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Control of Shunt Active Power Filter for Improvement of Power Quality

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Abstract: Presence of Harmonics, voltage & frequency variations deteriorates the performance of the system. Quality of Power supplied is affected by various factors of the power system. Most of the Power Quality problems are introduce in to the system by the Power Electronics equipment because of its fast switching and non-linear characteristics. In the market competition Power Quality issues become very large because of using more sensitive equipment. This sensitive equipment will introduce more problems due to the built in compensation and sometimes lack of enforced regulations. Thus, Power quality improvement is become more important factor as a point of view for reliable & continuous Power System operation. Power quality may be improved by using filters and compensators. For improvement of Power Quality active power filters are used. This paper present the Simulink model of Shunt Active filters for improvement of Power Quality.

Keyword: Harmonics, THD, Active Filters, Shunt Active Filter.

I. INTRODUCTION

Most of the power quality problems are introduce by the Power Electronics devices because of its fast switching & non-linear characteristics. Because of increase in non-linearity causes different undesirable features like low system efficiency and poor power factor. It also causes disturbance to other consumers and interference in nearby communication networks. Hence, it is very important to overcome these undesirable features. Any Power Quality problem manifested in voltage and/or current deviations result into failure or disoperation of customer equipment. Both electric utility and end users of electric power are becoming increasingly concerned about the quality of electric power.

II. ACTIVE POWER FILTER

Active Power filters have wide application in modern electrical distribution system for eliminating the harmonics associated with it. The Shunt active power filter (SAPF) is one of power filters which have better dynamic performance and it needs an accurate control algorithm that provides robust performance. The control methods are responsible for generating the reference currents which used to trigger the Voltage Source Inverters (VSI). Need of Active Power filter is Due to harmonic injection in power system due to various nonlinear loads such as uninterrupted power suppliers (UPS), adjustable speed drives (ASD), furnaces and single phase computer power supply etc. has resulted serious power quality problems. Most of these of non-linear loads cause harmonic injection into the power system and degrade the system performances and lower the system efficiency.

Topologies of Active Power Filter (1) Shunt Active Power Filter and (2) Series Active Power Filter

III. SHUNT ACTIVE POWER FILTER

Fig.1 shows the basic block diagram of the shunt active filter, it is highly reliable with adequate compensation abilities. Shunt active filter has the capability for compensating load harmonic currents and reactive power requirement of the non-linear loads in power network. It is connected in parallel to power system network at a point of common coupling (PCC) between supply authority and consumers.

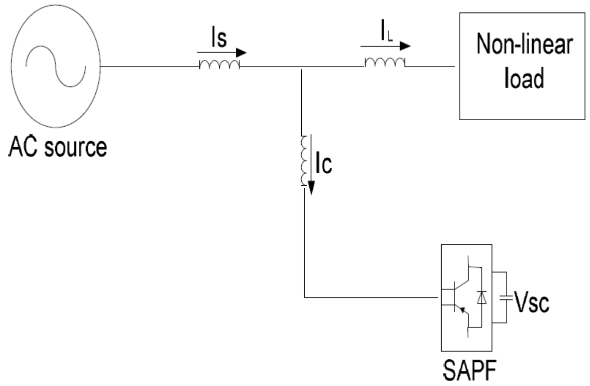

Figure 1: Shunt Active Filter

IV. SYSTEM CONFIGURATION

The configuration model of shunt active power filter using a voltage source converter (VSC) is shown in Fig.2. In this model; the resistance R_f in series with the voltage source inverter represents the sum of the coupling inductor resistance losses and the inverter conduction losses. The inductance L_f represents the leakage inductance of the coupling inductor. The sum of the switching losses of the inverter and the power losses in the capacitor is represented by R_{dc} which is in shunt with the DC-link capacitor C_{dc}. In Fig. 1, V_{fa} , V_{fb} , and V_{fc} are the three-phase Shunt Active Power Filter output voltages; V_{La} ,V_{Lb} , and V_{Lc} are the three phase bus voltages at load-side; i_{fa}, i_{fb} , and i_{fc} are the three-phase Shunt Active Power Filter output currents.

