Modelling of Shunt Active Power Filter (SAPF) for stochastic and non-uniform Loads

Dr.Ramchandra Nittala[1], Dr.P.Santosh Kumar Patra[2]
HOD & Professor in EEE[1], Principal & Professor in CSE[2]
St. Martin's Engineering College, Secunderabad, India[1,2]
hodeee@smec.ac

***Abstract*— Rising power demand must comply with the generation of power in the current situation. The produced power must meet the requirements of quality. With the implementation of stochastic loads, such as static power converters, harmonics are introduced into the system, adversely affecting system operation. These harmonics are to be mitigated and reactive power must be compensated to increase the efficiency of the device. A Shunt Active Power Filter (SAPF) is intended to compensate for reactive power in the proposed work, and the system's behaviour is evaluated by adding reverse harmonic current.**
Keywords— **Shunt Active Power Filter, Instantaneous Power Theory, Clarkes Transformation, Total Harmonic Distortion (THD), Pulse Width Modulation.**

I.INTRODUCTION

The production of non-linear loads such as diode rectifiers, thyristor converters, adjustable speed drives, furnaces, computer power supplies, uninterruptible power supplies, etc. has provided scope for the development of non-linear loads that are economical, versatile and energy efficient but affect power quality by generating voltage harmonics from current harmonics and consuming extra reactive power supplies.[1] Since their inception in 1970, comprehensive research has been done on active filters. Improvements in the technology of power electronics have essentially led engineers to use active filters. Several numbers of shunt active filters using insulated biplolar transistors (IGBT) or gate turn-off (GTO) thyristors made up of Pulse Width Modulation (PWM) inverters are operating successfully. Passive LC filters are usually used to reduce line current harmonics and to increase the power factor. But passive filters have so many disadvantages, such as they are bulky in size, compensation is fixed and resonance is induced. Active power filters have been designed to overcome the disadvantages of passive filters. [3]

Modern active filters are better than traditional passive filters in terms of their behavior, small size, and their versatility in application. Moreover, active filters are available at a lower cost than passive filters, with a low operating loss. [2]

II. ACTIVE FILTERS

Active Power Filters (APF) are used in applications with low (<100kVA), medium (100kVA-10MVA) and large (>10 MVA) power [7]. A DC Capacitor Unit, DC/AC converter and Harmonic filter typically make up the power circuit of Active Power Filters.

A. DC Capacitor Unit

The functions of the DC Capacitor Device are twofold; first, a DC Voltage is preserved with a slight ripple during the steady state. Secondly, it provides real power difference between load and source acting as an energy storage element during the transient cycle.

B. DC/AC Converter

A power inverter or inverter is a circuit or electronic power system that converts direct current (DC) to alternating current (AC). ... Depending on the configuration of the particular system or circuitry, the input voltage, output voltage and frequency, and overall power handling are dependent.

C. Harmonic Filter

For minimizing the harmonic at different frequencies, an inductance for output filtering of VSI is used. The attenuation of switching ripple currents with various L and C filter combinations was investigated in [8]. A rectifier failure or shutdown occurs if it has an extra low inductance feature or is linked to a load with a high frequency input current with phase control. A reactor of 3-5 percent must be connected to the input side of the load to reduce the increasing rate of load input current for the above load. [9]. The LC passive filter is used in [10] for reactive power compensation and mitigation of harmonics. Smaller inductors can be used in the LCL-filter presented in [11] to achieve the necessary damping of switching harmonics compared to the L-filter due to cost and dynamic performance advantages. [5]

III. TYPES OF ACTIVE POWER FILTERS

In many power circuit configurations, Active Power Filters can be connected. Shunt Active Power Filters, Series Active Power Filters, and Hybrid Active Power Filters are typically categorized into three groups. [12][13].

