MITIGATION OF CURRENT HARMONICS USING SHUNT ACTIVE POWER FILTER

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ABSTRACT
A study on the shunt active power filter is brought out in this paper in order to mitigate source current harmonics due to the increasing non-linear loads. The shunt active power filters provide dynamic compensation of current harmonics. The shunt active power filters have been developed based on control strategies like instantaneous active and reactive power compensation scheme (P-Q control) .The compensation is carried out by the use of hysteresis based controllers. P-Q control scheme is implemented in simulation work and its harmonic compensation results are analysed for a non-linear load like thyristor convertor. Then this compensation is carried on a practical welding load (non-linear load). Its current waveform is captured using a power quality analyser meter and modelled in MATLAB simulink and then compensation is done using shunt active power filter.

KEYWORDS: *Non-linear load, Mitigate, Shunt Active Power Filter, P-Q Control, Harmonics, Compensation.*

I. INTRODUCTION

The increase of the nonlinear loads due to the proliferation of electronic equipment causes power quality in the power system to deteriorate. For example, solid-state conversion of AC power using diodes and thyristor is widely adopted to control a number of processes such as adjustable speed drives (ASD), furnaces, chemical processes such as electroplating etc., power supplies, welding, heating etc. These solid state converters are also used in power industries such as HVDC transmission systems, battery energy storage systems and interfacing renewably energy electricity generating. Some of these solid state controllers draw harmonic currents and reactive power from the supply network and behave as non-linear loads. Harmonic current drawn from a supply by the nonlinear load causes the distortion of the supply voltage wave format the point of common coupling (PCC) due to the source impedance. Both distorted current and voltage may cause end user equipment to malfunction, conductors to overheat and may reduce the efficiency and life expectancy of the equipment connected at the PCC. Classically, shunt passive filters, consist of tuned LC filters and/or high passive filters are used to suppress the harmonics and power capacitors are employed to improve the power factor. But they have the limitations of fixed compensation, large size and can also exile resonance conditions. Active power filters are now seen as a viable alternative over the classical passive filters, to compensate harmonics and reactive power requirement of the non-linear loads. The objective of the active filtering is to solve these problems by combining with a much-reduced rating of the necessary passive components.

II. SIMULATION OF NON LINEAR LOAD

The below simulation shows the simulation of DC Motor drive which has been performed in MATLAB

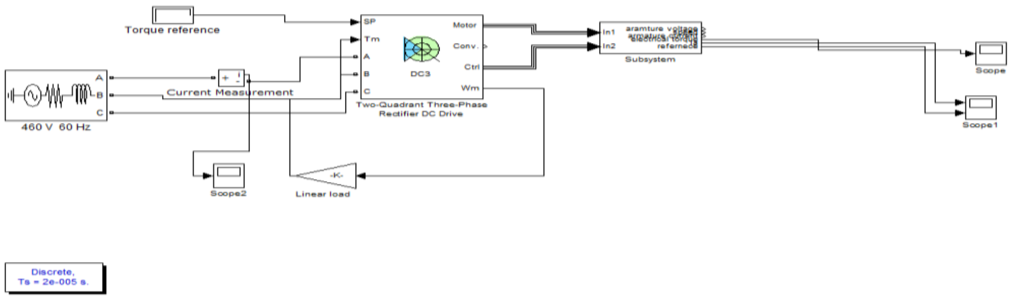

Figure 1: Simulation of DC Motor Drive

The rectifier is fed by a 460 V AC 60 Hz voltage source. The motor is coupled to a linear load, which means that the mechanical torque of the load is proportional to the speed. The initial torque reference is set to 0 N-m and the armature current is null. No electromagnetic torque is produced, and the motor stays still. At t = 0.05 s, the torque reference jumps to 800 N.m. This causes the armature current to rise to about 305 A.

The source current wave form is obtained as shown

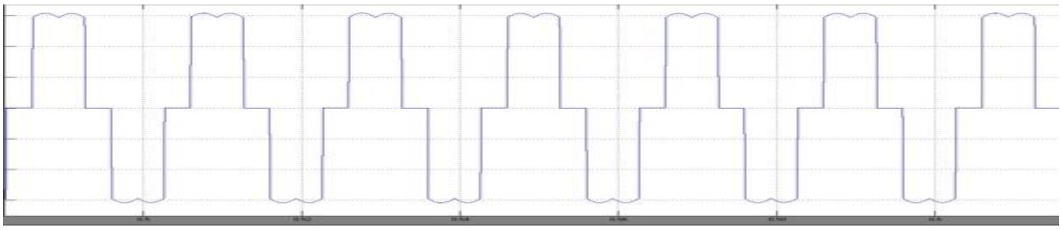

Figure 2: source current wave form

From the figure-2 we can observe the non-linear nature of the load as the source current wave form is non-sinusoidal. The major harmonics components that are present are 3rd and 5th which are to be mitigated.

Thus we can clearly observe the non- linear nature of the drive as the source current is non-sinusoidal.

III. ACTIVE POWER FILTERS

Harmonics drawn by non-linear loads the voltage at several buses will be distorted due to line impedance. These harmonics current will have additional frequency components which are multiple of fundamental frequency. So there is strong need to filter these harmonics. An active filter is implemented when the order numbers of harmonics currents are varying. This may be due to the nature of nonlinear loads injecting time-dependent harmonic spectra (e.g: variable speed drive) or may be caused by the change in the system configuration. The structure of an active filter may be that of series or parallel architectures. Active filters rely on active power conditioning to compensate undesirable harmonic current wave stemming from the nonlinear load. This is achieved by producing harmonic components of equal magnitude but opposite phase angle which cancels the injected harmonics components of the nonlinear loads.

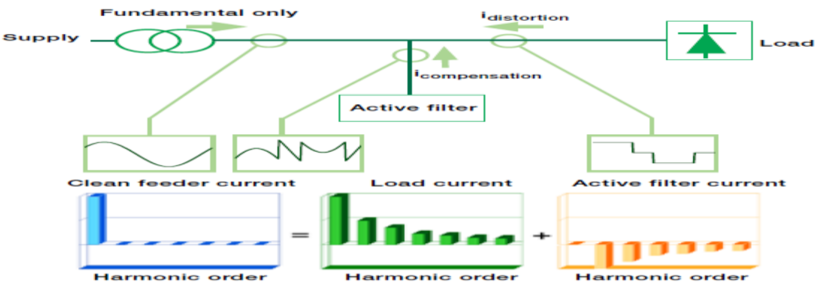

Figure 3: Active power filter arrangement

The figure-3 shows the arrangement of active power filter. As seen from the figure the active power filter is supplying the harmonics current and load current in supplying pure sinusoidal current. The source is supplying only the fundamental component of the load current while the higher order harmonic components are being supplied by shunt active power filter.

IV. SHUNT POWER FILTERS

Shunt active power filter compensate the load current by injecting equal but opposite compensating current , In this case the shunt active power filter acts as a current source injecting the harmonic components equal to that generated by the load but phase shift of 180.