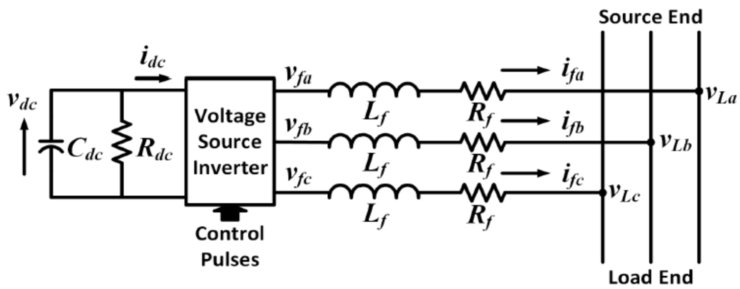

Figure 2: Equivalent circuit of SAPF

V. MODELING OF SHUNT ACTVE FILTER

In order to analyses the balanced three-phase system more conveniently, the three-phase voltages and currents are converted to synchronous rotating frame by *abc/dq0* transformation. The *dq*-frame rotate with an angle $\Theta = \omega t$ from the reference axis of the *abc*-frame. By this transformation, the control problem is greatly simplified since the system variables become DC values under the balanced condition. The transformation from phase variables to d and q coordinates is given as follows:

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \mathrm{T} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

Where,

$$T = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}$$

A linear mathematical model for each phase of the SAPF shown in Fig.2 can be written as:

$$\begin{aligned} L_f \frac{di_{fa}}{dt} &= -R_f i_{fa} + V_{fa} - V_{La} \\ L_f \frac{di_{fb}}{dt} &= -R_f i_{fb} + V_{fb} - V_{Lb} \\ L_f \frac{di_{fc}}{dt} &= -R_f i_{fc} + V_{fc} - V_{Lc} \end{aligned} \quad (2)$$

Equations (2) can be written in following form:

$$L_f \frac{d}{dt} \begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{bmatrix} = -R_f \begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{bmatrix} + \begin{bmatrix} V_{fa} \\ V_{fb} \\ V_{fc} \end{bmatrix} - \begin{bmatrix} V_{La} \\ V_{Lb} \\ V_{Lc} \end{bmatrix} \quad (3)$$

With *dq*-transformation from equation (1),

$$L_f \frac{d}{dt}\left(T^{-1} \begin{bmatrix} i_{fd} \\ i_{fq} \\ i_{f0} \end{bmatrix} \right) = -R_f T^{-1} \begin{bmatrix} i_{fd} \\ i_{fq} \\ i_{f0} \end{bmatrix} + T^{-1} \begin{bmatrix} V_{fd} \\ V_{fq} \\ V_{f0} \end{bmatrix} - T^{-1} \begin{bmatrix} V_{Ld} \\ V_{Lq} \\ V_{L0} \end{bmatrix}$$

The above equation can be simplified as:

$$L_f T \left(\frac{d}{dt}(T^{-1}). \begin{bmatrix} i_{fd} \\ i_{fq} \\ i_{f0} \end{bmatrix} + (T^{-1}) \frac{d}{dt} \begin{bmatrix} i_{fd} \\ i_{fq} \\ i_{f0} \end{bmatrix} \right) = -R_f \begin{bmatrix} i_{fd} \\ i_{fq} \\ i_{f0} \end{bmatrix} + \begin{bmatrix} V_{fd} \\ V_{fq} \\ V_{f0} \end{bmatrix} - \begin{bmatrix} V_{Ld} \\ V_{Lq} \\ V_{L0} \end{bmatrix} \quad (4)$$

Where,

$$\frac{d}{dt}(T^{-1}) = \omega \sqrt{\frac{2}{3}} \begin{bmatrix} -\sin\theta & \cos\theta & 0 \\ -\sin(\theta - \frac{2\pi}{3}) & \cos(\theta - \frac{2\pi}{3}) & 0 \\ -\sin(\theta + \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) & 0 \end{bmatrix}$$

$$T.\frac{d}{dt}(T^{-1}) = \omega \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$\frac{d\theta}{dt} = \omega$$