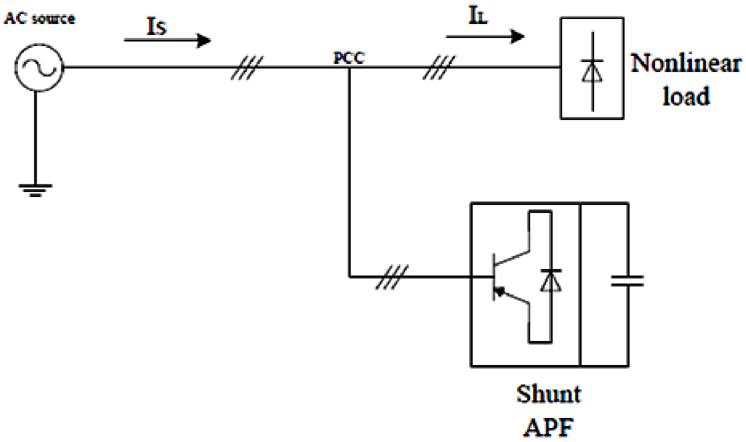

Fig. 1. Shunt Active Power Filter

A. Shunt Active Power Filter:

The most significant and most commonly used category in active filtering applications is this class of filter configurations. In Fig 1, the Shunt Active Power Filter is shown. Its purpose is to cancel the harmonics of the load current fed to the supply. Balancing three-phase currents and reactive power compensation are its contributions. A small amount of active fundamental current plus the compensation current is supplied by Parallel filters to compensate for device losses. A variety of filters can be attached in parallel to get greater currents for a wide range of power ratings.

B. Series Active Power Filter

In this design, the active filter generates a Pulse Width Modulated voltage waveform which is instantaneously added or subtracted to/from the supply voltage to maintain a pure sinusoidal voltage waveform across the load. Active filters in the general series are hardly used in industries as opposed to parallel active filters. The key downside is high current ratings on the secondary side of the coupling transformer, as these filters must bear high load currents. These are used for controlling three phase voltages and reducing the harmonics of the voltage. For voltage sensitive applications, these are favored.

C. Hybrid Active Power Filters

The technological limitations of traditional Active Power Filters can be solved by these setups. Both APFs and passive filters are made up of hybrid APFs. Hybrid APFs have provided cost-effective solutions with better efficiency, with the benefits of both passive and active filters. In addition to the traditional APF, this system uses a low-cost passive high-pass filter. These two filters split the filtering task between them. APF handled the lower order harmonics, while passive filters handled the higher order harmonics. Hybrid APF provides better filtering efficiency of higher order harmonics with cost efficient low order harmonics mitigation. [4]

IV. INSTANTANEOUS POWER THEORY

The regulation of active power filters in real time is carried out in the time domain by the p-q principle or instant power theory; it can also be used for generic voltage and current waveforms in either steady-state or transient state. A Clarke transformation of a stationary reference system of co-ordinates a-b-c to a reference system of co-ordinates a-β-0, also stationary, is performed by the p-q principle. In ABC coordinates axes are set on the same plane, displaced from each other by 120^0.

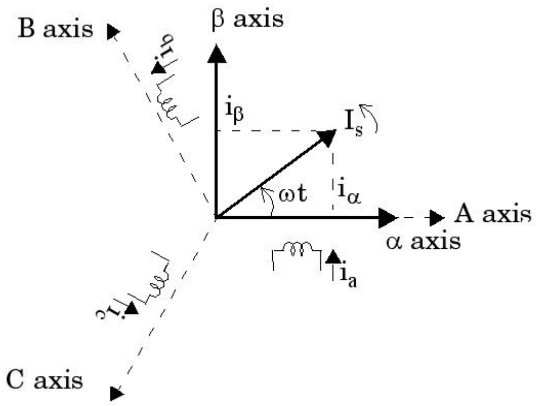

Fig. 2. ABC to αβ0 Transformation

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \\ v_0 \end{bmatrix} \tag{4}$$

where i_a, i_b, i_c are the load currents and v_a, v_b, v_c are the load voltages The equations of active, reactive and zero-sequence powers are defined as in equations.

$$p = v_\alpha i_\alpha + v_\beta i_\beta \qquad (5)$$

$$q = v_\alpha i_\beta - v_\beta i_\alpha \qquad (6)$$

$$p_0 = v_0 i_0 \qquad (7)$$

The currents, voltages and powers in the α-β system can be decomposed in mean and alternating values, in terms of the fundamental and harmonic components, as in equation.

$$x = \bar{x} + \tilde{x} \text{ (8)} \qquad (8)$$

Where x can be powers, currents, or voltages. The power components have the following physical meaning [14]

p_0 Zero Sequence Power
$\bar{p}$ Mean Value of the Instantaneous Real Power
$\tilde{p}$ Alternating Value of the Instantaneous Real Power
$\bar{q}$ Mean Value of the Imaginary Power
$\tilde{q}$ Alternating Value of the Imaginary Power

