Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

(Special Issue for ITECE 2016)

Performance Analysis of 3 – level Shunt Active Power Filter using Different Control Strategies

D.R.S Manikanta[1], Mihir C. Shah[2]

Department of Electrical Engineering
Nirma University
Institute of Technology
Ahmedabad, Gujarat

Abstract - ***A load is called as non-linear when with application of applied voltage the impedance is changed, this changing impedance will make current a non-sinusoidal one even when sinusoidal voltage is applied. The main objective of this paper is to address one of the power quality issues i.e. supply side current distortion due to which voltage distortion is also seen at distribution system. This paper presents the design of shunt active filter (SAPF) based three level inverter which provides balanced three phase source current with improved power factor. The control strategies such as hysteresis current control and multicarrier based PWM technique are used for control of SAPF and comparing the THD of source current at PCC. The simulation results in MATLAB/Simulink validate the control strategy applied for SAPF.***

Keywords - PCC (Point of common coupling), SAPF, IRP Theory, LPF (low pass filter), Uninterruptible power supplies (UPS).

I. INTRODUCTION

The overall electrical power generated by generating station is supplied to various types of non-linear loads, such as solid state control of AC power using diodes, thyristors, furnaces, adjustable speed drives consisting of solid state controllers for both DC and AC motors, and other semiconductor switches widely used to provide controlled power to electrical equipment such as computers, fan, printer, solid state AC voltage controller feeding fans, UPS.

The non-linear loads mainly composed of odd harmonic currents, which are multiple of fundamental frequency and these harmonics current does not even contribute or active power and need to be eliminated for better power quality. [1]. Most APFs which are proposed in literature are standard two level voltage-source inverter. However for medium voltage applications, three level VSIs have been proven to be more advantageous so three-level Diode clamped inverter can be employed in the SAPF.

In two level inverter each switch is rated for maximum D.C link voltage of the inverter, i.e. V_{dc}. Here as in one leg of the inverter, both the switches are operated in complementary manner, hence each switch has to block maximum DC link voltage at any instant of time. For domestic 3-ϕ supply, maximum D.C link voltage is between 400V to 600v, but for high power, medium voltage application D.C link voltage is much higher than this range, so in the conventional topology of the inverter, blocking voltage requirement of the switching devices is very high. The objective of the paper is to compare the performance of three level inverter and three level inverter in shunt active filter.

II. SHUNT ACTIVE FILTER

Fig.1 shows a non-linear load i.e. 6-pulse rectifier integrated with three level SAPF. The SAPF is connected to the PCC where compensation of the harmonic current takes place with appropriate compensating current generated by SAPF. Conventional hysteresis control technique is used as a control strategy for control of SAPF. [2]

Here voltage across the D.C link is 600v so shunt active filter will require IGBT as power device. Instead of two level inverter in shunt active filter multi-level neutral point clamped (NPC) inverter as shown in Fig.2 is used due to the advantage including output harmonics distortion (THD) of the voltage and current generated is low, the high efficiency of the system, the voltage stress on device is low, and the common mode voltage is also low, small size filter requirement [3]. So to implement three level inverter in SAPF different techniques for generating compensating current such as instantaneous reactive power theory, synchronous detection method, and synchronous d-q frame method are proposed [4]. Now after the generation of reference compensating current, inverter have to track it for that various current control methods proposed for such active filter configuration [5]. There is a current controlled voltage source inverter, as the load harmonics may be complex, change rapidly and APF has to respond quickly with high control accuracy in current tracking.