Applying all the above relation in equation (4)

$$\frac{d}{dt} \begin{bmatrix} i_{fd} \\ i_{fq} \\ i_{f0} \end{bmatrix} = \begin{bmatrix} \frac{-R_f}{L_f} & \omega & 0 \\ -\omega & \frac{-R_f}{L_f} & 0 \\ 0 & 0 & \frac{-R_f}{L_f} \end{bmatrix} \begin{bmatrix} i_{fd} \\ i_{fq} \\ i_{f0} \end{bmatrix} + \frac{1}{L_f} \begin{bmatrix} V_{fd} \\ V_{fq} \\ V_{f0} \end{bmatrix} - \frac{1}{L_f} \begin{bmatrix} V_{Ld} \\ V_{Lq} \\ V_{L0} \end{bmatrix} \quad (5)$$

Suppose, the output voltage of the SAPF can be expressed as:

$$v_{fd} = K v_{dc} \cos\theta \quad (6)$$

$$v_{fq} = K v_{dc} \sin\theta \quad (7)$$

Where K is a factor that relates the DC voltage to the peak phase-to-neutral voltage on the AC side; v_{dc} is the DC-link voltage; α is the phase angle which the SAPF output voltage leads the bus voltage.

Using the relation (6) and (7), the equation (5) can be modified as

$$\frac{d}{dt}\begin{bmatrix} i_{fd} \\ i_{fq} \end{bmatrix} = \begin{bmatrix} \frac{-R_f}{L_f} & \omega & \frac{K\ \cos\alpha}{L_f} \\ -\omega & \frac{-R_f}{L_f} & \frac{K\ \sin\alpha}{L_f} \end{bmatrix} \begin{bmatrix} i_{fd} \\ i_{fq} \\ v_{dc} \end{bmatrix} - \frac{1}{L_f}\begin{bmatrix} V_{Ld} \\ V_{Lq} \\ V_{L0} \end{bmatrix} \quad (8)$$

From the SAPF input-output power balance equation, it can be written as:
$p_{dc} = p_f$

Or, $v_{dc} i_C + v_{dc} i_R = v_{fa} i_{fa} + v_{fb} i_{fb} + v_{fc} i_{fC}$

Or, $v_{dc} C_{dc} \frac{dv_{dc}}{dt} + \frac{v_{dc}^2}{R_{dc}} = v_{fd} i_{fd} + v_{fq} i_{fq}$

Or, $\frac{dv_{dc}}{dt} = \frac{K\ \cos\alpha}{C_{dc}} i_{fd} + \frac{K\ \sin\alpha}{C_{dc}} i_{fq} - \frac{v_{dc}}{R_{dc} C_{dc}}$ (9)

From the equations (8) and (9), the relation for the dynamic model of the SAPF can be derived and is given below:

$$\frac{d}{dt}\begin{bmatrix} i_{fd} \\ i_{fq} \\ v_{dc} \end{bmatrix} = \begin{bmatrix} \frac{-R_f}{L_f} & \omega & \frac{K}{L_f}\cos\alpha \\ -\omega & \frac{-R_f}{L_f} & \frac{K}{L_f}\sin\alpha \\ \frac{K}{C_{dc}}\cos\alpha & \frac{K}{C_{dc}}\sin\alpha & \frac{1}{R_{dc} C_{dc}} \end{bmatrix} \begin{bmatrix} i_{fd} \\ i_{fq} \\ v_{dc} \end{bmatrix} - \frac{1}{L_f}\begin{bmatrix} v_{Ld} \\ v_{Lq} \\ v_{L0} \end{bmatrix} \quad (10)$$

VI. SIMULATON MODEL OF SHUNT ACTVE FILTER

The model used in Simulink to study with Shunt Active Filter is shown below:

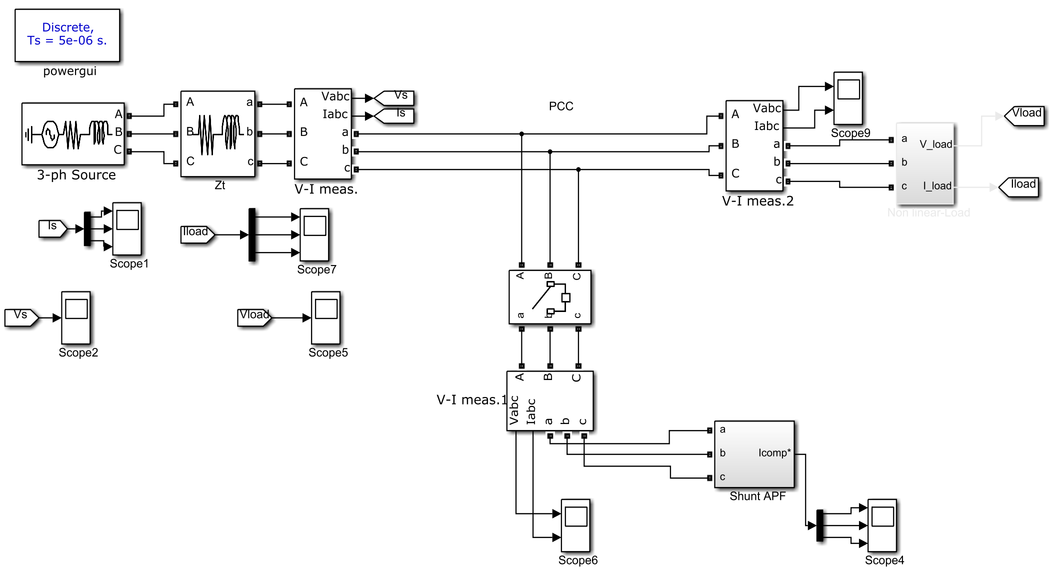

Figure 3: Simulation model of shunt active filter

Figure 4 depicts SIMULINK model of with shunt active filter, whereas Figure 3 shows the implementation details of shunt active filter which consist the four block such as Universal bridge, PQ & I-compensation, PI-controller and DC capacitor. PI-controller is connected with dc capacitor which regulates the dc voltage.