The powers required to be compensated by the APF are calculated as in equation

$$\begin{bmatrix}\tilde{p}\\ q\end{bmatrix} = \begin{bmatrix}\overline{v_\alpha} & \overline{v_\beta}\\ 0 & 0\end{bmatrix}\begin{bmatrix}\widetilde{i_\alpha}\\ \widetilde{i_\beta}\end{bmatrix} + \begin{bmatrix}0 & 0\\ -\overline{v_\beta} & \overline{v_\alpha}\end{bmatrix}\begin{bmatrix}i_\alpha\\ i_\beta\end{bmatrix} \qquad (9)$$

The reference currents are calculated by adding the active power required to regulate the DC bus voltage, ploss to the alternative value of instantaneous real power from the following equation.

$$\begin{bmatrix}i_\alpha^*\\ i_\beta^*\end{bmatrix} = \frac{1}{\Delta}T\begin{bmatrix}0\\ \bar{q}\end{bmatrix} + \frac{1}{\Delta}T\begin{bmatrix}\tilde{p} + p_{loss}\\ \tilde{q}\end{bmatrix} \qquad (10)$$

$$\text{Where } \Delta = \overline{v_\alpha^2} + \overline{v_\beta^2} \text{ and } T = \begin{bmatrix}\overline{v_\alpha} & -\overline{v_\beta}\\ \overline{v_\beta} & \overline{v_\alpha}\end{bmatrix}$$

From (9) the APF computes $\tilde{p}$ using the harmonic components of the currents while $q= \bar{q}+\tilde{q}$ are computed using the load current, including AC and DC components, according to Fig. 3.

Transformation of load currents from three-phase abc to αβ0 components is done using Clarke transformation, as in (11).

$$\begin{bmatrix}i_a^*\\ i_b^*\\ i_c^*\end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix}1 & 0 & \frac{1}{\sqrt{2}}\\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}}\\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}}\end{bmatrix}\begin{bmatrix}i_\alpha^*\\ i_\beta^*\\ i_0^*\end{bmatrix} \qquad (11)$$

Shunt active power filter provides compensation strategy based on the p-q theory of all undesired power components (p $p_0$and q). [4].

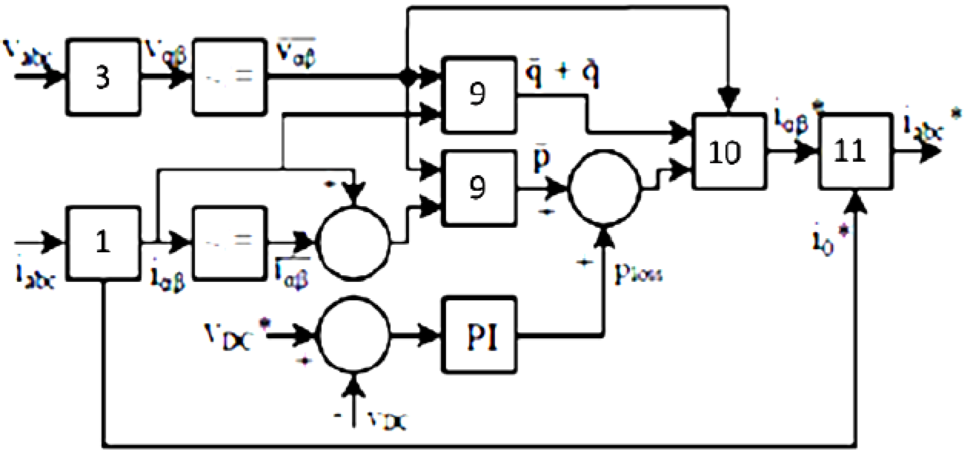

Fig. 3. Proposed Control Strategy

V. DESIGN OF SHUNT ACTIVE POWER FILTER USING MATLAB

A Shunt Active Power Filter is designed with MATLAB/Simulink as shown in the Fig. 4.
The model consists of a three phase source supplying a phase to phase RMS voltage of 400Volts, 50Hz with Yg internal connection having a source resistance R_S=0.001Ohms, source inductance Ls=1e-8Henries, series resistance R=0.01Ohms and series inductance of L=1e-6Henries.
Two types of loads are connected to the system, they are firstly a rectifier with a load resistance of 10 Ohms and a three phase non-uniform star connected resistive load with 10 Ohms, 20 Ohms & 30 Ohms in the respective a, b, & c phases.

