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Analysis of Shunt and Universal Active Power Filter for Three-Phase Four-Wire Distribution System

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Abstract: Active power filters are eventually a reliable technology for harmonic reduction. This paper presents the analysis of performances of shunt and universal active power filters. Compensation potency of both shunt and universal active power filter for harmonics, reactive power and neutral current compensation capabilities are analyzed for a three phase four wire system. The performances analysis is done for both balanced and unbalanced loads using matlab-simulink.

Keywords: Active power filter, Universal Active power filter, Harmonics , power quality, Total Harmonic Distortion

I. INTRODUCTION

With active escalation in capacity and nonlinear loads being connected to the system the distribution system is deliberately getting complex. On the other side modern load is becoming more sensitive to power quality. This direction is leading to new power quality concerns in the distribution network.

Researchers are facing new challenges in handling with the new power quality problems[1]-[2]. Due to increase in employment of power electronic loads enormous amount of current and voltage harmonics are introduced which leads to distorted waveforms, power losses, undesirable function of the devices etc. Currently to resolve on the uncertainties of current harmonics, reactive power, unbalanced load current and excessive neutral current, the three phase four-leg active power filters are assayed to be mere efficacious [3]. Single phase nonlinear loads in three phase four –wire system are sources of third order zero-sequence harmonics, Whose magnitude can 1.73 times the phase current[4].

A distinctive practice is ruled to introduce compensations at various levels to maintain power quality regulations [5]-[6]. In this work only Active power filters(shunt, Universal) are focalized. A series active power filter is inserted in series with sensitive loads to protect critical loads from source side harmonics. To protect sensitive loads from other harmonic loads, shunt active power filter is connected in parallel to the load at common coupling point.

A Universal active power filter consists of voltage source converters(VSC) associated back to back to a common DC bus, one VSC is connected in series with AC lines through series injecting transformer and another VSC is shunt connected across the PCC.

2. SYSTEM DESCRIPTION

Custom power devices are efficient to mitigate the troubles relevant to power quality. These devices are grouped into Active power filter (APF), SSTs, Dynamic voltage restore (DVR), Unified power quality controller(UPQC), SVC, DSTATCOM etc. Shunt active power filter are select base on topology, type of converter and number of phases. In this work a three phase four leg VSC with self-supporting DC voltage bus is designed. Synchronous reference frame algorithm is used as control algorithm for generation of reference current signals Fig.1 shows a voltage source converter base shunt APF with nonlinear load.

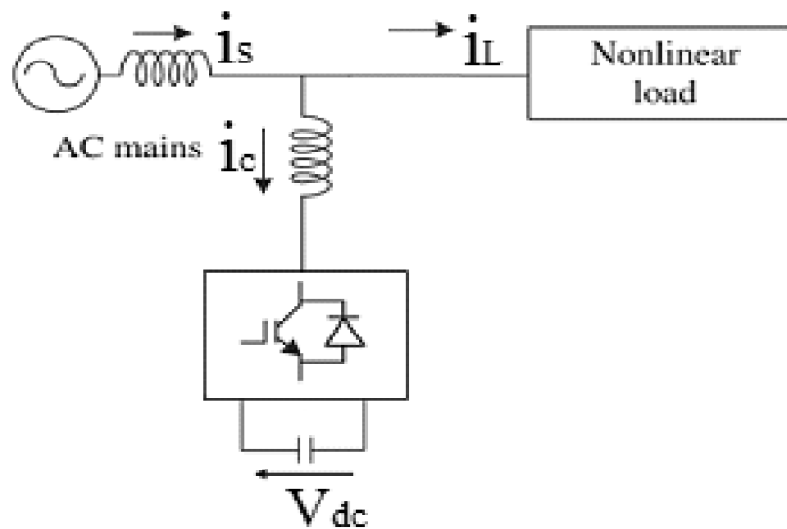


Figure 1: Shunt Active Filter

In Universal APF two VSC are connected back to back with common DC bus link as shown in Fig.2. A series VSC is used as an active series filter and shunt VSC is used as active shunt filter. Shunt active power filter VSC is of four leg for neutral current compensation. Series active power filter is connected in series with the AC source, using matching transformer which is used for injection of voltage and as isolation transformer.

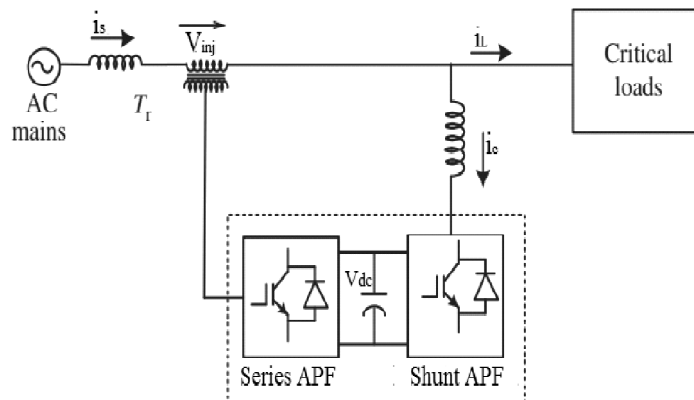


Figure 2: Universal Active Power Filter

3. CONTROL SCHEME FOR SHUNT APF

Three phase four-leg VSC of shunt APF is controlled by using synchronous reference frame (SRF) algorithm. A complete block diagram of SRF theory is shown in Fig. 3. Common coupling point voltages (V_{sa} , V_{sb} , V_{sc}), DC bus voltage and the currents at load (I_{La} , I_{Lb} , I_{Lc}) are used as feedback signals. By using Parks transformation three phases load currents are transformed into the dq frame.