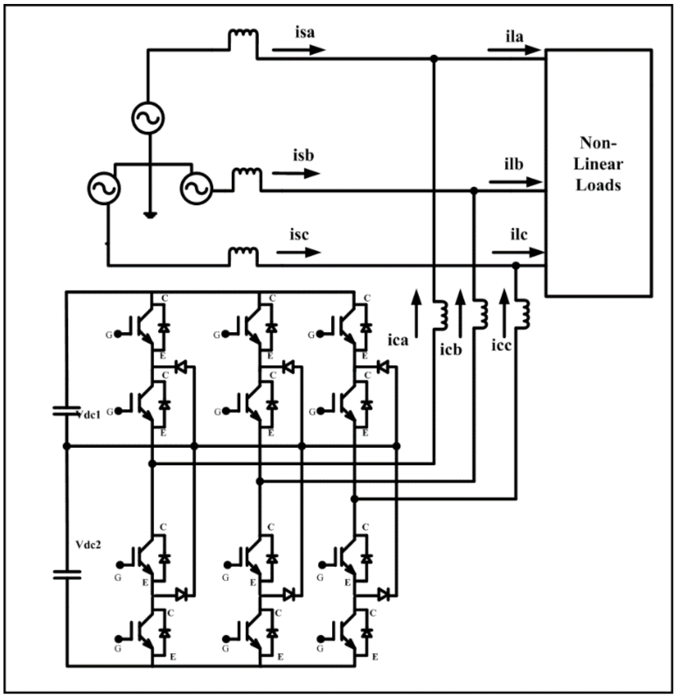


Fig 2.Three-Level Shunt Active Filter.

III. REFERENCE GENERATION AND CONTROL METHOD

Different reference current generation schemes are been implemented as stated in [6]. The reference current generation of shunt active filter is shown in Fig.3 where reference current generation is based on instantaneous reactive power theory. To control active two level inverter hysteresis current controller is implemented in SAPF and for three level multicarrier technique is used for the generation of gate pulse for three level inverter

3.1. Reference Current generation method.

Instantaneous reactive power theory was proposed by H. Akagi [7]. The expression of reference current generation for fundamental instantaneous reactive power current i_q and active power current i_d is given below:

$$\begin{bmatrix} i_p \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} sin\omega t & -cos\omega t \\ -cos\omega t & -sin\omega t \end{bmatrix} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\begin{bmatrix} i_p \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} sin\omega t & \sin(\omega t - \frac{2\Pi}{3}) & \sin(\omega t + \frac{2\Pi}{3}) \\ -cos\omega t & -\cos(\omega t - \frac{2\Pi}{3}) & -\cos(\omega t + \frac{2\Pi}{3}) \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\begin{bmatrix} i_p \\ i_q \end{bmatrix} = C_{abc-pq} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tilde{i_p}$$

From Fig.3 it is clear that once the load current i.e. $i_{la,}$ $i_{lb,}$ i_{lc} are converted from three phase to two phase component i.e. $i_{q,}$ i_d the harmonics component $\tilde{p}$ and $\tilde{q}$ are eliminated using LPF.

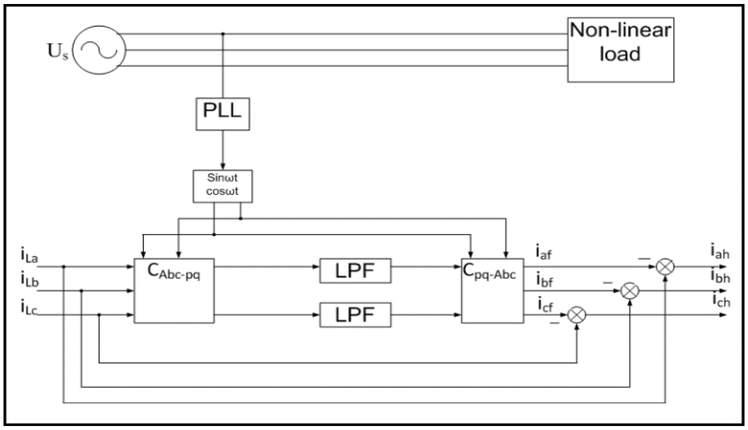


Fig 3.Block Diagram for the Generation of Reference Current.

Now although the resulting real and imaginary powers have no ripple, the current related to the average imaginary $\bar{q}$ is still flowing in the network, which makes the power factor lower than unity so the undesirable current component of the load are being eliminated. The compensated current is sinusoidal, produces a constant real power, and does not generate any imaginary power [8].

3.2. Control Strategy.

There are two main methods to control the operation of two level inverter and three level inverter.