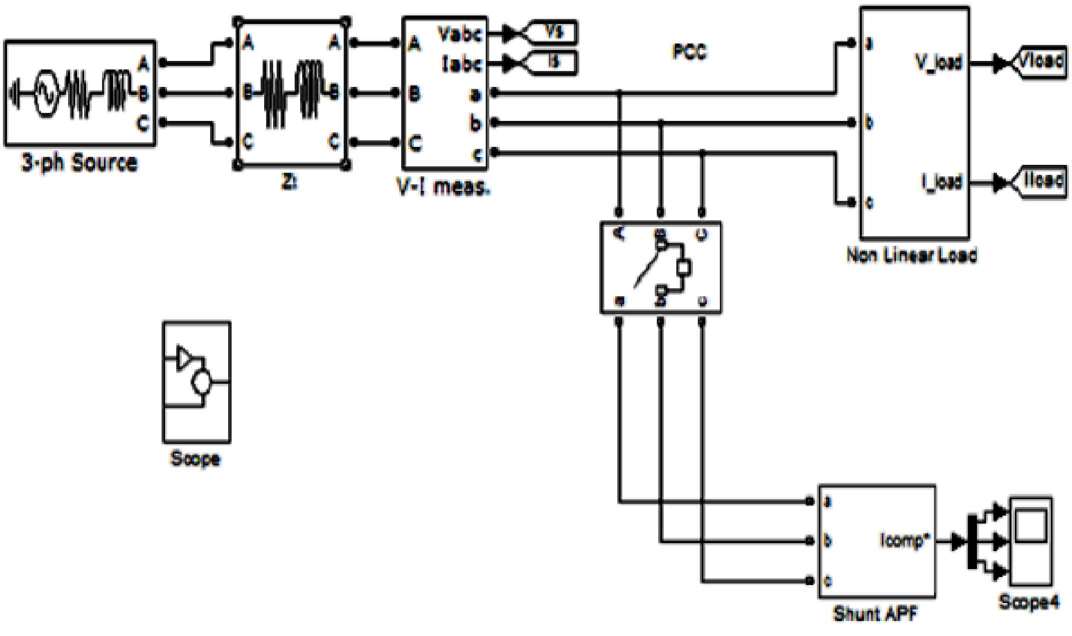

Fig. 4. Simulink Model of Shunt Active Power Filter

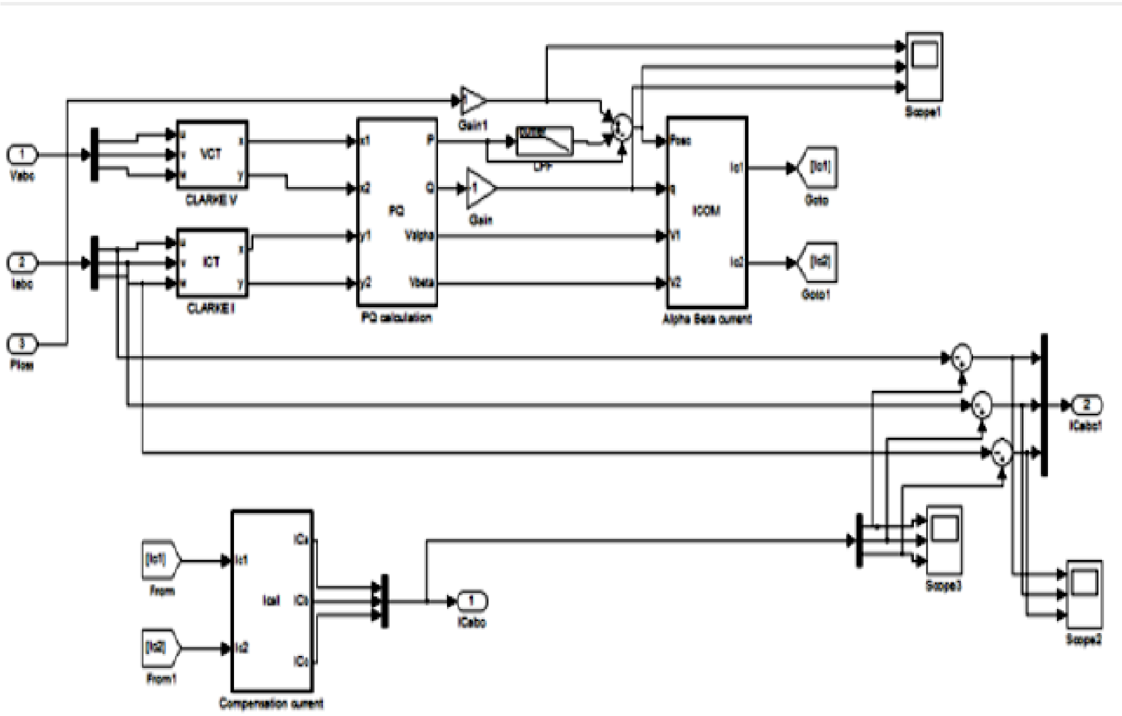

Fig. 5. Simulink Model of Control of Shunt Active Power Filter

VI. SIMULATION RESULTS

Shunt Active Power Filter MATLAB model is simulated by connecting stochastic load from starting and the non-uniform load at T=0.1 seconds with a sampling time of Ts=5e-6seconds without connecting filter and the performance of the system is analyzed by the output waveforms and the Total Harmonic Distortion (THD) of the signals are calculated. The output waveforms are shown in Fig. 6 & Fig. 7.