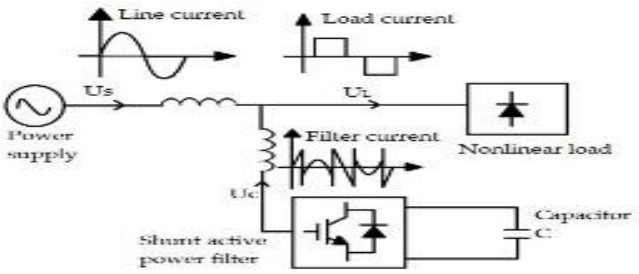

Figure 4: The shunt active power filter topology

The figure-4 shows the basic arrangement of the shunt active filter. The utility generates the compensating current which removes the harmonic content of the source current. Generally a voltage source inverter is used as active power filter and generates the nonlinearities opposite to that load nonlinearities , to make the source current purely sinusoidal.

4.1 Topology

Depending on the particular application or electrical problem to be solved, active power filters can be implemented as shunt type, series type, or a combination of shunt and series active filters (shunt-series type). These filters can also be combined with passive filters to create hybrid power filters.
The shunt-connected active power filter, with a self-controlled dc bus, has a topology similar to that of a static compensator (STATCOM) used for reactive power compensation in power transmission systems. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase-shifted by 180°.

4.2 Voltage Source Converters

Most of the active power filter topologies use voltage source converters, which have a voltage source at the dc bus, usually a capacitor, as an energy storage device. This topology, shown in Figure 5, converts a dc voltage into an AC voltage by appropriately gating the power semiconductor switches. Although a single pulse for each half cycle can be applied to synthesize an AC voltage, for most applications requiring dynamic performance, pulse width modulation (PWM) is the most commonly used today. PWM techniques applied to a voltage source inverter consist of chopping the DC bus voltage to produce an AC voltage of an arbitrary waveform. There are a large number of PWM techniques available to synthesize sinusoidal patterns or any arbitrary pattern. With PWM techniques, the ac output of the filter can be controlled as a current or voltage source device.

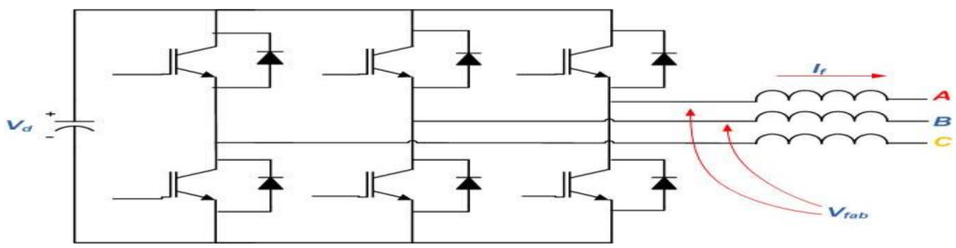

Figure 5: Voltage source converter topology for active filters

4.3 Control Strategies

Most of the active filters developed are based on sensing harmonics and reactive volt-ampere requirements of the non-linear load and require complex control. In some active filters, both phase voltages and load currents are transformed into the α-β orthogonal quantities, from which the instantaneous real and reactive power. The compensating currents are calculated from load currents and instantaneous powers. The control circuit of the DC capacitor voltage regulates the average value of the voltage to the reference value.

Some of the control schemes that are employed for the generation of the reference currents are

- Instantaneous power theory.
- $I_d - I_q$ theory.
- Synchronous reference frame theory.
- Hysteresis current control algorithm.

Instantaneous power theory makes use of clarkes transformation to generate the compensating currents. It converts abc co-ordinates to αβ0 axis. This can be applied to three-phase three-wire or three-phase four-wire system. It then computes the real and reactive powers and then generates the compensating currents.

Id-Iq theory makes use of parks transformation to generate the compensating currents. It converts abc co-ordinates to d-q co-ordinates. According to this theory only the average value of the d-axis component of load current must be drawn from the supply. Using this principle the compensating currents are generated.

In synchronous reference frame theory the source currents on abc axes are converted to two phase stationary frame (αβ). Now these quantities are transformed into two-phase synchronous frame(d-q) using phase locked loop control.

V. INSTANTANEOUS POWER THEORY

Instantaneous power theory is also called P-Q theory. P-Q theory is based on abc to αβ0 transformation.

5.1 Basis Of P-Q Theory

P-Q THEORY is based on a set of instantaneous powers defined in time domain. It can be applied to 3-phase systems with or without a neutral wire. It is valid not only in the steady state but also in the transient state. This theory is very efficient and effective for designing controllers for power filtering. The P-Q theory transforms currents and voltages on αβ0 axes and defines instantaneous power on these axes. The αβ0 transformation is also known as CLARKE'S transformation which consists of a real matrix that transforms 3-phase voltages and currents to αβ0 stationary reference frames.

5.2 Clarkes Transformation

The αβ0 transformation or the clarke's transformation maps the three phase instantaneous voltage (V_a , V_b , V_c) on the abc axes to αβ0 axes(V_0 , V_α , V_β). The clarkes transformation matrix is given by

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

The inverse Clarkes transformation matrix is given by

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

The same formulae are valid even for 3 phase currents.
One of the advantages of αβ0 transformation is that it is power invariant. They separate zero sequence components form abc components. In a 3-phase 3-wire system no zero sequence components exist so i_0 can be eliminated. Similarly in a balanced four-wire system no zero sequence vo9ltages exist so that V_0 can be eliminated. In that case the clarkes and inverse clarkes matrices can be re written as

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

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

The abc axes are specially shifted from each other by 120 degrees whereas the α,β axes are orthogonal to each other.

5.3 Calculation Of P And Q From Voltage And Current Vectors

Instantaneous voltage vector is defined from α,β axes as

$$e = V_\alpha + j\, V_\beta$$

Similarly the instantaneous current vector is defined as

$$I = i_\alpha + j\, i_\beta$$

These instantaneous vectors can be represented in a complex plane where the real axis is α axis and the imaginary axis is the β axis. These quantities are functions of the time since they depend upon the instantaneous voltages and currents.
From the above definitions of e and I we get

$$\begin{aligned} P_{3\phi} &= V_\alpha\, i_\alpha + V_\beta\, i_\beta \\ Q_{3\phi} &= V_\beta\, i_\alpha - V_\alpha\, i_\beta \end{aligned} \tag{5}$$

Writing the above equations in the matrix form we get

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{6}$$

Taking the inverse of the above matrix we can obtain the currents i_α , i_β in terms of p,q which forms the basis for the calculation of the compensating currents.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{7}$$

The above current components can be defined as Instantaneous active current on the α axis

$$i_{\alpha p} = \frac{v_\alpha}{v_\alpha^2 + v_\beta^2} p \tag{8}$$

Instantaneous reactive current on the α axis

$$i_{\alpha q} = \frac{v_\beta}{v_\alpha^2 + v_\beta^2} q \tag{9}$$

Instantaneous active current on the β axis

$$i_{\beta p} = \frac{v_\beta}{v_\alpha^2 + v_\beta^2} p \tag{10}$$

Instantaneous reactive current on the β axis

$$i_{\beta q} = \frac{-v_\alpha}{v_\alpha^2 + v_\beta^2} q \tag{11}$$

Similarly the instantaneous powers can be defined as $P_{\alpha p}$, $P_{\alpha q}$,$P_{\beta p}$, $P_{\beta q}$

Where

$$p_{\alpha p} = v_\alpha \cdot i_{\alpha p} = \frac{v_\alpha^2}{v_\alpha^2 + v_\beta^2} p \tag{12}$$

$$p_{\alpha q} = v_\alpha \cdot i_{\alpha q} = \frac{v_\alpha v_\beta}{v_\alpha^2 + v_\beta^2} q \tag{13}$$

$$p_{\beta p} = v_\beta \cdot i_{\beta p} = \frac{v_\beta^2}{v_\alpha^2 + v_\beta^2} p \tag{14}$$

$$p_{\beta q} = v_\beta \cdot i_{\beta q} = \frac{-v_\alpha v_\beta}{v_\alpha^2 + v_\beta^2} q \tag{15}$$

- Sum of $P_{\alpha p}$ and $P_{\beta p}$ corresponds to real power P.
- Sum of $P_{\alpha q}$ and $P_{\beta q}$ is zero.

