's phase current at M.I=0.9

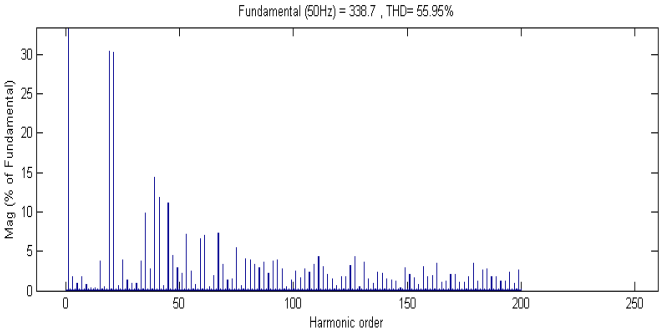


**Fig-4.16:** THD analysis of POD-SPWM controlled Flying capacitor inverter's line voltage at M.I=0.9

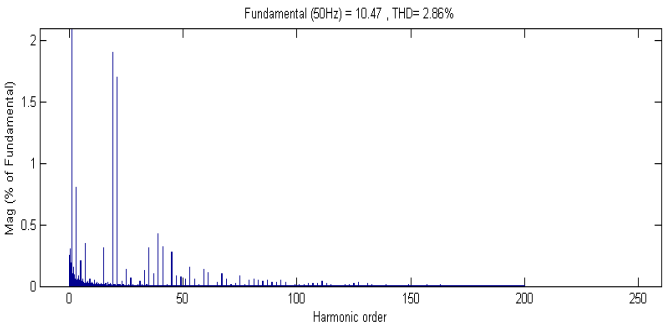


**Fig-4.17:** THD analysis of POD-SPWM controlled Flying capacitor inverter's phase current at M.I=0.9

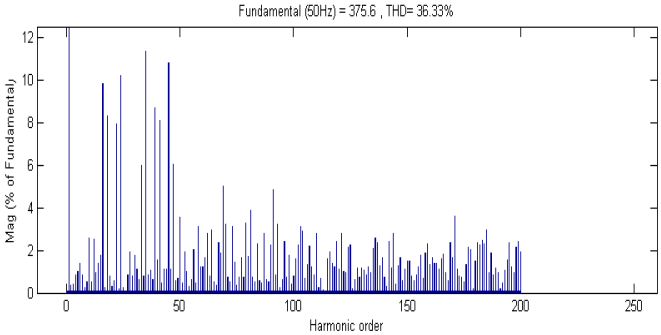


**Fig-4.18:** THD analysis of PD-SPWM controlled Flying capacitor inverter's line voltage at M.I=1

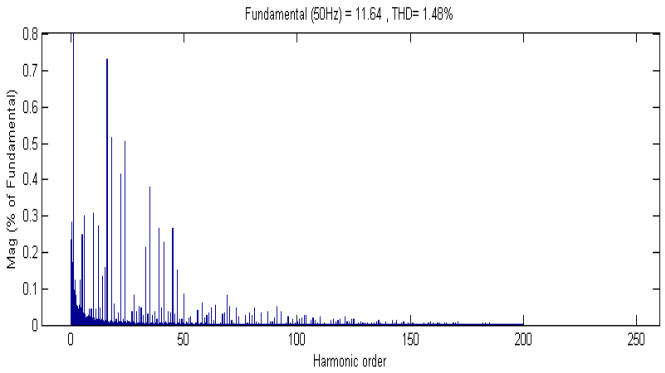


**Fig-4.19:** THD analysis of PD-SPWM controlled Flying capacitor inverter's phase current at M.I=1

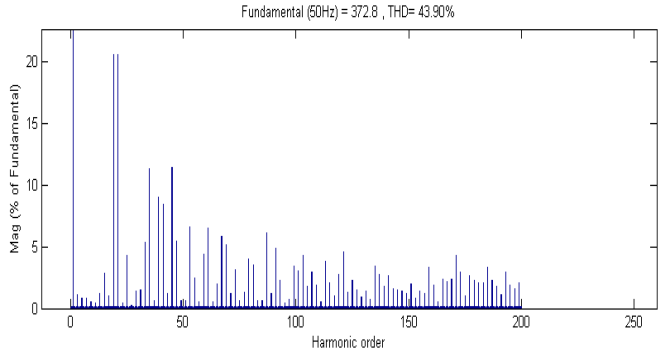


**Fig-4.20:** THD analysis of POD-SPWM controlled Flying capacitor inverter's line voltage at M.I=1

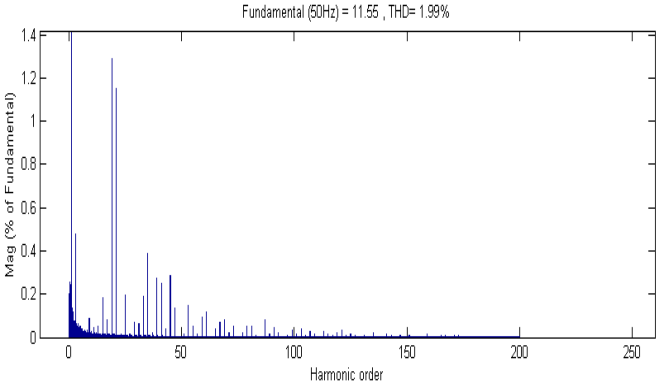


**Fig-4.21:** THD analysis of POD-SPWM controlled Flying capacitor inverter's phase current at M.I=1

## 5. RESULT

In this THD analysis of PD-SPWM and POD-SPWM controlled three phase three level flying capacitor inverter the modulation index is varied from 0.6 to 1.Table-5.1 shows comparative THDV and THDI values of 3 level flying capacitor inverter with PD- SPWM and POD-SPWM control strategies.