1) Voltage Controlled PWM (VCPWM)
2) Current Controlled PWM (CCPWM)

In Current Controlled PWM three main techniques are:-

a) Hysteresis Loop Controller
b) Ramp Control
c) Predictive control

Generally hysteresis controller are more preferred due to its inherent simplicity and fast dynamics response. In hysteresis current controllers give variation in switching frequency in one fundamental cycle, while ramp comparison controllers cannot give such variation. In ramp comparison controllers switching frequency of the inverter compared with fixed ramp frequency. Here the major drawback of the hysteresis controller is that the switching frequency of the controller cannot determined. In predictive Controller Predictive control involves the selection of the optimum space vector voltage to be applied to the load at any instant, to force the load currents to follow an optimum trajectory so it is complex to implement.
In hysteresis current controller the hysteresis band is narrow, ripple in the output wave will be less, but as the tolerance band becomes narrower switching frequency of the inverter increases and as the hysteresis becomes broader ripples in the output waveform is high. Here nature of current in hysteresis band is decide by the system dynamics and load parameters hence switching frequency in this case cannot be predicted.

3.2.1. Three-level hysteresis current controller:

The implementation of three level modulations hysteresis controller are set as upper and lower band overlap boundaries and displacement by a small offset current. Whenever the current error e (t) crosses an outer hysteresis boundary, that time the inverter output is set to an active positive or negative output to force a reversal of the current error. Similarly whenever the current error reaches an inner hysteresis boundary, that time the inverter output is set to a zero condition and the current error will be forced to reverse direction without reaching the next outer boundary. If the selection of a zero output does not reverse the current error, it will continue through the inner boundary to the next outer hysteresis boundary, at which point an opposite polarity inverter output will be commanded and the current will reverse anyway.

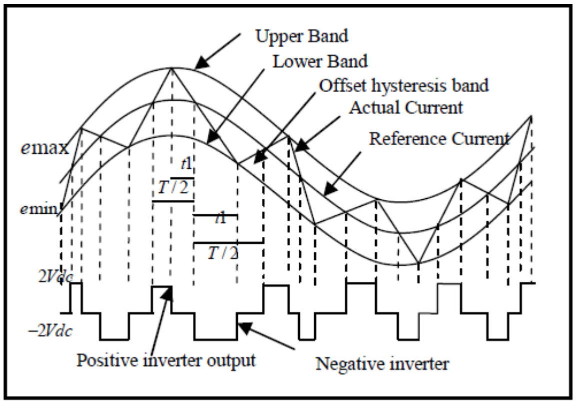


Fig 4.Three Level Hysteresis Current Controller

3.2.2. Carrier-Based PWM for Three Level SAPF

The Carrier-based modulation technique for multilevel inverters can be classified into two categories:

1. Phase-shifted Modulations
2. Level-Shifted Modulations

1. Phase-Shifted Modulation:-In phase shifted PWM (PSPWM) method, all the (n - 1) carrier signals have same amplitude and frequency but phase shifted by 360º/ (n - 1). This method is widely used in cascaded and flying capacitor topologies. This method results in lower distortion factor at an inverter output voltage for all modulation indices. The gate pulse are generated by comparing the modulating wave with carrier waves.
2. Level-Shifted Modulation: - Similar to Phase shifted modulation, level shifted multicarrier modulation scheme requires (n-1) triangular carriers, all having the same frequency and amplitude. The (n-1) triangular carriers are vertically disposed such that band are sequentially placed.
   Figure 4(a) and 4(b) shows two schemes for level shifted multicarrier modulation.
   a) In-Phase Disposition, where all carriers are in-phase.
   b) Phase opposite Disposition (POD), where all carriers above the zero reference are in phase but in opposite with those below the zero reference.

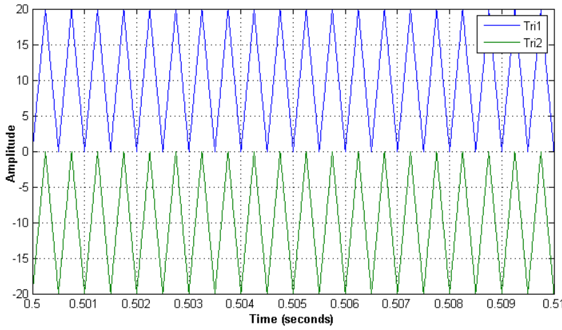


Fig 5. (a) In-Phase Disposition (IPD)