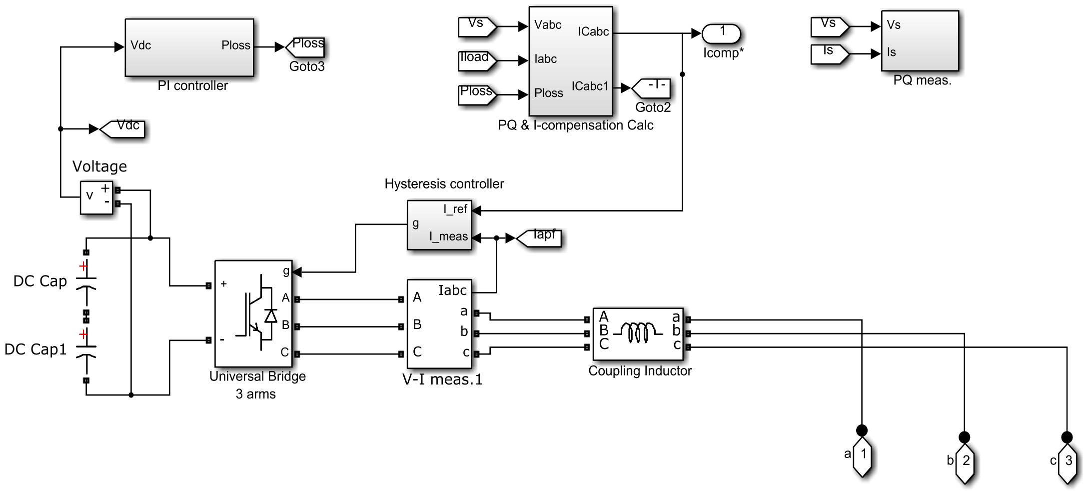

Figure 4: Subsystem of shunt active filter

VII. RESULTS AND DISCUSSION

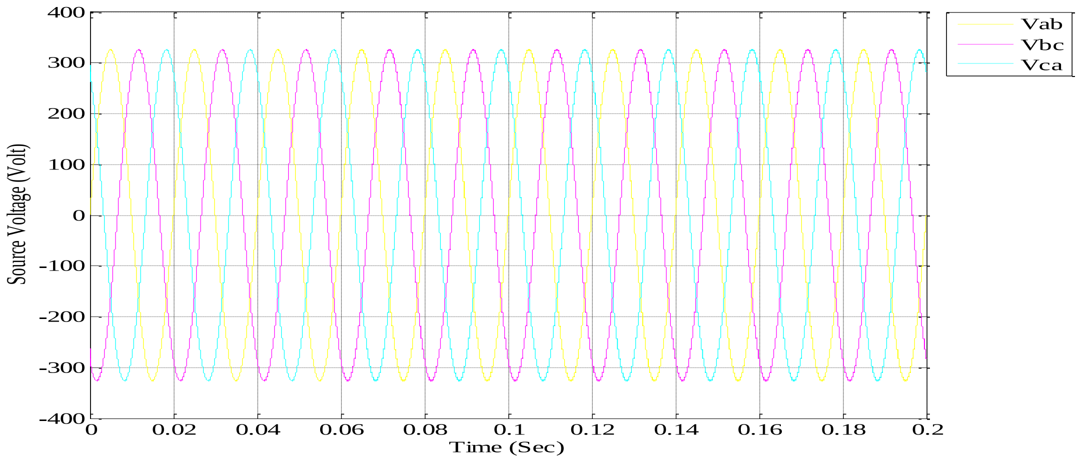

Figure 5: Waveform of Source Voltage

Fig (5) and (6) shown the waveform of source voltage and current respectively.