**Table -5.1:** The variation of current THD and voltage THD for both PD-SPWM and POD-SPWM controlled 3 level Flying capacitor inverter

| M.I | PD-SPWM | | POD SPWM | |
|---|---|---|---|---|
| | THDV (%) | THDI (%) | THDV (%) | THDI (%) |
| 0.6 | 52.8 | 2.25 | 100.06 | 5.43 |
| 0.7 | 45.15 | 2.01 | 83.18 | 4.62 |
| 0.8 | 41.98 | 1.86 | 70.04 | 3.77 |
| 0.9 | 38.76 | 1.48 | 55.95 | 2.86 |
| 1 | 36.33 | 1.48 | 43.9 | 1.99 |

The variation of current THD and voltage THD with reference to Modulation Index in form of plot for PD-SPWM controlled inverter is shown in chart 5.1.

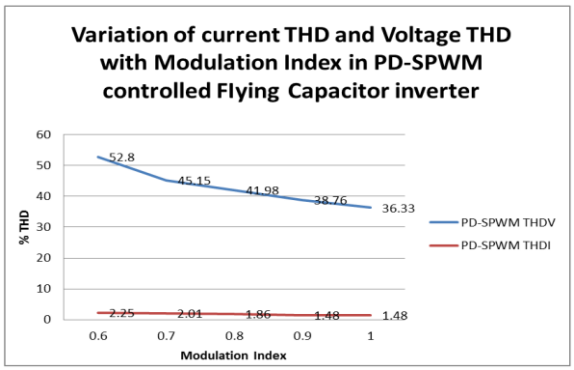


**Chart-5.1:** Variation of current THD and voltage THD with reference to Modulation Index for PD-SPWM controlled 3 phase 3 level flying capacitor Inverter

The variation of current THD and voltage THD with reference to Modulation Index in form of plot for POD-SPWM controlled inverter is shown in chart 5.2.

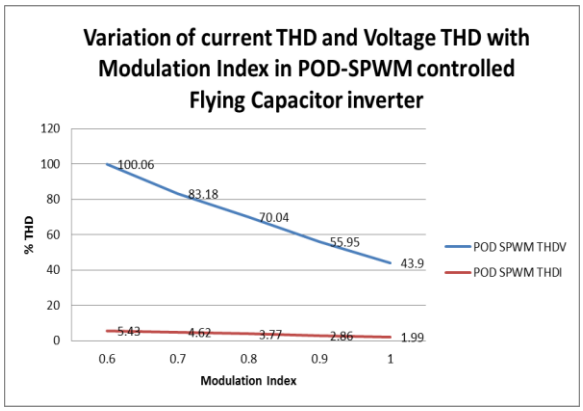


**Chart-5.2:** Variation of current THD and voltage THD with reference to Modulation Index for POD-SPWM controlled 3 phase 3 level flying capacitor Inverter