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin \theta & \sin \left(\theta - \frac{2\pi}{3} \right) & \sin \left(\theta + \frac{2\pi}{3} \right) \\ \cos \theta & \cos \left(\theta - \frac{2\pi}{3} \right) & \cos \left(\theta + \frac{2\pi}{3} \right) \end{bmatrix} \quad (1)$$

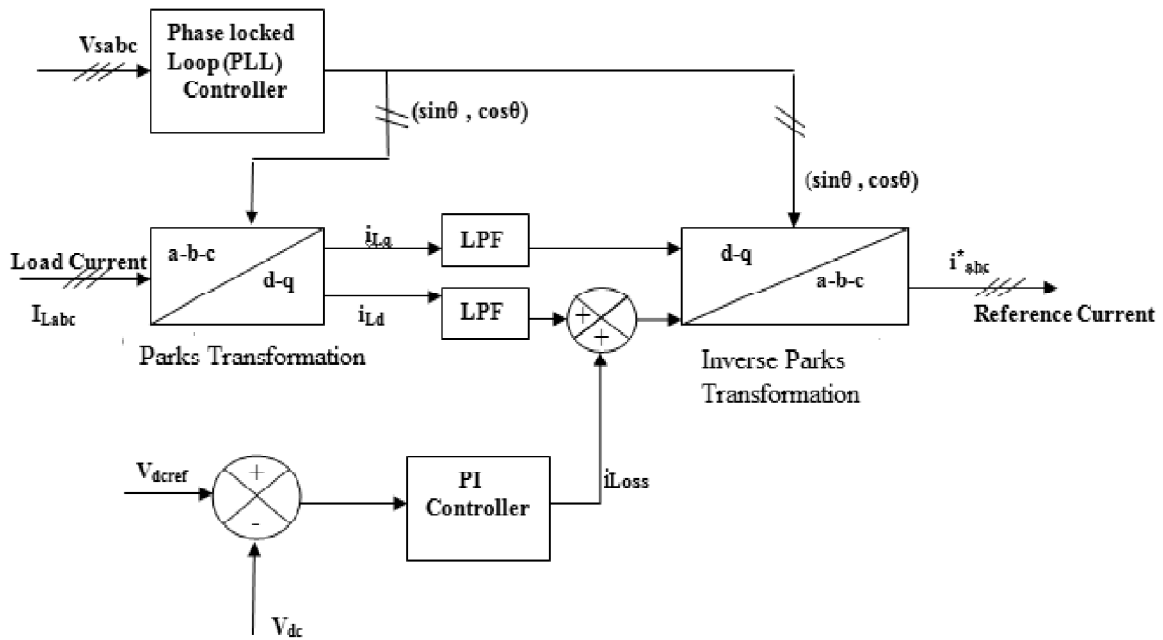


Figure 3: SRF theory control scheme for Shunt APF

To synchronize these signals with common coupling point voltages a three phase locked loop is used. A low pass filter is used to extract the DC components of i_{Ld} and i_{Lq} . These currents consists of harmonics and fundamental values as

$$i_{Ld} = \bar{i}_{dDC} + \tilde{i}_{dAC} \quad (2)$$

$$i_{Lq} = \bar{i}_{qDC} + \tilde{i}_{qAC} \quad (3)$$

Reactive power compensation can be achieved if the source delivers the DC component of direct axis components of load current and active power components of the current for meeting DC bus and the losses (i_{Loss}) in the APF.

Directs axis reference current is given as

$$i_d^* = i_{dDC} + i_{Loss} \quad (4)$$

The reference source current is obtained by applying reverse parks transformation with i_d , i_q and i_o as zero.

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin \theta & \cos \theta \\ \sin \left(\theta - \frac{2\pi}{3} \right) & \cos \left(\theta - \frac{2\pi}{3} \right) \\ \sin \left(\theta + \frac{2\pi}{3} \right) & \cos \left(\theta + \frac{2\pi}{3} \right) \end{bmatrix} \begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} \quad (5)$$

4. CONTROL SCHEME FOR UNIVERSAL APF

Control algorithm for series VSI of universal APF is shown in Fig. 4. Synchronization for distorted source voltage is achieved by using phase locked loop[7]-[8].The output of PLL is two quadrature unit vectors ($\sin\theta$, $\cos\theta$). Only ‘d’ component will be present in a distortion free, constant magnitude and balanced three- phase voltage. The desired peak voltage value of common coupling point (i.e. 415V) is obtained using inverse parks transformation. The control strategy for shunt VSI of Universal APF is same as that of shunt APF.