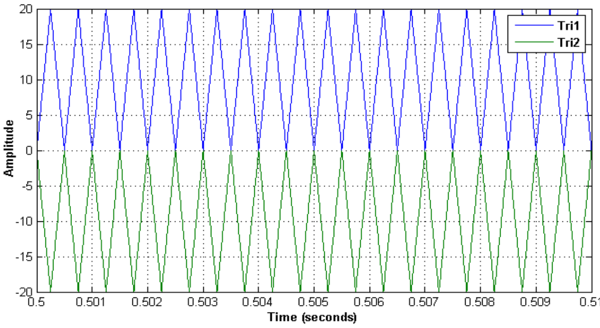


Fig 5. (b) Phase Opposite Disposition (POD)

IV. Simulation Model And Results

The main parameters of SAPF based on three-level are:

1. Supply: - A 3-ϕ , 400 v power supply at 50 Hz, with a source inductance (L_s) = 10 μh is considered here.
2. Load: - A 3-ϕ , three wire rectifier is used as a non-linear load, with rectifier o/p current as 36A.

- The rms value of rectifier i/p current is

$$I_{Lrms} = 0.816*36 = 29.37 \text{ A.}$$

- The value of fundamental component of rectifier i/p current is

$$I_{L1} = 0.779*36 = 28.04 \text{ A.}$$

- Harmonic current is given by

$$I_h = \sqrt{(I_{Lrms}{}^2 - I_{L1}{}^2)} = 8.72 \text{ A}$$

- Rating of SAPF is given by

$$3{*}V_{ph}{*}I_{ph} = 3{*}230{*}8.725 = 4013.5 {*}1.25 = 5 \text{ KVA}$$

3. DC Bus Voltage: - The value of DC bus voltage V_{dc} of APF depends on PCC line voltage .for a 3-ϕ VSC, the DC bus voltage is defined as

$$V_{dc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}*m} = 600\text{V}.$$

Table 1. Simulation parameters.

Filter Inductance(L_c)	1mh
Source inductance(L_S)	10µh
DC voltage(V_{dc})	600V
DC capacitor	3650µf
Frequency	50hz
Input AC voltage	230Vp

4.1. Simulation Results of SAPF based on Three Level Inverter using Conventional Hysteresis Controller.

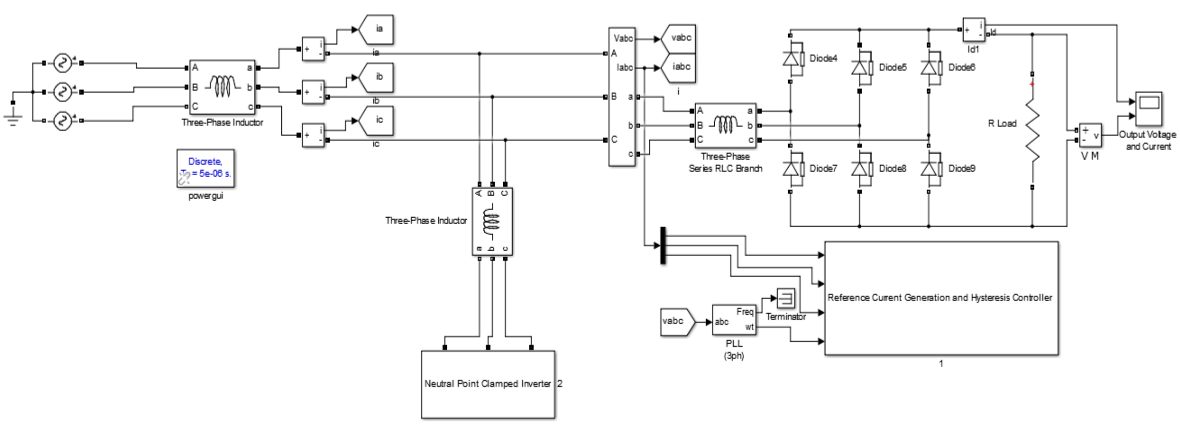


Fig 6. MATLAB Simulink Diagram of SAPF Based on Three Level Inverter using Conventional Hysteresis Controller.