5.4 P,Q Simulated Waveforms For A Balanced Linear Load

Consider a 3-phase source is supplying power to a 3-phase balanced(RLC) load. The wave forms of P,Q were simulated in the MATLAB and the results are analysed.

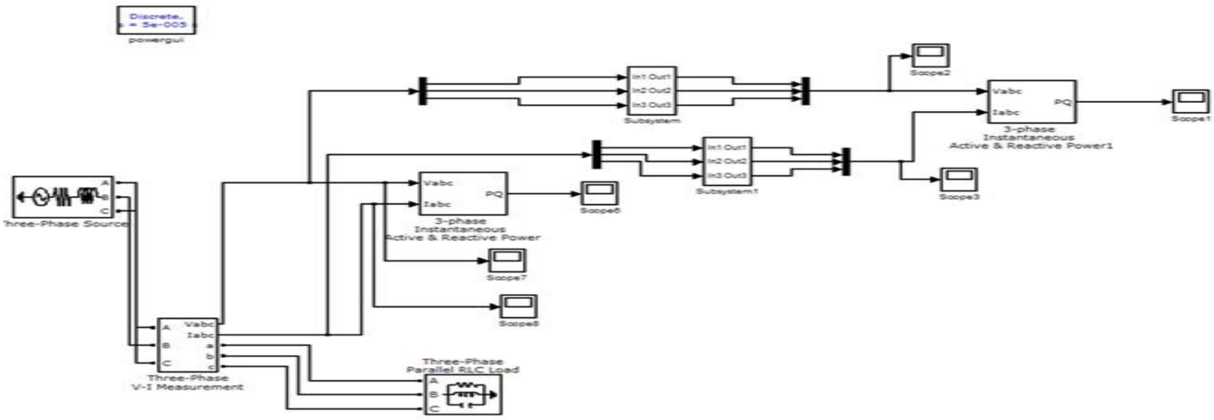

Figure 6: Simulation for a linear load

Figure-6 shows the simulated waveforms for a balanced RLC load. The blocks subsystem and subsystem1 are used to perform Clarke's transformation for three phase voltages and currents. The three-phase instantaneous active and reactive power block computes P,Q from the obtained Clarke's components.

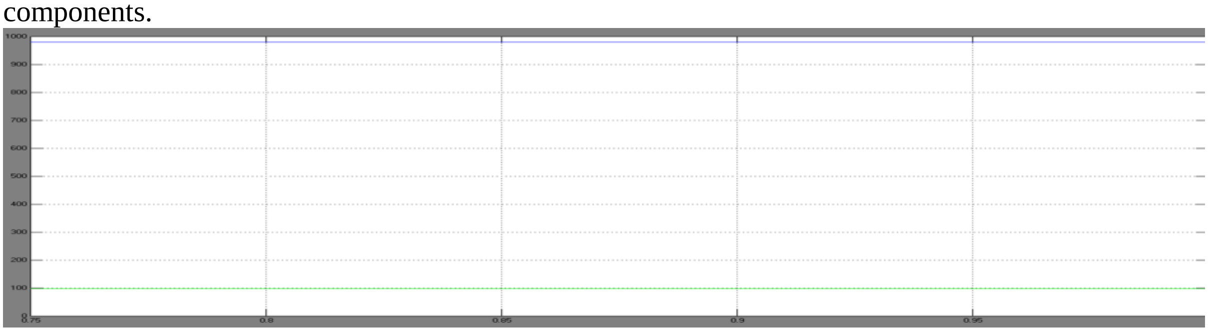

Figure 7: Wave Forms for P And Q

As seen in the figure-7 the waveforms for P,Q for a balanced linear load is almost a straight line. This leads to an important conclusion that if we want sinusoidal voltages and currents we need three-phase real and reactive powers to be constant.

Now a non-linear load is simulated in MATLAB and wave forms for P,Q were analysed. A fully controlled rectifier is taken as a non-linear load and it is operated at a firing angle of 30 degrees.

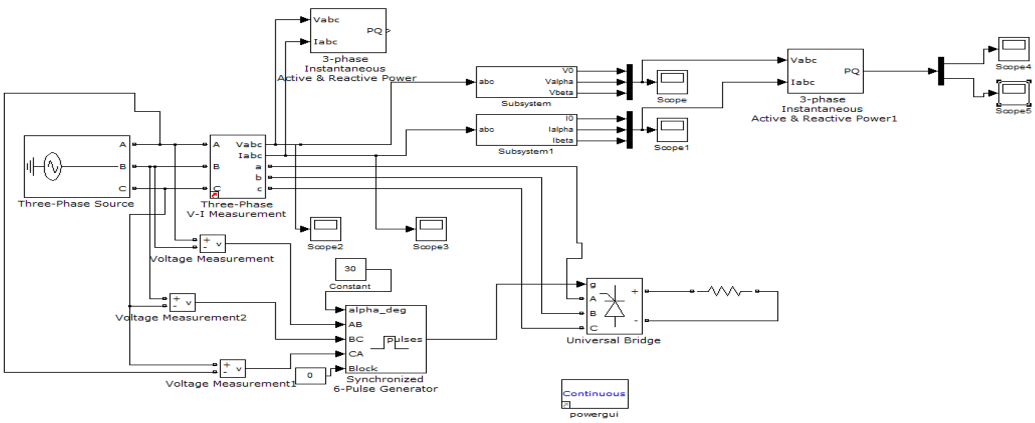

Figure 8: Simulink diagram for a non-linear load

As seen from the figure-8 a fully controlled rectifier operating at a firing angle of 30 degrees feeding a resistive load. The synchronized 6-pulse generator generates the pulses at a specified time delay. The blocks subsystem and subsystem1 are used to convert voltages and currents from abc axes to αβ0 axes. The 3-phase instantaneous active and reactive power block is used for measuring the wave forms for P and Q.