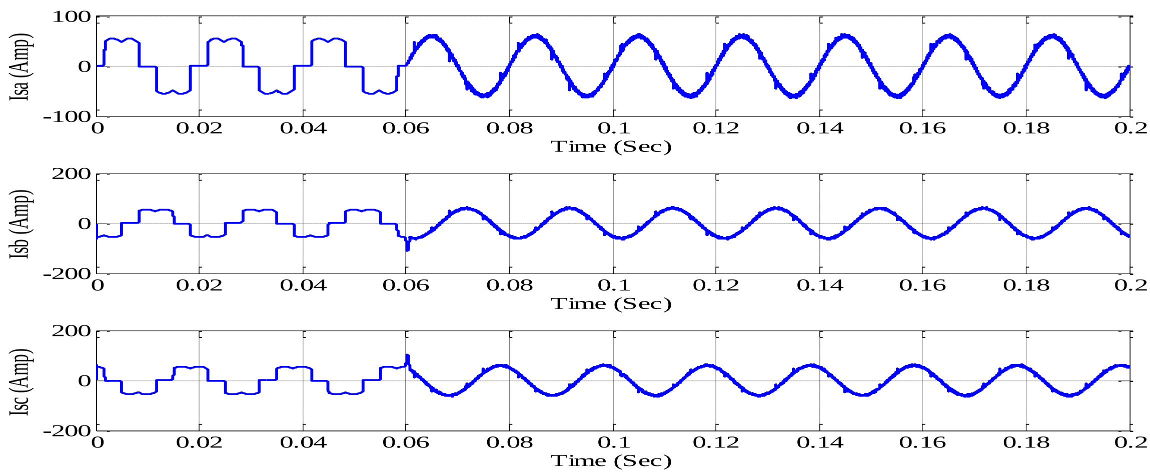

Figure 6: Waveform of Source Current

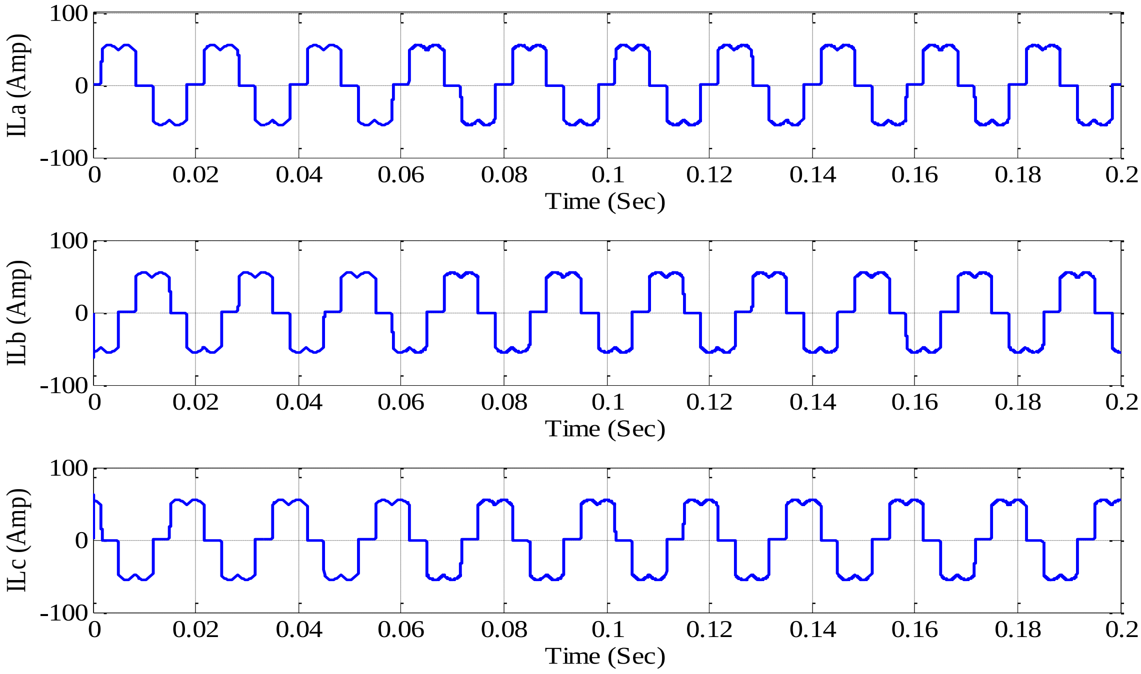

Figure 7: Waveform of Load Current

Figure (8) and (9) THD analysis of the load current before and after CB is ON respectively.