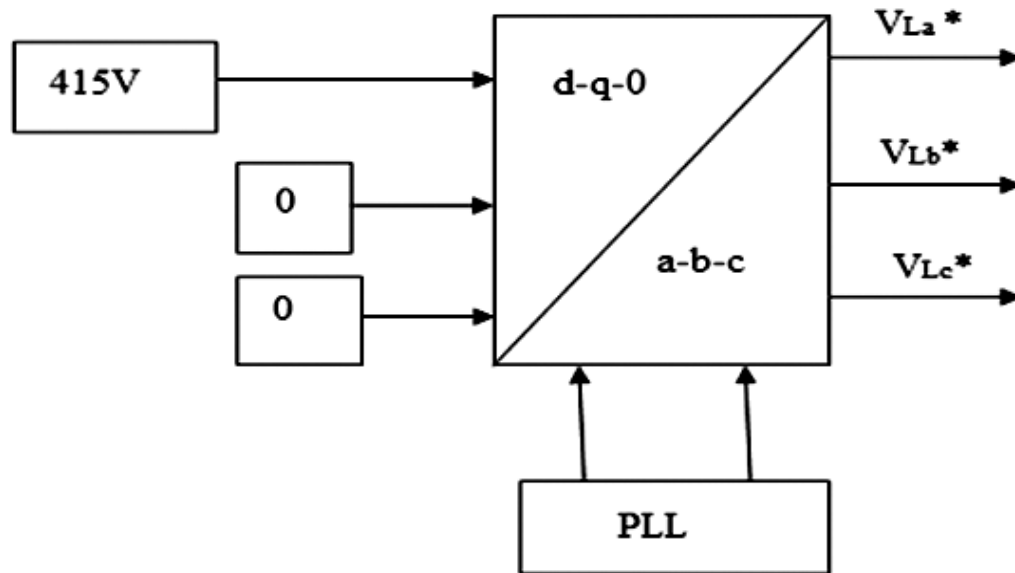


Figure 4: Control scheme of Series APF

5. RESULTS AND ANALYSIS

The performance analysis of each APF topology is carried out for three phase four wire system, using MATLAB/ SIMULINK. Parameters for the simulation model are as shown in table 1. Fig. 5 shows the waveforms of voltage and current of both source and load without compensation. From $t_0 = 0.25s$ to $t_1 = 0.3s$ balanced three phase load is applied. From $t_1 = 0.3s$ to $t_2 = 0.35s$ single phase load is applied to phase A. Due to this source current drawn will be unbalanced. The utility voltage is distorted by inserting 5th and 7th order harmonics.

Table 1
Model Parameters

S.No.	System Elements	Parameters
1.	Source	415V, f=50Hz
2.	Inverter	Shunt VSC, IGBT based 4-arm
3.	Injection Transformer	1:1, 20KVA
4.	Load	Three Phase: DBR With R = 60Ω, L=20mH Single Phase: DBR With R=100Ω
5.	Vdc	Shunt APF : 800V UAPF : 800V
6.	Ripple filter	R=1Ω, C=100μF
7.	PI Controller	Kp= 0.2, Ki = 0.5

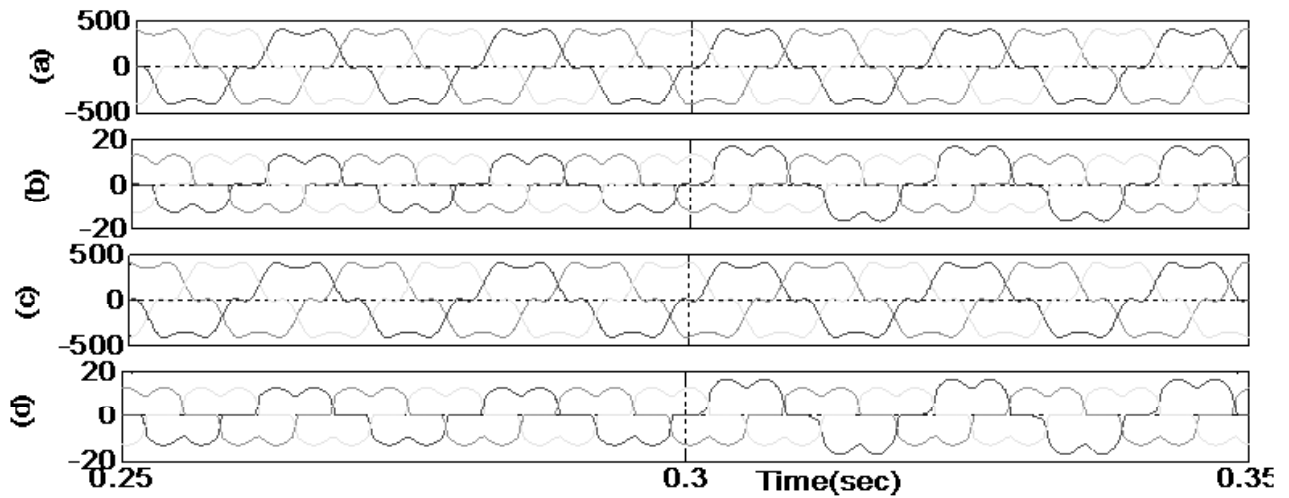


Figure 5: Without Compensation a) supply voltages b) supply current c) load voltage d) load current