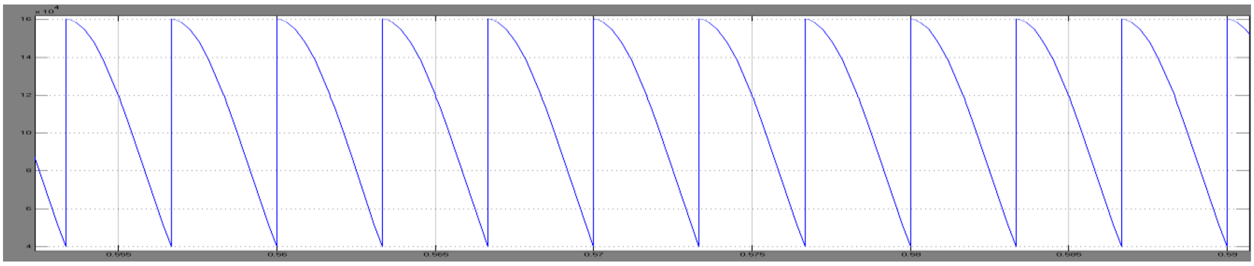

Figure 9: Simulated Wave Form For P

From the figure-9 it can be observed that P waveform has DC component and also an oscillating component. The oscillating component is responsible for production of harmonics

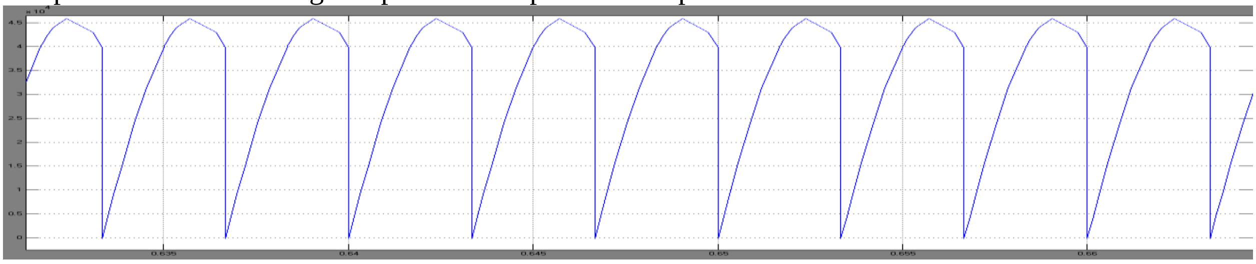

Figure 10: Simulated Waveform For Q

From the figure-10 it can be observed that similar to P even Q has both oscillating and DC components which are responsible for production of harmonics.
From the above simulations we conclude the following:

- For a linear load i.e. if voltage and currents are purely sinusoidal, the 3-phase active and reactive powers are constant.
- If the load is non-linear, P and Q wave forms will have an oscillating component in addition to the DC component.

$$P = \bar{P} + \tilde{P}$$
$$Q = \bar{Q} + \tilde{Q}$$

$\tilde{P}$ and $\tilde{Q}$ are oscillating powers which are undesirable are due to the presence of harmonics. We need to remove them for removing harmonics.

5.5 Use Of The P-Q Theory For Shunt Current Compensation

One important application of the p-q theory is the compensation of undesirable currents . If a source is supplying a nonlinear load that is being compensated by a shunt compensator. The shunt compensator behaves as a three phase controlled current source , that can draw any set of arbitrarily chosen reference current . The figure-13 shows a general control method to be used in the controller of a shunt compensator.
The calculated real and imaginary power of the load (P and Q) can be separated into its average and oscillating parts. The undesired portions of real and imaginary powers of the loads that should be compensated as selected. The power to be compensated are represented by $-P_c$ and $-Q_c$.

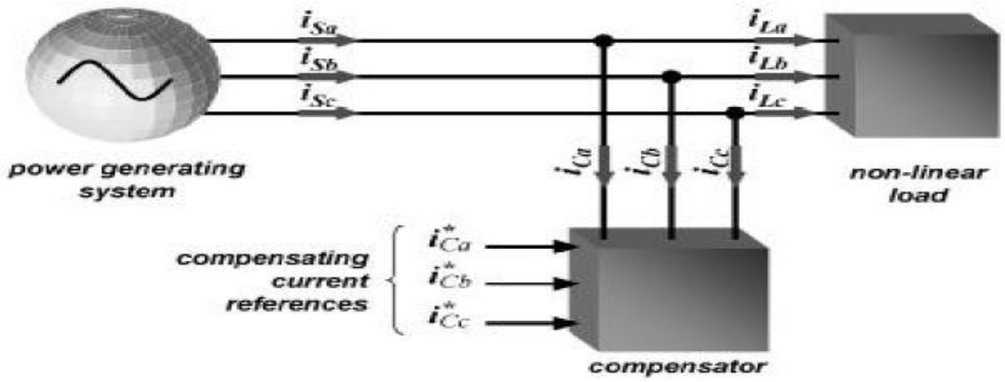

Figure 11: Basic principle of shunt current compensation

The calculated real and imaginary power of the load (P and Q) can be separated into its average and oscillating parts. The undesired portions of real and imaginary powers of the loads that should be compensated as selected. The power to be compensated are represented by $-P_c$ and $-Q_c$.
The minus sign is included to emphasize that compensator should draw a compensating current that produces exactly the inverse of the undesirable power drawn by the non-linear load . The current convention is that source current is some of load current and compensating current. Then inverse transformation from αβ to abc is applied to calculate the instantaneous values of the three phase compensating current references i_{ca}, i_{cb}, i_{cc}.

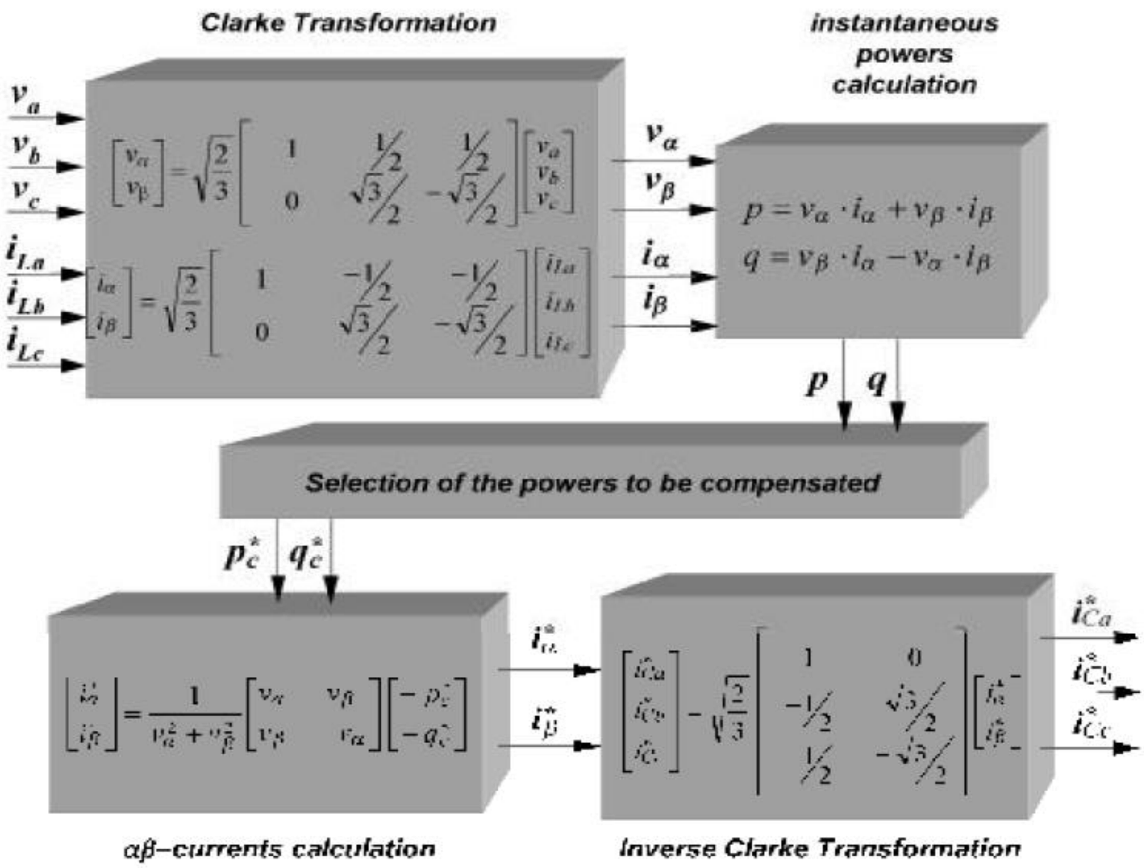

Figure 12: control method for shunt compensation based on PQ theory

The figure-12 shows the complete block diagram for generation of compensating currents. The 3-phase voltages and currents are transformed to αβ axes using the clarkes transformation. Then the instantaneous powers are calculated. Then the compensating powers are calculated. Then i_α , i_β are calculated.