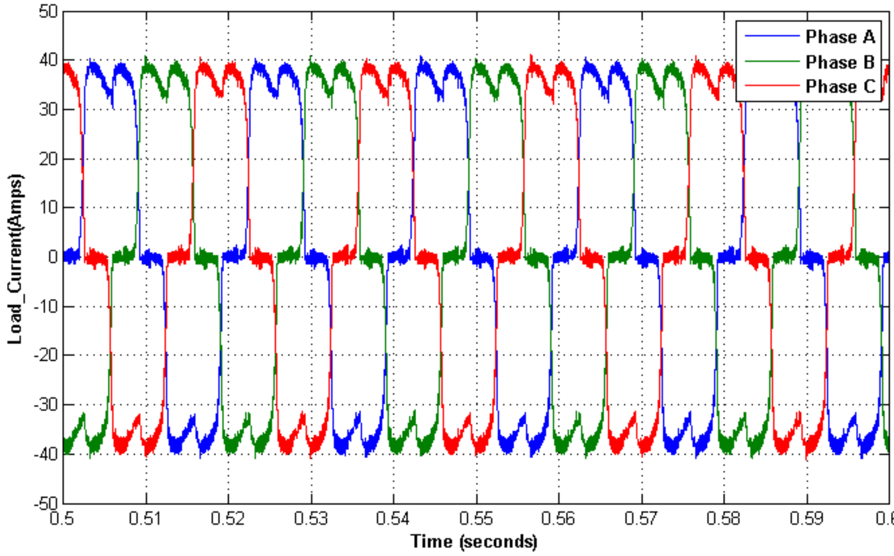


Fig. 7. Load Current due to Non-Linear Load.

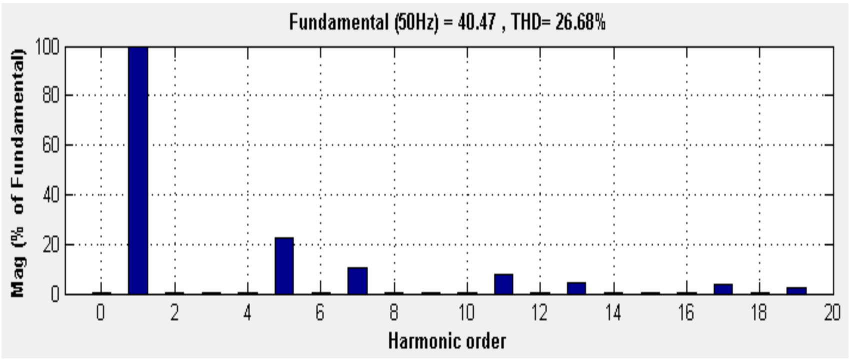
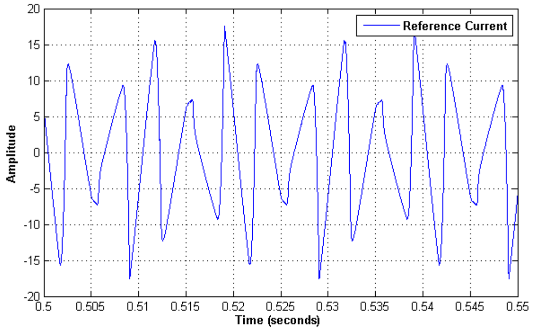
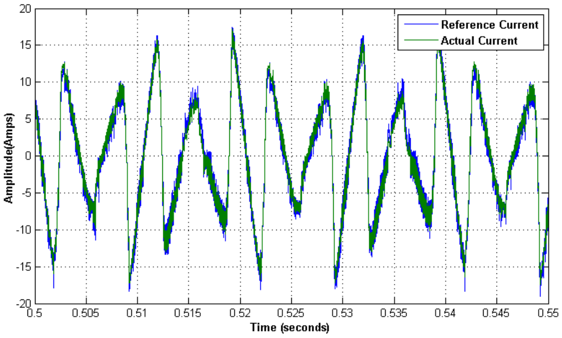


Fig. 8.Harmonic Spectrum and THD for Phase 'a' load Current.

By connecting the shunt active filter at PCC (point of common coupling), the compensation performance can be established.