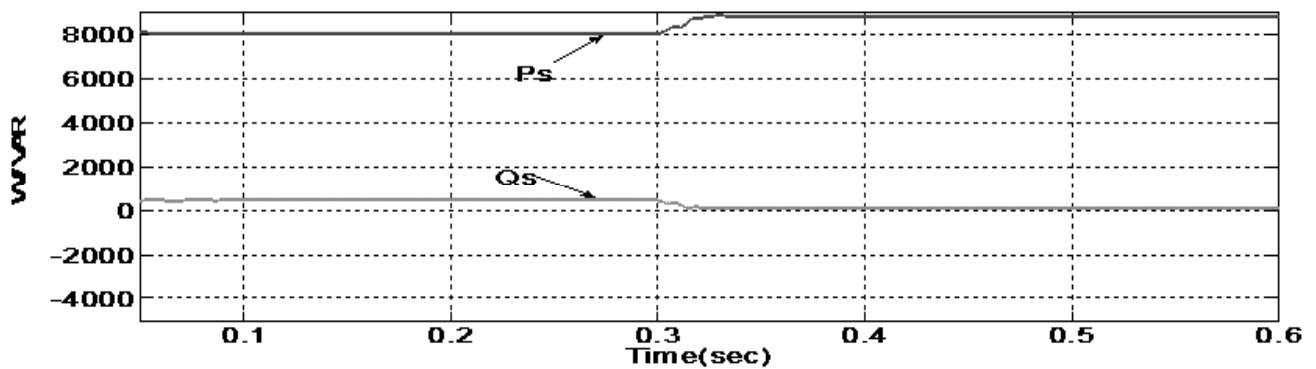


Figure 6: Active and Reactive Power without Compensation

Fig. 6. Shows wave forms active and reactive power flow. The multiplication of mean values of voltage and current for one cycle of fundamental frequency gives the real and reactive power at fundamental frequency. The harmonic spectrum without compensation for voltage and current are as shown in Fig. 7.

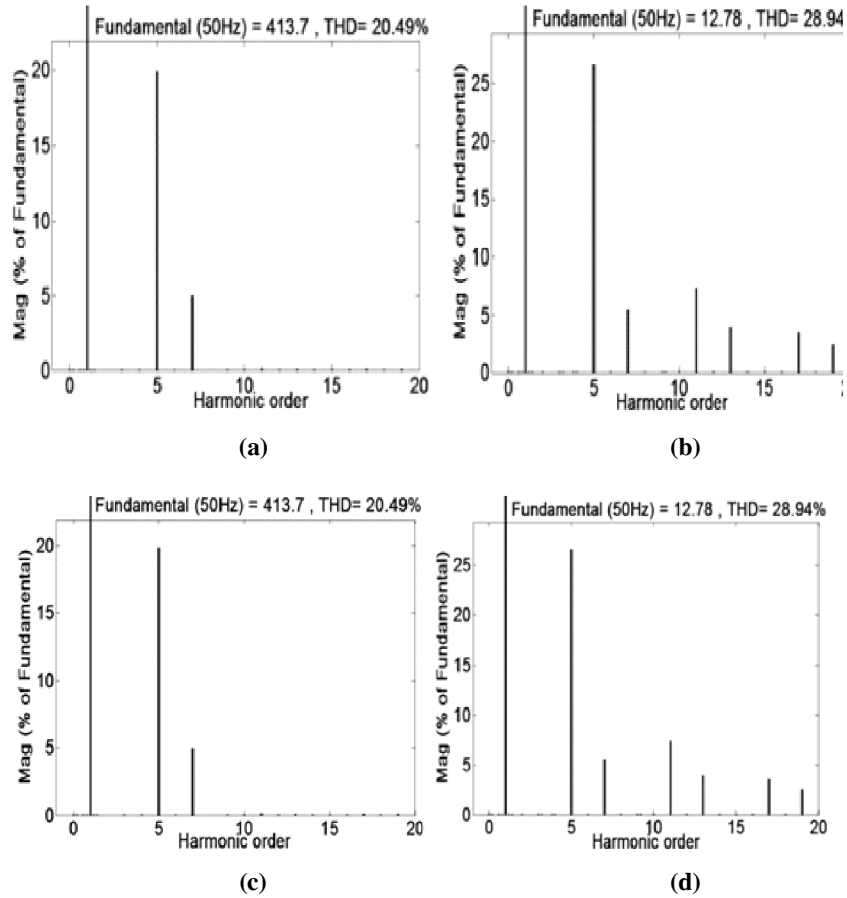


Figure 7: Harmonic FFT analysis without compensation With balanced load a) Supply voltage b) supply current c) load voltage d) Load current

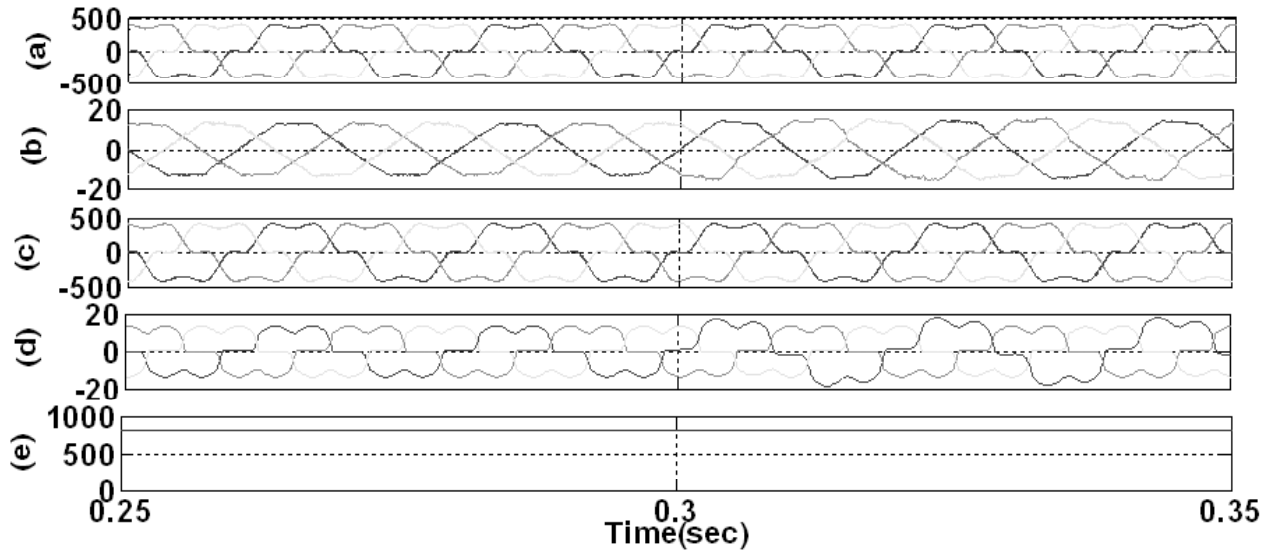


Figure 8: Waveforms using shunt APF a) supply voltage (Vsabc) b) supply current(Isabc) c) load voltage d) load current e) DC link voltage (Vdc)