After knowing them inverse Clarke transformation is performed and the compensating currents are calculated(i_{ca} , i_{cb} , i_{cc})

Shunt active filters generally consist of two main distinct blocks as shown in figure 13:

1- The PWM converter for power processing

2- The active filter controller for signal processing

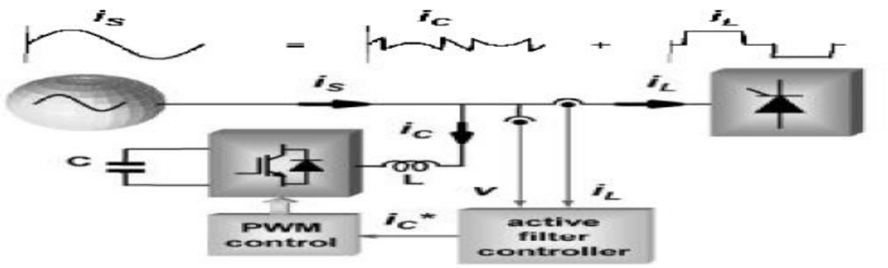

Figure 13: Basic configuration of a shunt active filter

The PWM converter is responsible for drawing the compensating current. The active filter controller is responsible for signal processing in determining the instantaneous compensating current references which are continuously passed to the PWM converter. The figure shows the basic configuration of shunt active power filter for harmonic current compensation.

The shunt active filter controller works in a closed loop manner, continuously sensing the load current and calculating the instantaneous values of compensating current reference for PWM converter. The PWM converter should have a high switching frequency to reproduce accurately the compensating current. The PWM converter is a voltage source inverter which has a DC capacitor at the input and IGBT with an anti-parallel diode.

The active filter controller consist of four functional blocks as shown in figure-14

1-Instantaneous power calculation

2-Power compensating selection

3- DC voltage regulator

4-Current reference calculation

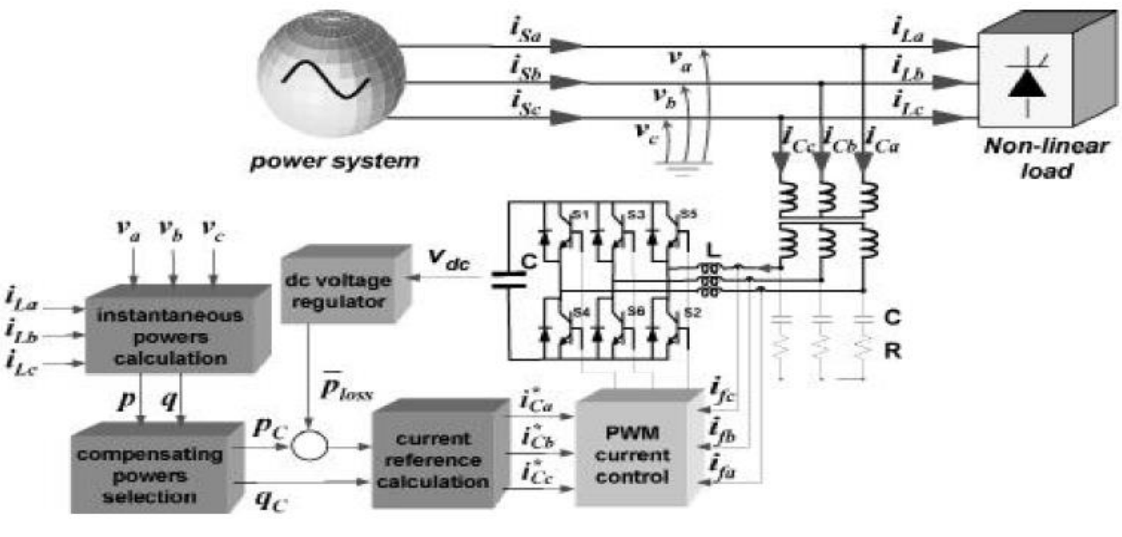

Figure 14: The three-phase three wire shunt active filter

The first block calculate s the instantaneous power of non-linear load using p-q theory .The second block selects the parts of real and imaginary power of the non-linear load, that should be compensated by shunt active filters.

In a real implementation the separation of $\overline{P}$ from P is realized through a low–pass filter. In practice a fifth order Butterworth low pass filter with a cutoff frequency between 20 and 100Hz has been used to separate $\overline{P}$ from P.

The DC voltage regulator determines the amount of real power represented by P_{loss} that causes additional flow of energy to dc capacitor in order to keep its voltage around a fixed reference value. This real power P_{loss} is added to compensating real power P_c , together with the compensating imaginary power Q_c are passed to current reference calculation block .It determines the instantaneous compensating current references from the compensating powers and voltages.

In order to avoid high di/dt , the VSC should be connected to the power system through a series inductor .

5.6 Hysteresis Current Controller

This current controller decides the switching pattern in SHAPF. The switching logic is formulated as

- If $I_{measured} > I_{reference}$ then upper switch is "OFF" and bottom switch is "ON" in the inverter leg
- If $I_{measured} < I_{reference}$ then upper switch is "ON" and bottom switch is "OFF" in the inverter leg.

The same switching pattern is followed for all the 3 legs. Since the signals given to the 2 switches in a same leg are complimentary there is no chance of dead short. If the top switch is "ON" the current produced by the inverter increases since a positive voltage is applied. If the bottom switch is "ON" then the current produced decreases as a negative voltage is applied. Here we get a hysteresis band around the reference currents. In this fashion the generated currents by the inverter are regulated within the hysteresis band of their respective reference values.

VI. SIMULATIONS AND RESULTS

A MATLAB SIMULINK model is developed to simulate SHAPF based on instantaneous power theory. A fully controlled thyristor converter operating at a firing angle of 45 degrees feeding a resistive load is taken as a non-linear load for the purpose of simulation.

SYSTEM PARAMETERS	VALUES
Source voltage(Line-Line) RMS	400V
R_S , L_S	0.01ohms, 1mH
System frequency	50 Hz
Filter inductance	1.2mH
DC link capacitance	40uF
DC link voltage	850V
Load(R-L)	7 ohms, 20mH
PI controller	$K_P = 0.1$, $K_I = 1$

Keeping the above parameters the simulation is performed.