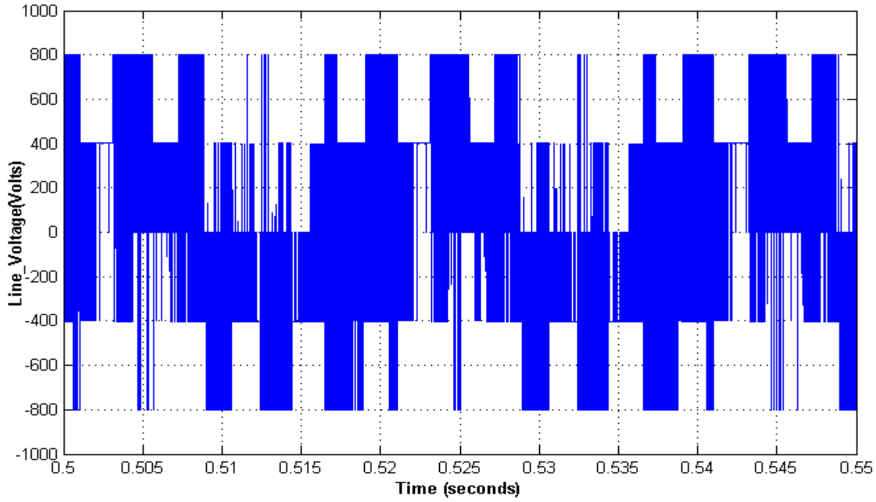


(a)

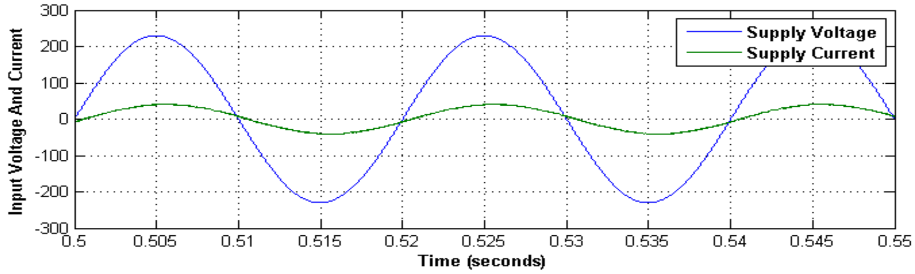


(b)

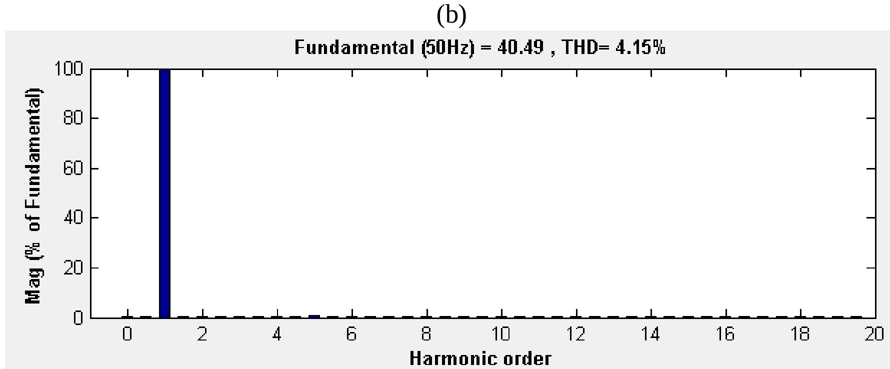
Fig. 9.Reference Current Generation using IRP Theory for three level SAPF



(a)



(b)



(c)

Fig. 10. (a) Three Level Inverter Pole Voltage, (b) Waveform for Input Voltage and Current, (c) Harmonic Spectrum and THD for Phase ‘a’ Supply Current.