The voltage and current waveforms of both source and load with shunt APF compensation is as shown in Fig.8, From $t_0=0.25s$ to $t_1=0.3s$ balanced three phase load is applied. From $t_1=0.3s$ to $t_2=0.35s$ single phase load is applied to phase A.

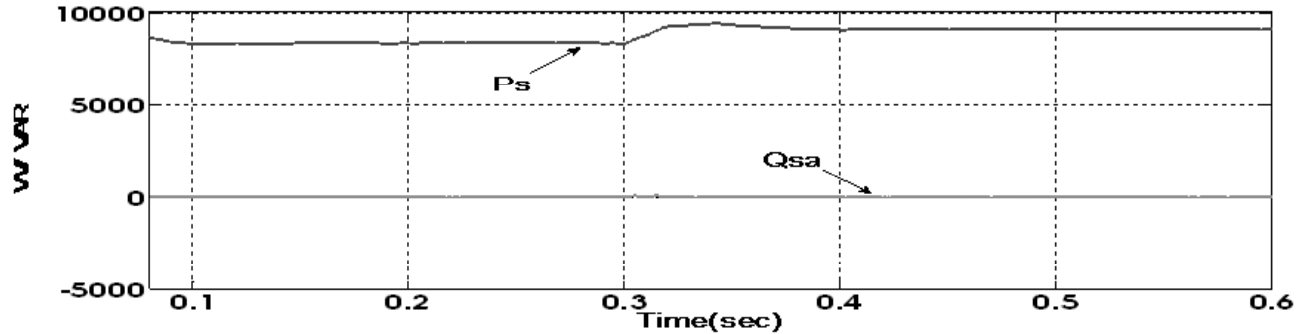


Figure 9: Active and Reactive Power with Shunt APF

The harmonic spectrum with shunt APF compensation of voltage and current of source and load are as shown in Fig. 10.

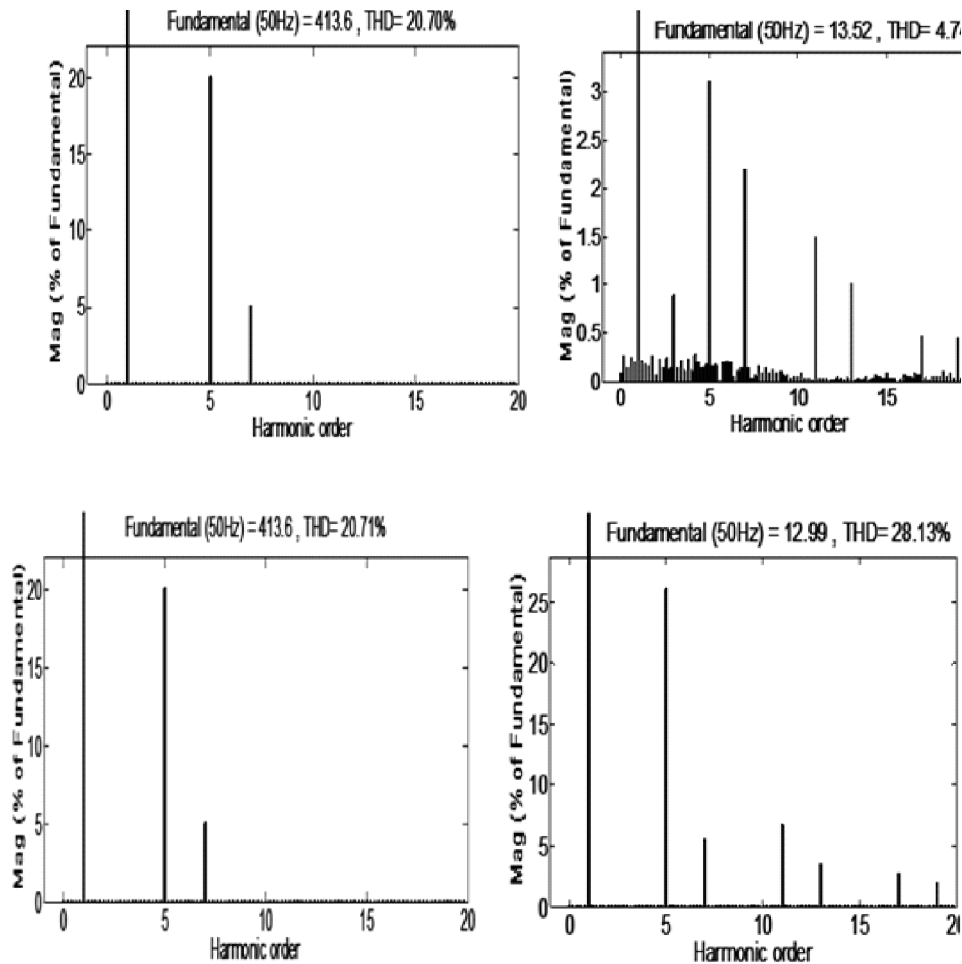


Figure 10: Harmonic FFT analysis with shunt APF with balanced load a) supply voltage b) supply current c) load voltage d) load current

During unbalanced load, source current THD is of 4.67% and load voltage THD is of 20.70%. Load current THD is of 25.73% the harmonic content in the load voltage is more than the IEEE standards which should be less than 5 %. With the shunt compensation three phase source currents are balanced and harmonics are reduced to 4.74%. Reactive power compensation is also achieved with the shunt APF. Fig. 9 shows the reactive power drawn from the source it has reduced to 30VAR. The waveforms with Universal APF compensation is as shown in Fig. 11.