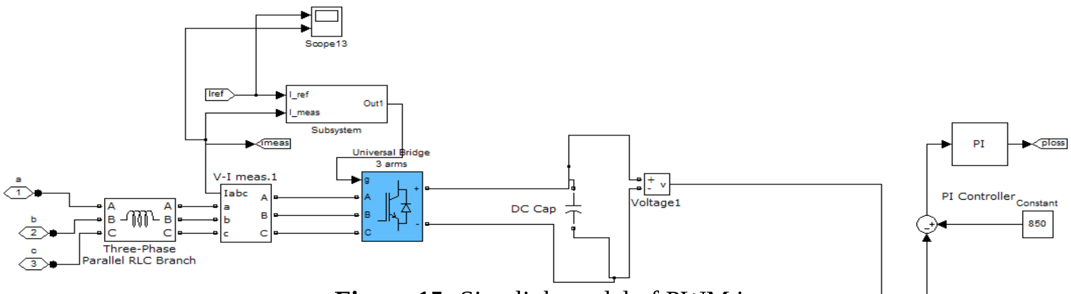

Figure 15: Simulink model of PWM inverter

Figure-15 shows the Simulink model of PWM inverter. The block named subsystem is the hysteresis controller whose output is being given to the switches of the inverter. The DC capacitor voltage is being controlled by the PI controller whose reference value is set at 850V.

A series RLC branch is added at the output of the inverter before connecting it to the PCC to limit high value of rate of change of current (di/dt).

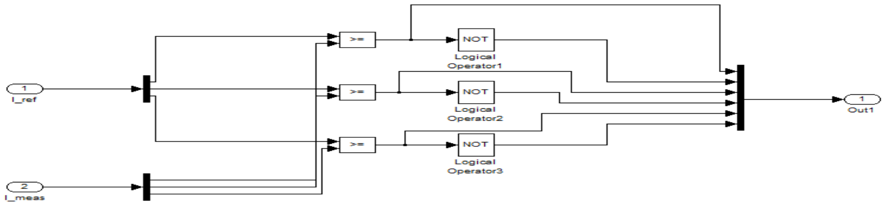

Figure 16: Hysteresis current control block

The figure-16 shows the Simulink model of the hysteresis current controller. The reference currents generated by IPT theory and the actual currents produced by the inverter are compared. If reference current is greater than measured current then top switch of the corresponding leg in the inverter is turned ON. A complimentary signal is given to the bottom switch using the logical “NOT” operator. If reference current is lesser than measured current then top switch of the corresponding leg in the inverter is turned OFF and bottom switch is turned ON.

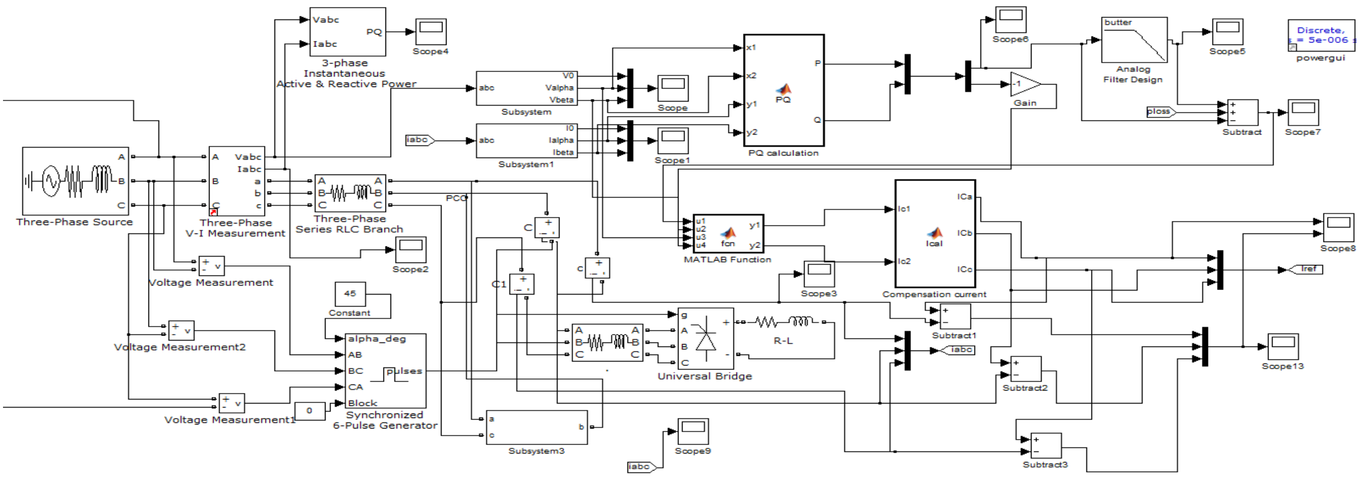

Figure 17: Simulink model of SHAPF complete

The figure-18 shows the entire Simulink block diagram of the whole system including shunt active power filter and a non-linear load. The blocks subsystem and subsystem-1 are used to convert abc to αβ0 axes. The MATLAB function block is used to compute the compensating currents on αβ axes from the oscillating powers obtained. The compensation current block is used to perform inverse clarkes transformation to convert from αβ axes to abc axes. The block named subsystem-3 is the SHAPF which is connected in parallel across the PCC. The load is a fully controlled converter operating at a firing angle of 45 degrees.

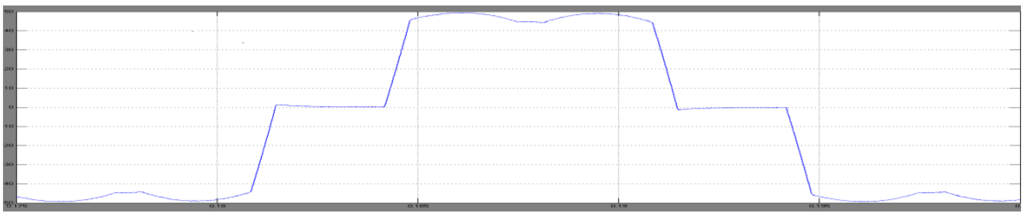

Figure 18: Source current waveform without compensation

Figure-18 shows the source current wave forms without compensation. The harmonics can be clearly seen from the figure. The peak value of the current is 49 A. The major harmonic orders will be that of 3rd and 5th

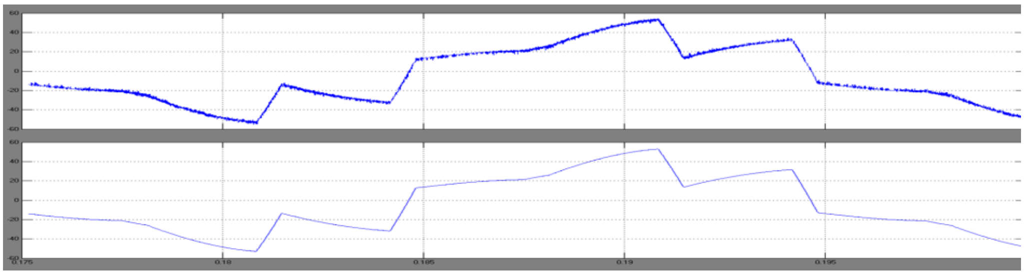

Figure 19: Comparison of inverter and reference currents

From the figure-19 we can see the relation between the reference currents generated by P-Q theory and the actual currents produced by the inverter. They are closely related. The band obtained in the inverter waveform is due to the action of hysteresis controller.