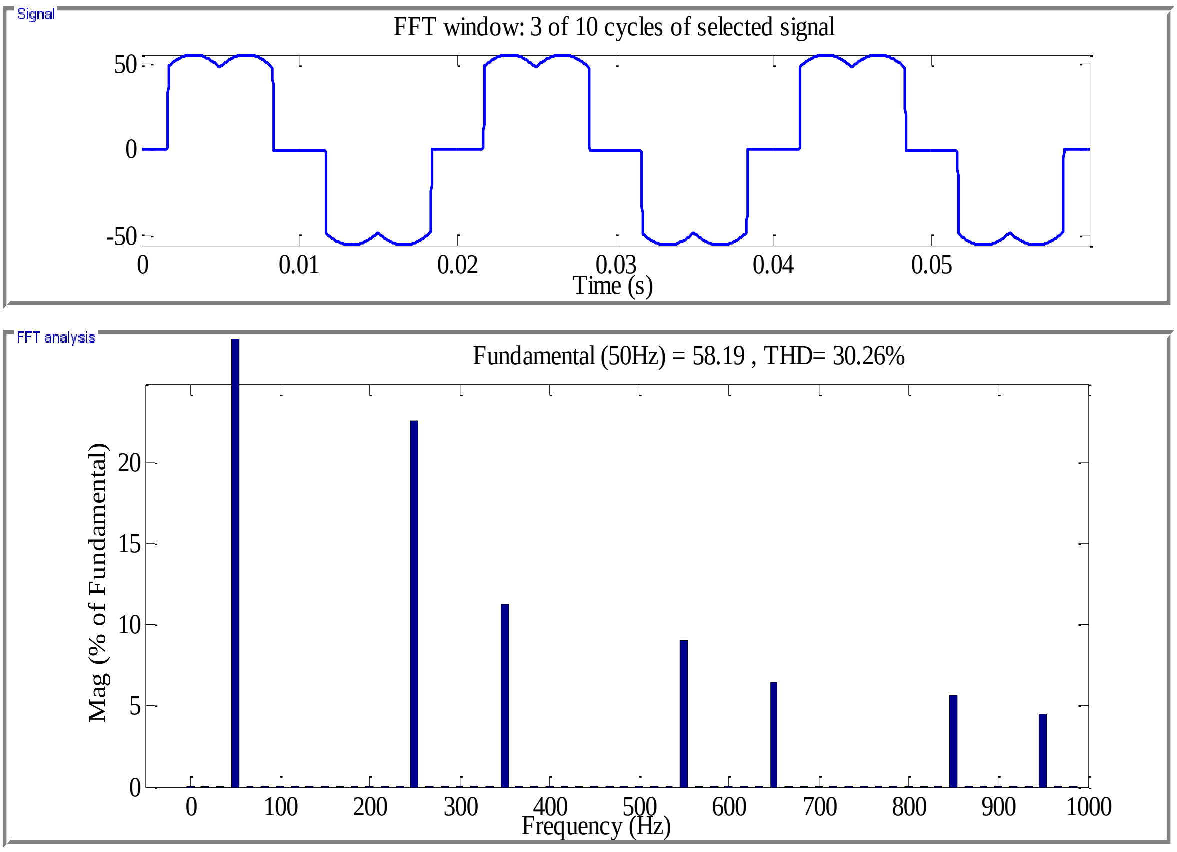

Figure 8: THD of Load Current before CB ON

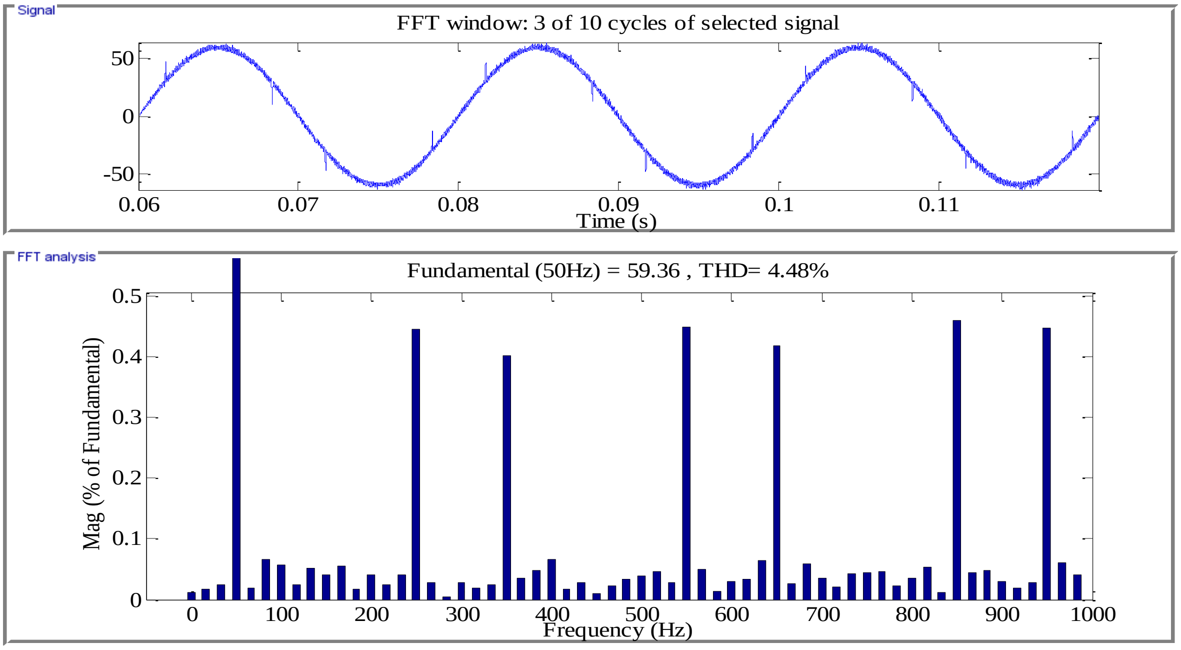

Figure 9: THD of Load Current after CB ON

When Shunt Active Filter is not connected to the system, the THD at the load Side is calculated as 30.26%. After Shunt Active Filter involve in to the system the THD is decrease to 30.26% to 4.42% which is shown in Table-1.

Table: 1 THD analysis

Without Shunt Active Filter	**30.26%**
With Shunt Active Filter	**4.48%**

VIII. CONCLUSION

Performance of shunt active power filter is checked with the use of MATLAB software. In the proposed scheme one type of load has been considered as nonlinear loads. Fig. 9 shows the performance of shunt active power filter under restive rectifier load. In this case the before the insertion of the shunt active power filter, Total Harmonic Distortion (THD) of source current was 30.26 % and after the insertion it comes down up to 4.42 %. Output result of load current for this case is shown in fig. 7.The shunt active filter was inserted at 0.06 second in the system.

IX. FUTURE WORK

The three phase active filter based on p-q theory can be implemented for harmonic mitigation and power factor correction. The PI controllers are applied to control the injection of the compensating currents and the DC bus voltage following on the command value. The design method of these controllers is completely presented in the paper.

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