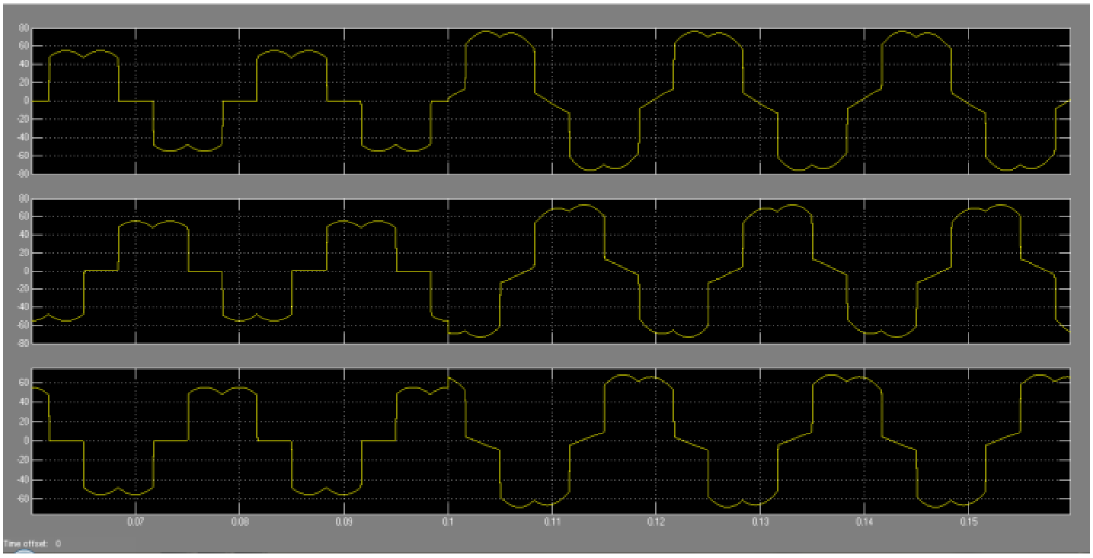

Fig. 6. Three Phase Supply Current without Filter

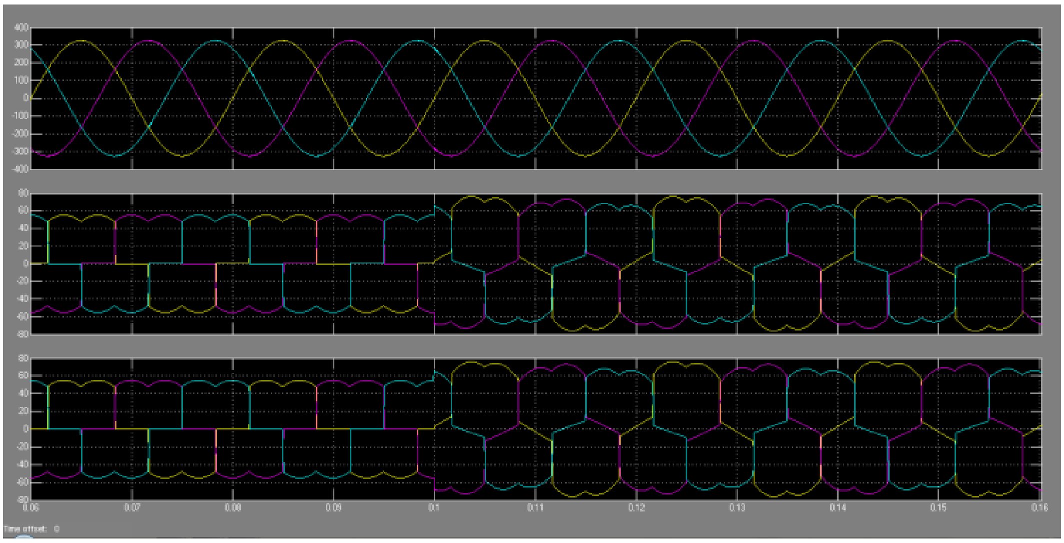

Fig. 7. Three Phase Load Voltage, Load Current and Supply Current without Filter

Now Shunt Active Power Filter is connected to the model with a Transition time of T=0.01 seconds and the model is simulated again, it was observed that at T=0.01 seconds the filter got turned on and the process of mitigating current harmonic has started and the performance of the system started to improve. The results from the simulation were observed from the waveforms and the Total Harmonic Distortion (THD) of the signals. The output waveforms after connecting the filter were shown in Fig. 8, Fig. 9 & Fig.10.