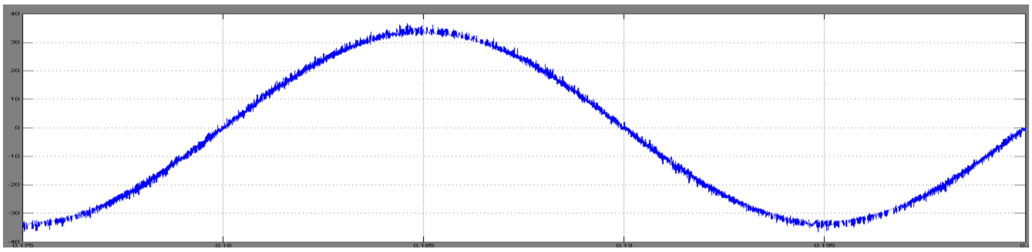

Figure 20: Source current after compensation

Figure-20 shows the source current after compensation on a single-phase basis. We can see that the waveform is almost sinusoidal with a peak value of 36A. There is band obtained in the source current due to the action of hysteresis controller.

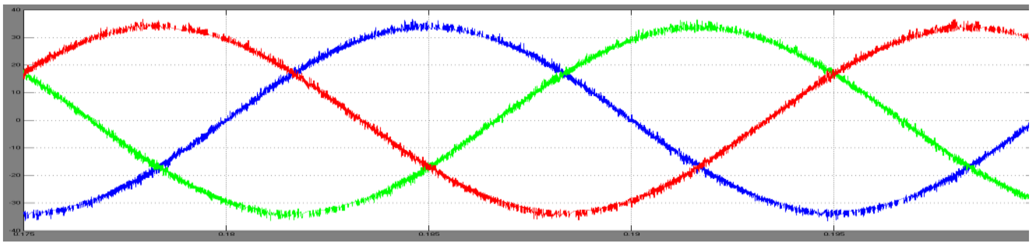

Figure 21: Three- phase source currents after compensation

Figure-21 shows the three-phase source currents after compensation. The three currents are phase displaced by 120 degrees. The distortions in the waveforms are due to the hysteresis band.

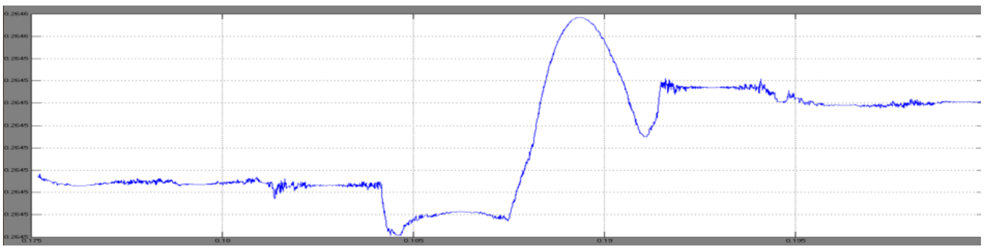

Figure 22: THD before compensation

Figure-22 shows the THD of a source current waveform before SHAPF is used. The THD is varying between 26.42% to 26.46% which is out of the desirable standards prescribed by IEEE which is 5%.

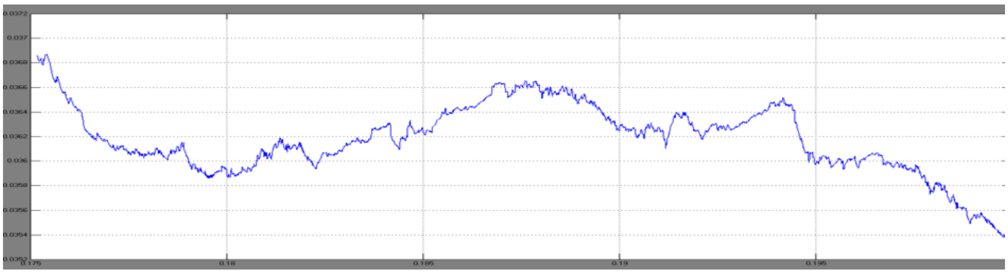

Figure 23: THD after compensation

Figure-23 shows the THD of a source current waveform after SHAPF is used. The THD is varying between 3.54% to 3.68% which is in the desirable limits prescribed by IEEE 5%. By this we can infer that mitigation of current harmonics have been done successfully by SHAPF.
From the response it is depicted that the source current became almost sinusoidal with some hysteresis band. Also the THD for the uncompensated case was nearly 26% but after compensation the THD became 3% which is well within the desirable limits. For further reduction in THD we can employ a passive filter in addition to it

VII. Case Study – Welding Load

The practical source current wave forms are captured for welding load which is highly non-linear using power quality analyser (FLUKE 435 SERIES-2).
This analyser is made use in measuring the phase currents of welding loads in WORKSHOP. The experimental setup is as shown in figure -24.

Figure 24: Experimental setup to capture welding current waveforms

The current probe of FLUKE meter is encircled around the phase wire of transformer which is supplying current to the welding machine. Due to the magnetic field produced by the current, the FLUKE meter is able to capture the current waveform which is flowing in the transformer.
The current waveform is measured by the meter using current probes and harmonic spectra are recorded by it.

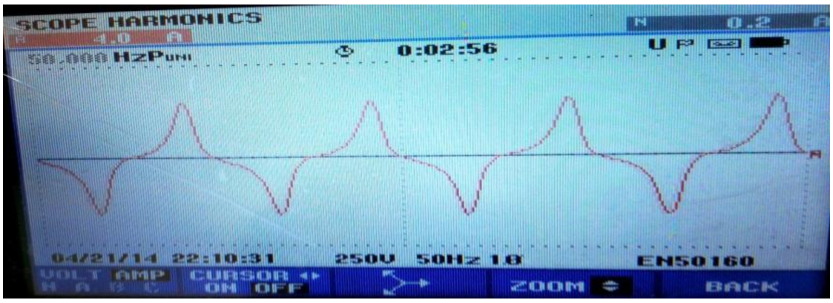

Figure 25: current waveform of welding load captured by analyser

The current waveform is measured by the meter using current probes and harmonic spectrum is recorded by it. Figure-25 shows the waveform captured by it. We can clearly see from figure 30 the non-sinusoidal nature of the current waveform with an RMS value of 4A.

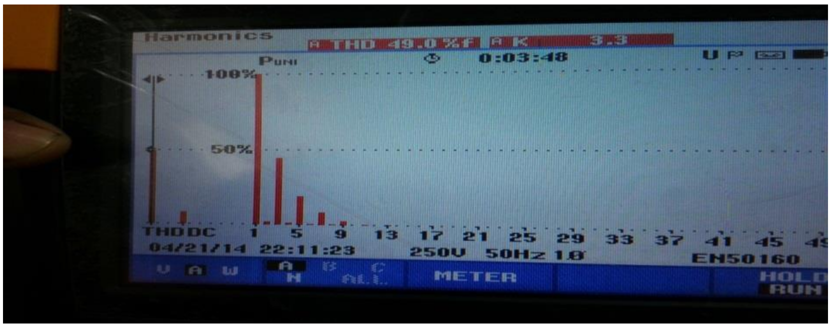

Figure 26: harmonic spectra of the current wave form

Figure-26 shows the harmonic spectrum of the current waveform captured by the meter. The major harmonic components are 3rd and 5th harmonics. 3rd harmonic nearly 40% of the fundamental while 5th harmonic is nearly 20% of the fundamental which accounts to a THD of 49% as recorded by the meter.

We can see that 3rd and 5th harmonics are the main contents present in the source current. Now this waveform is generated in the MATLAB SIMULINK and compensation is done. The non-linear welding load is modeled as a harmonic current source. Since there is no programmable current source a voltage dependent current source is taken and thus the harmonics are generated.