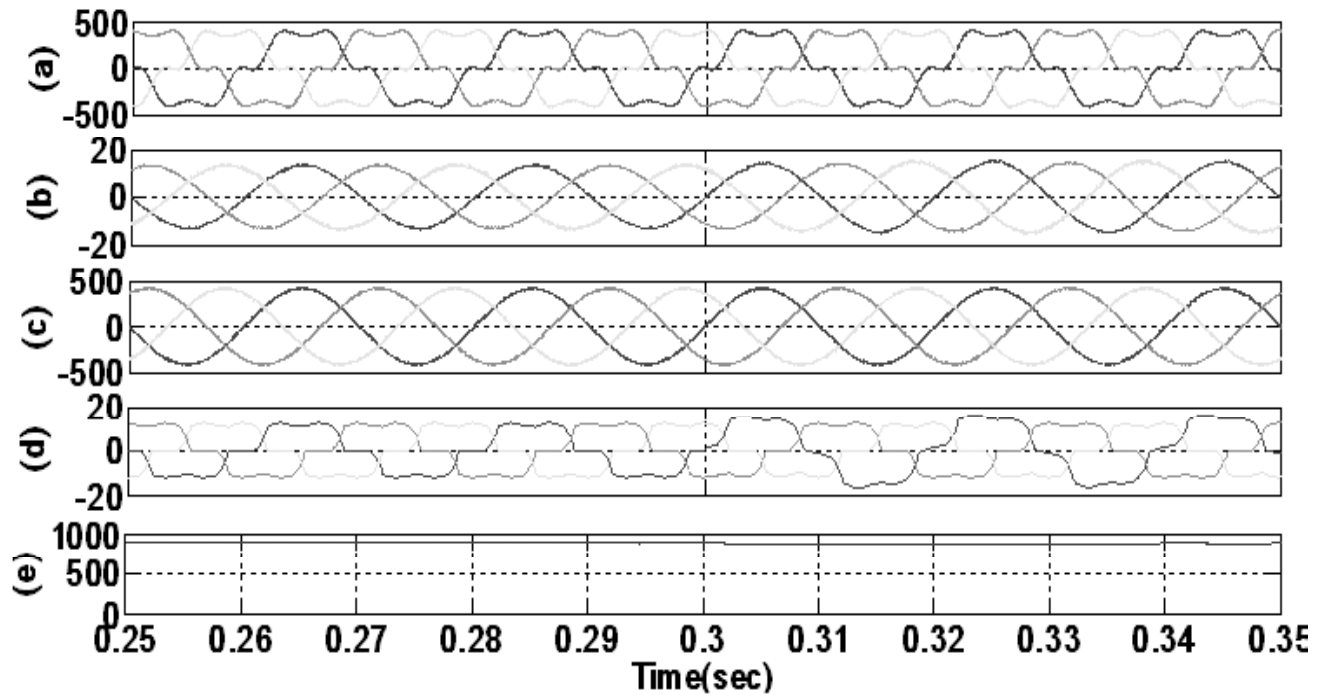


Figure 11: Using Universal active power filter a) supply voltage b) supply current c) load voltage d) load current e) DC link voltage (Vdc)