4.2. Simulation Results of SAPF based on Three Level Inverter using Carrier –Based PWM Schemes.

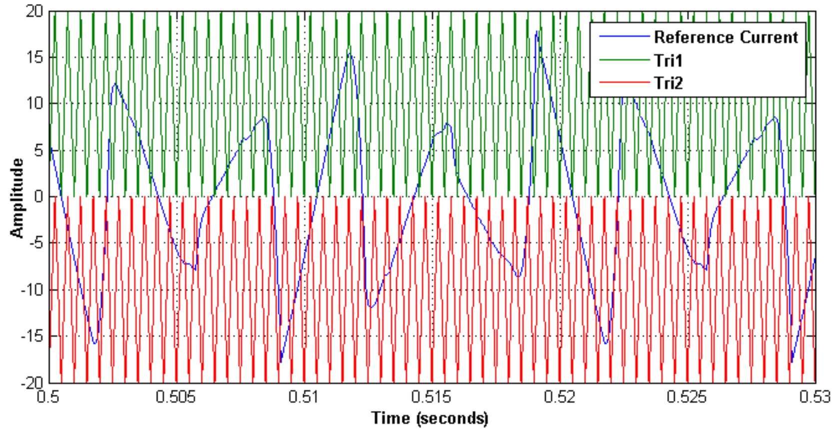


Fig. 11. Modulating Wave V_{mA} with IPD Modulation Technique.

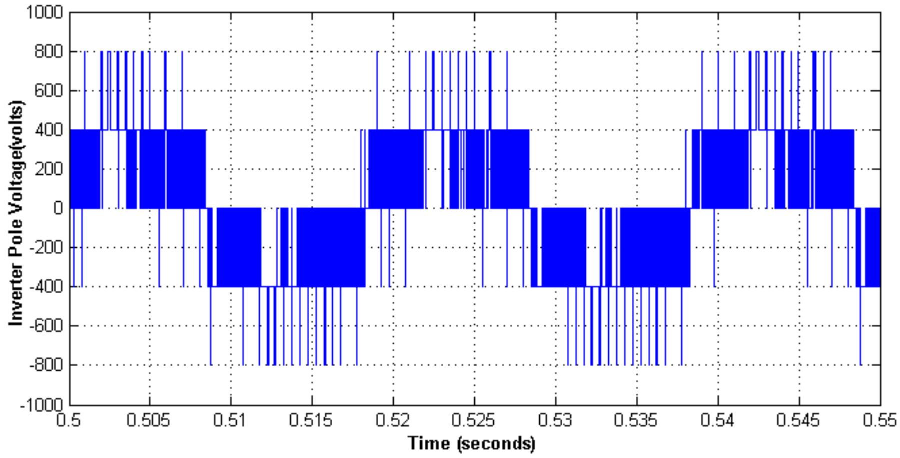
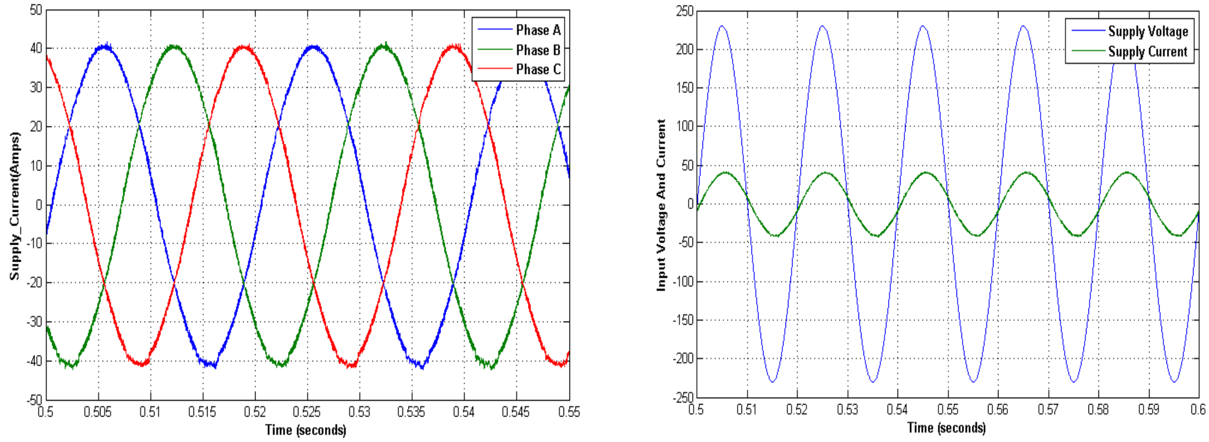


Fig. 12. Three Level Inverter Pole Voltage using IPD



(a) (b)