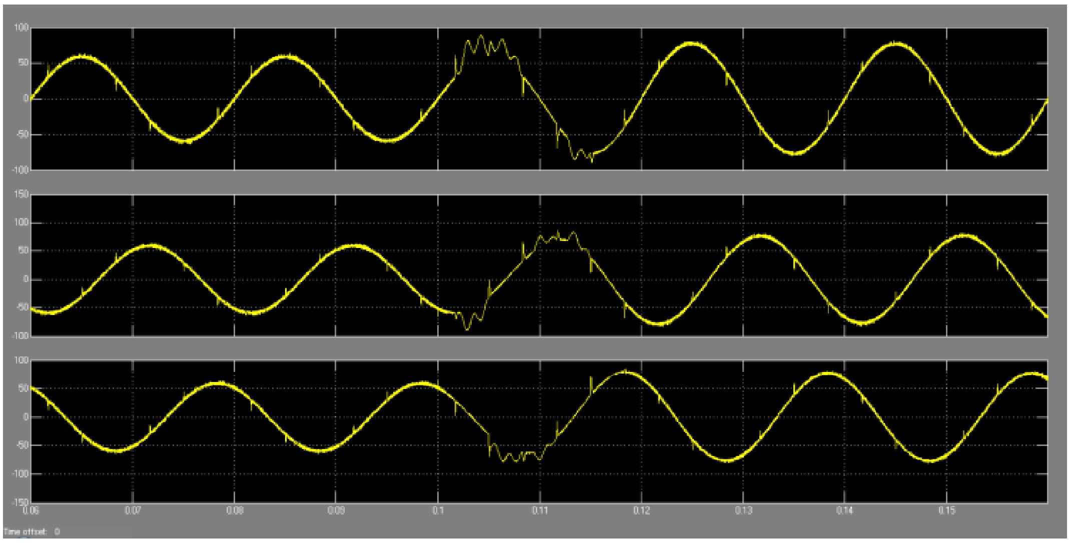

Fig. 8. Three Phase Supply Current with Filter

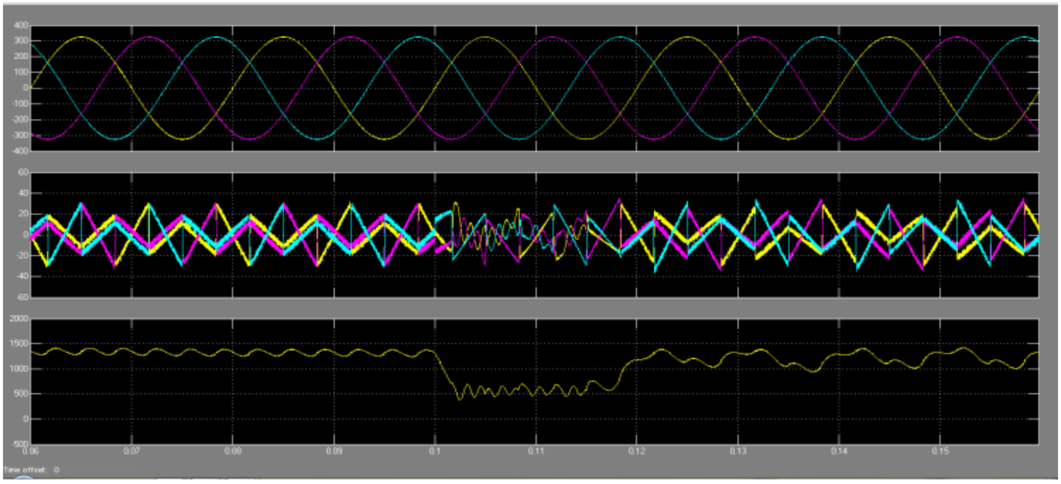

Fig. 9. Three Phase Supply Voltage, Filter Current and DC Voltage with Filter

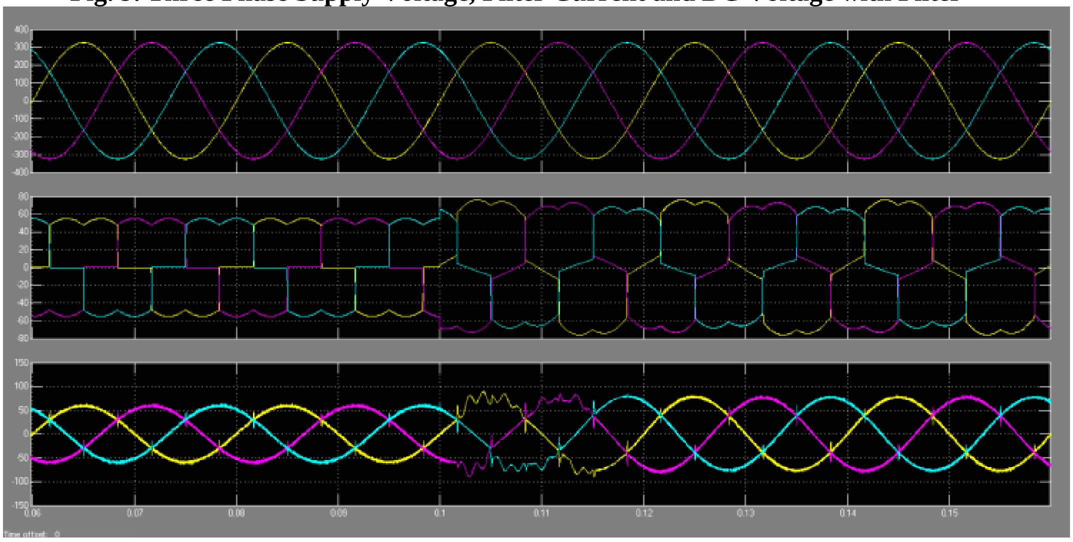

Fig. 10. Three Phase Load Voltage, Load Current and Supply Current with Filter

TABLE I

TOTAL HARMONIC DISTORTION OF SUPPLY CURRENT WITH AND WITHOUT FILTER FOR STOCHASTIC AND NON-UNIFORM Loads.

Signal	Signal Number	THD in % without filter	THD in % with filter
NON LINEAR LOAD & UNBALANCED LOAD			
Is	1	21.88	3.31
	2	23.11	3.79
	3	24.59	3.70
NON LINEAR LOAD			
Is	1	30.26	4.60
	2	30.26	4.48
	3	30.26	4.60

VII. CONCLUSIONS

The Shunt Active Power Filter (SAPF) model is simulated with MATLAB/Simulink and the Total Harmonic Distortion (THD) of the supply current (Is) is decreased with SAPF from 21.88% to 3.31% for non-linear load and unbalanced load and from 30.26% to 4.60% for non-linear load only. This increases the system's output by compensating for reactive strength and mitigating the harmonics.

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