From the chart 5.1 and 5.2 it is observed that as the modulation index increases both current THD and Voltage THD decreases. The comparison of voltage THD for PD-SPWM and POD-SPWM controlled 3 phase 3 level flying capacitor inverter is shown in chart 5.3 & the comparison of current THD for PD-SPWM and POD-SPWM controlled 3 phase 3 level flying capacitor inverter is shown in chart 5.4

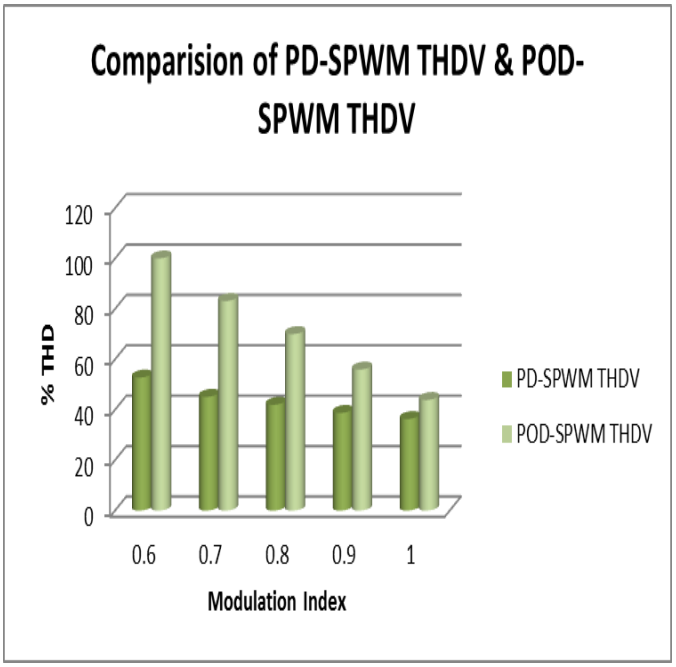


**Chart-5.3:** Comparison of voltage THD's for PD-SPWM & POD-SPWM controlled 3 level Flying capacitor inverter

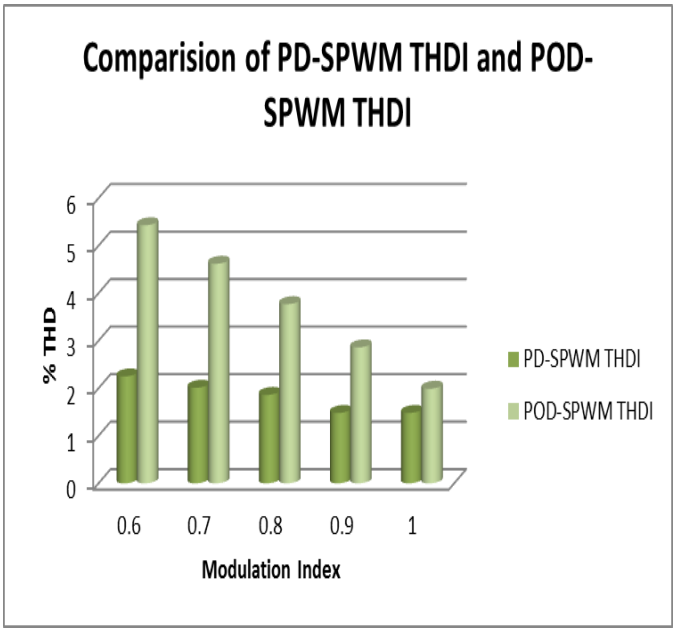


**Chart-5.4:** Comparison of current THD's for PD-SPWM & POD-SPWM controlled 3 level Flying capacitor inverter

## 6. CONCLUSION

A three phase three level flying capacitor inverter has been implemented with PD-SPWM and POD-SPWM control strategies. Analysis of current THD and voltage THD is done at Modulation index from 0.6 to 1(Unity). Simulation results of PD-SPWM controlled flying capacitor inverter and POD SPWM controlled flying capacitor inverter are compared. From chart 5.3 and chart 5.4 it can be concluded that PD-SPWM provides better quality of output voltage and current when compared to POD-SPWM controlled inverter i.e. both current THD and voltage THD is lesser in case of PD-SPWM.

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## BIOGRAPHIES

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Syeda Naheed is currently pursuing M.E. (Power Electronics systems) from Muffakham Jah College of Engineering and Technology, Hyderabad. She Received her B.Tech. Degree from Jawaharlal Nehru Technological University, Hyderabad. Her area of Interest includes power electronics and drives