Fig. 13. Three Level Waveform for (a) Supply Side Voltage (b) Waveform for Input Voltage and Current

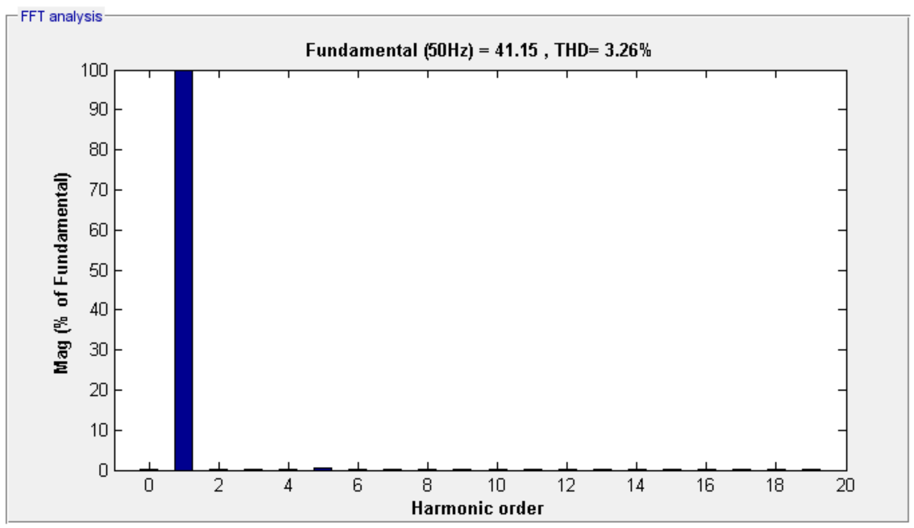


Fig. 14. Harmonic spectrum and THD for phase 'a' Supply current.

V. Conclusion

Power Quality is a major area of concern for industrial as well as domestic loads. Thus power electronics has proved as a major field in the area of power quality improvement. Active Power Filters are implemented on a wide scale where current compensation is required. In this work, current harmonic compensation is being carried out by reference current generation required for the Shunt Active Power Filter. The strategy implemented is Instantaneous Reactive Power Theory Technique. The simulation results carried out in MATLAB/Simulink software shows the following results of the THD before as well as after compensation.

Table 2. Comparison of %THD using Different Control Techniques

Control Technique	Before Compensation	After Compensation
Hysteresis Current Control	26.68%	4.15%
In-Phase Disposition	26.68%	3.26%

From the Table 2 it is observed that the %THD in source current before compensation is above 5%, and after compensation the source currents are sinusoidal and no distortion it is observed that the %THD is less than 5%.

REFERENCES

[1] Oleg Vodyakho, Chris C. MI, "Three-level Inverter-based shunt active power filter in the three phase three wire and four wire system". IEEE Trans. On power electronics , vol. 24 ,no.5, May 2009

[2] Swamy, M.M.; Rossiter, S.L.; Spencer, M.C.; Richardson, M., "Case studies on mitigating harmonics in ASD systems to meet IEEE 519-1992 standards", pp 685-692, vol1, 1994.

[3] Oleg vodyakho and chris c. mi "Three-level inverter based shunt active power filter in three phase three wire and four wire systems", *IEEE Trans. On Power electronics*, vol.24, No.5, May 2009.

[4] H. Akagi, Y. Kanazawa , and A. Nabae, "Generalized theory of the instantaneous reactive power in the three-phase circuits" in conf. REC. IEEJ-IPEC, 1983, pp. 1375-1386, 1983.

[5] H. Akagi, "New trends in active filters for improving power quality", IEEE Conference Publications, pp. 417-425, 1996.

[6] Abdalla, I.I.; Perumal, N., "Five level cascaded inverter based shunt active power filter in four wire distribution system". *IEEE Conference Publications*, pp. 690-695, 2013.

[7] H.Akagi, "The theory of instantaneous power in three-phase four-wire systems: a comprehensive approach" *IEEE Conference Publications*, pp. 431-439, 1999.

[8] H. Akagi. "The Instantaneous Power Theory", Instantaneous Power Theory and Applications to Power Conditioning, IEEE press.