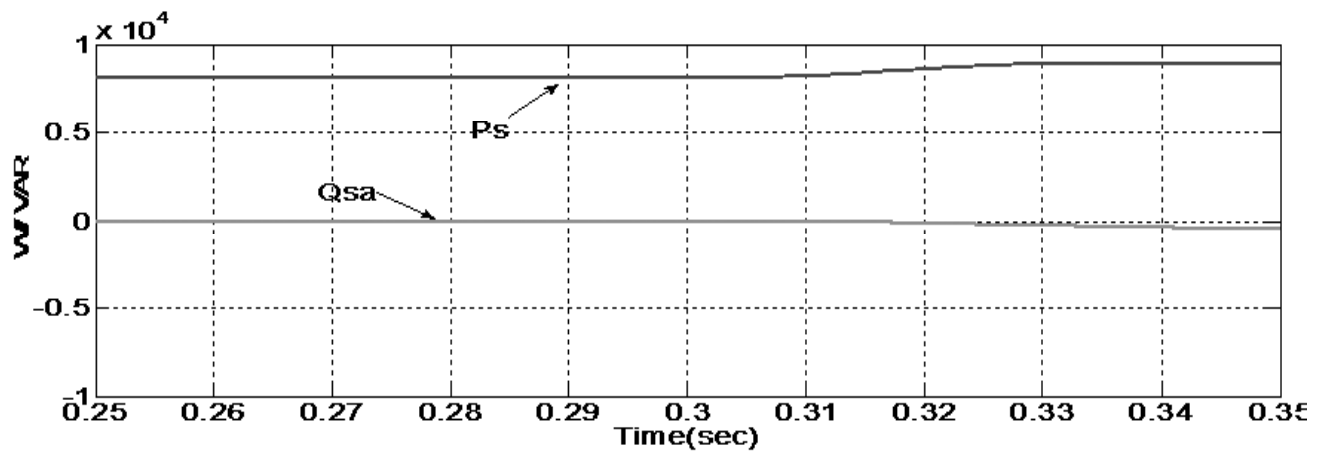


Figure 12: Active and Reactive Power with Universal APF

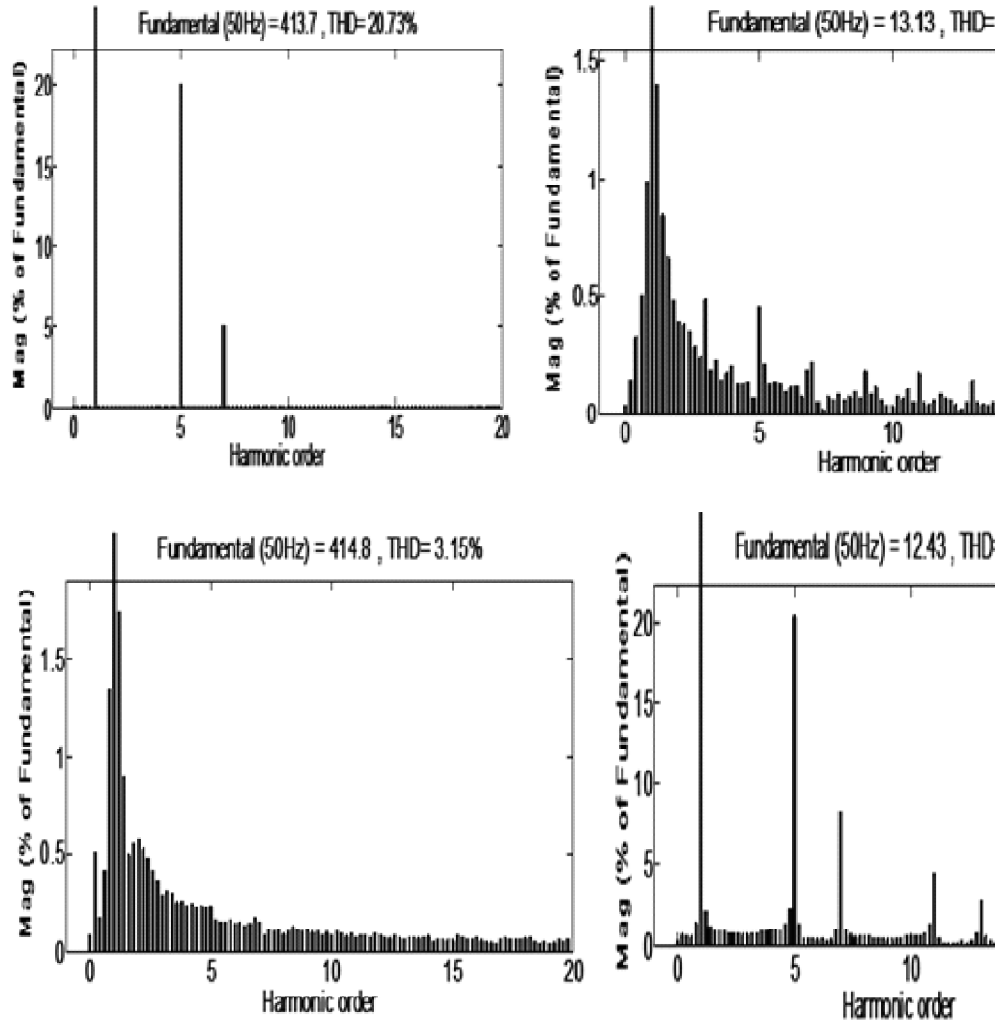


Figure 13: Harmonic Spectrum with Universal APF a) supply voltage b) supply current c) load voltage d) load current

Neutral current waveform without compensation is shown in Fig. 14.

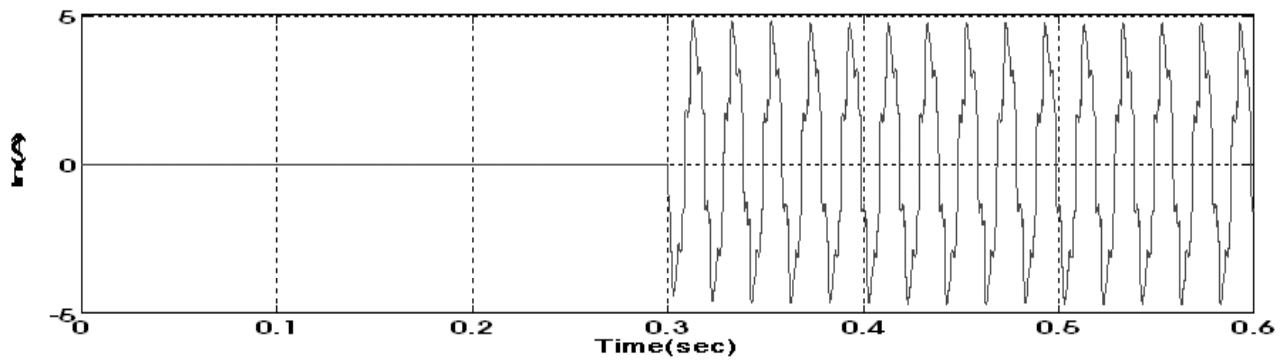


Figure 14: Neutral current without compensation

During balanced load no current flows through the neutral wire. When unbalanced load is applied the load current will be unbalanced and current start flowing in the neutral wire. The source current will be of unbalanced.