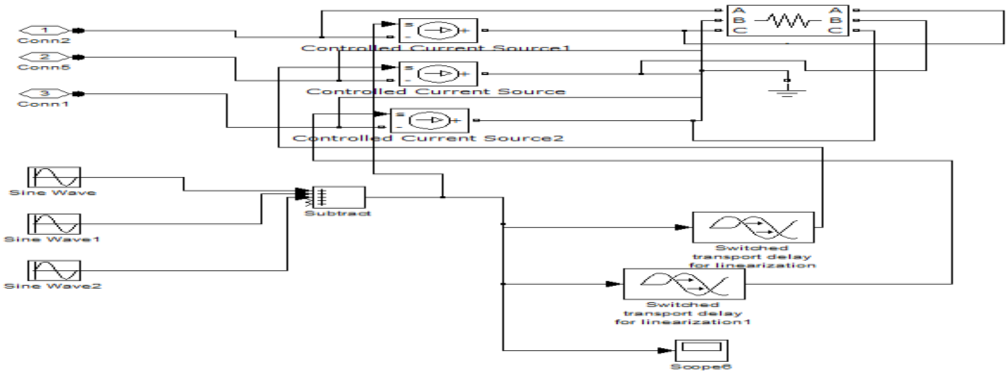

Figure 27: Block diagram for modelling of non-linear load

Figure-27 shows the SIMULINK block diagram for modelling of welding load.. The non-linear welding load is modelled as a harmonic current source. Since there is no programmable current source a voltage controlled current source is taken and thus the harmonics are generated. Three sine waves are taken one is at a fundamental frequency and other two are at 3rd and 5th multiples of fundamental frequency. Relative magnitudes taken are obtained from the harmonic spectra of welding load that is recorded by the meter. Thus harmonics are generated.

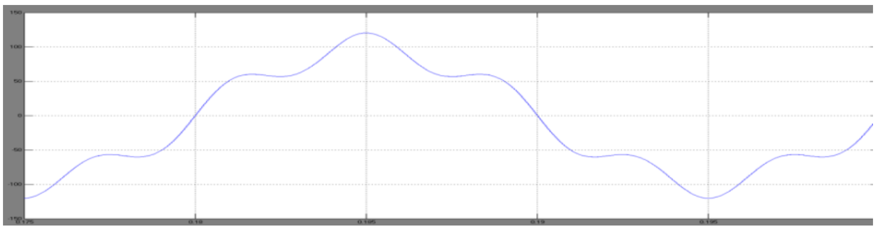

Figure 28: Source current waveform before compensation

Figure-28 shows the source current waveform of the welding load before compensation. The current waveform couldn't be produced exactly to that what is obtained in the meter but it is nearly same. The harmonics can be seen clearly as the waveform is non-sinusoidal.

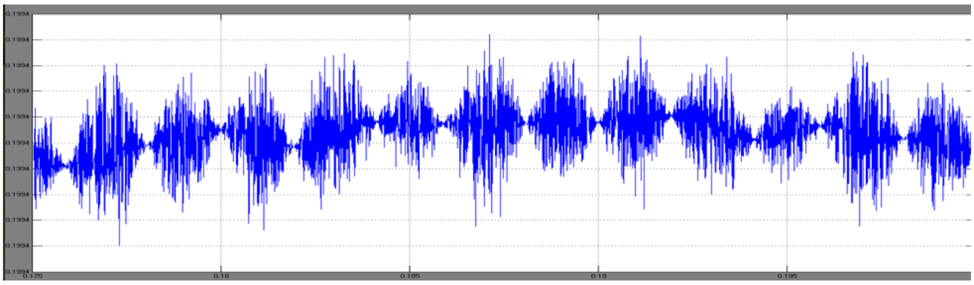

Figure 29: THD before compensation

Figure-32 shows the THD of the source current waveform when the welding load is modeled as a non-linear load for the purpose of simulation. The value of THD is nearly 19.4% which is not in the limits prescribed by IEEE.

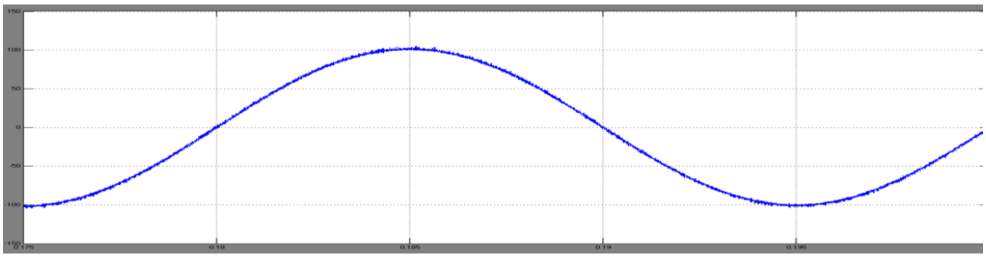

Figure 30: Source current waveform after compensation

Figure-33 shows the source current wave form after compensation. The source current wave form became almost sinusoidal. There is a band obtained in the waveform due to the action of the hysteresis control.

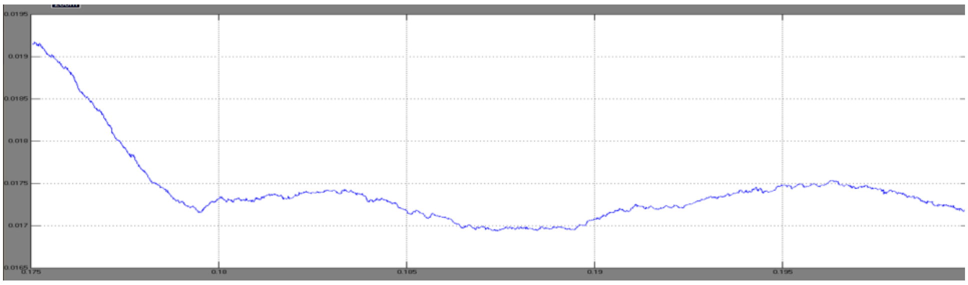

Figure 31: THD after compensation

Figure-34 shows the THD of the source current waveform after compensation. The THD is varying between 1.6-1.7%.Intially it was 19% for the uncompensated case, now it has decreased by a large extent. So, it can be inferred that SHAPF has successfully mitigated the current harmonics.

VIII. CONCLUSION

The wave forms for linear and non-linear loads are analyzed in the MATLAB SIMULINK. A shunt active power filter is developed using instantaneous power theory. The source current waveforms are analyzed with and without SHAPF. With SHAPF the source waveform which was non-sinusoidal earlier became almost sinusoidal with some hysteresis band. There was also a sharp reduction in THD from 26% to 3% after compensation. Later practical non-linear load like welding load is taken. Its current waveform is captured using a power quality analyser meter. It is modelled in SIMULINK and compensation is done for it. The THD has decreased from 19.94% to 1.7% after compensation. Thus we have successfully mitigated current harmonics using SHAPF.

IX. FUTURE SCOPE

More than one-nonlinear load may be taken at a time and non-linear loads may be switched at different instances of time so that harmonic spectra changes. Compensation can be done for the above load conditions to prove that SHAPF can mitigate current harmonics even under dynamic conditions unlike passive filter. Also to reduce THD still to a lower value passive filter can be used along with active filter which is termed as a hybrid power filter.

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