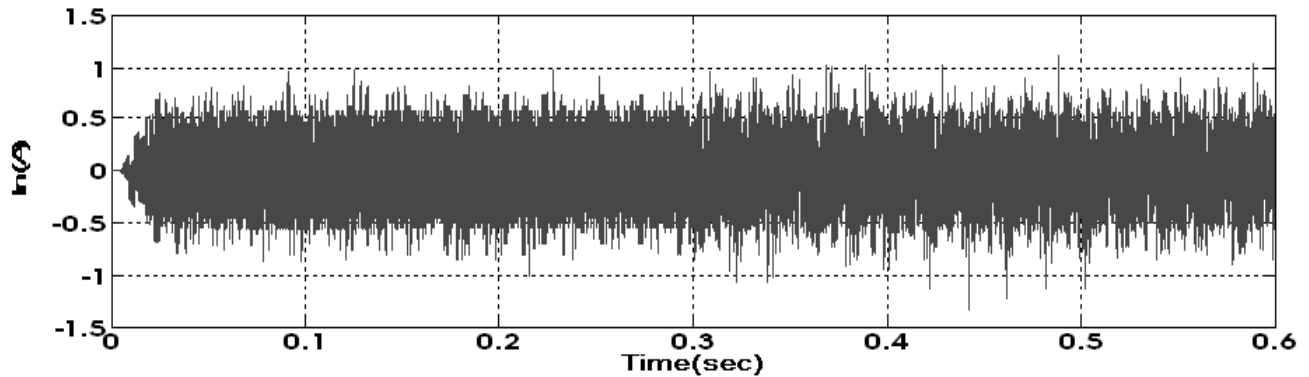


Figure 15: Neutral current with Shunt APF

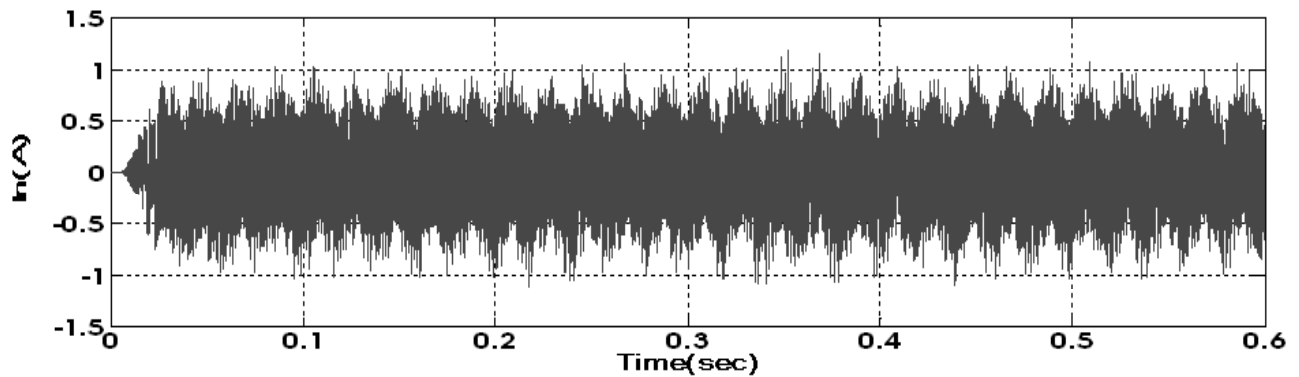


Figure 16: Neutral current with Universal APF

Neutral current compensation achieved using shunt and Universal active power filters as shown in Fig. 15 and Fig. 16. Table 2 gives the complete comparison of Total Harmonic Distortion (THD) compensation by different active power filters. The source voltage harmonics are of 20.49% and load current harmonics are of 26.25%.

Table 2
Harmonic Content

Type of load	Parameter	% Total Harmonic Distortion		
		WithOut APF	With Compensation	
			Shunt APF	Universal APF
Balanced Load	I_{sa}	28.9	4.74	2.89
	V_{La}	20.49	20.71	3.05
UnBalanced Load	I_{sa}	25.44	4.67	3.53
	V_{La}	20.49	20.70	2.31

Active and reactive power measured is given in Table 3 reactive power compensation is achieved by both the filters.

Table 3
Active and Reactive Power

<i>Type of load</i>	<i>Power</i>	<i>Without APF</i>	<i>With Shunt APF</i>	<i>With Universal APF</i>
Balanced Load	Active Power (KW)	8040	8340	8150
	Reactive Power (VAR)	450	30	30
UnBalanced Load	Active Power (KW)	8807	9100	8900
	Reactive Power (VAR)	120	40	39

6. CONCLUSION

In this paper work has been done to compare shunt and UAPF topologies. Performance analysis has done by comparing the harmonic compensation of each compensator, reactive power compensation and neutral current compensation. Shunt active power filter is proved to compensate current harmonics and neutral current compensation. The load current has THD of 28.94% with compensation it has reduced to 4.74% at source side. UAPF is verified to reduce both source current and load voltage harmonics. The harmonics of load voltage and source current are compensated considerably with UAPF. Current harmonics generated at load side has THD of 28.94%. With compensation the source current harmonics has reduced to 2.89%. Load voltage has THD of 20.49% which is reduced to 3.05% at load side voltage. UAPF has got better performance than shunt active power filters.

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