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Dynamic Power Factor Correction in a Non Linear Environment

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***Abstract**: Electric power quality mainly refers to maintaining a near sinusoidal power distribution bus voltage at rated magnitude and frequency. In modern electric power supply distribution systems, there is a sharp rise in use of both single phase and three-phase non-linear loads and due to these non-linear loads, non-sinusoidal unbalanced current is drawn from ac mains resulting in harmonic injection, burden of reactive power, more neutral currents and unbalanced loading of ac mains. In this paper the simulation of ideal shunt active power filter is carried out to eliminate harmonics and also improving the power factor for three-phase, three-wire system. In addition to this, simulation of shunt APF for three-phase, three-wire distribution system using time domain p-q theory has been carried out to eliminate harmonics. Also an attempt is made to find out various power quality problems and among these problems most prominent and frequently occurring problem harmonics is analyzed and its causes, effects and mitigating or improving techniques are explained in detail. A case study using ideal shunt AF and Shunt AF using p-q theory is also carried out in this paper.*
***Keywords:** Active Power Filter, Harmonic Filter, Power Factor Correction, Shunt Voltage.*

I. Introduction

In modern electric power supply distribution systems, there is a sharp rise of voltage in both of the single phase and three-phase non-linear loads like as computer power supplies, commercial lighting, rectifier equipment used for telecommunication, daily usable equipments like TVs, ovens, adjustable speed drives (ASD) and asynchronous AC–DC link systems **[1].** These non-linear loads draw non-sinusoidal unbalanced currents from ac mains resulting in harmonic injection, excess load of reactive power, higher neutral currents and unbalanced loading of ac mains. Further, they cause poor power factor, less efficiency, neutral conductor satisfaction only and interference with close by communication networks **[2].** With restructuring of electric power utilities, the problems of waveform distortion start appear on the transmission side due to the increasing implementation of HVDC and FACTS devices, which are used in increasing the transmission line power capability. Also in the generation side a problem of waveform distortion may arise because the Independent Power Producers IPPs, which are using wind and solar energy, are granted permission to transmit their generated power using the interconnected power system through the use of static switches **[3].** These actions beside the expected reduction in maintenance budget for both transmission and distribution systems, which may result in increasing number of service interruptions, raise the issue of power quality after restructuring of power system **[4].** Unless suitable counteractions are taken, the problems of power quality will spread over the whole system and will not reside only on the distribution system. New techniques for power quality monitoring and mitigation should be adopted to cope with the new deregulation era **[5].** Because of increased irregularities of the supply system, this power quality field has concerned the attention of power electronics experts in the last two decades and a number of attempts have been made on the analysis, design and development of techniques for balancing the load, reducing the harmonics and improving the power factor. In this directions case study is carried out using ideal shunt AF and Shunt AF using p-q theory. The power supplied to a customer must be uninterrupted from the reliability point of view and purely sinusoidal from quality point of view. It is to be noted that even though power quality (PQ) problems is mainly concerned with distribution system **[2],** but power transmission systems may also have an impact on quality of power. Usually, a well designed generating station is not source of trouble for supplying quality power. The generated system voltages are almost perfectly sinusoidal.

As mentioned above, the PQ problems start with the transmission systems. For transmission of power for a long distance, firstly the generated voltage is stepped up by transformers. However, this high voltage transmission line has its own problem due to corona and other losses. These high voltage lines are hung overhead between two tall transmission towers which are supported by long porcelain insulators that are connected to steel towers. The towers and lines are exposed to nature. Therefore they are ideal targets for lightning strikes that cause spikes in the transmission voltage. Moreover, high wind may cause two sagging transmission lines to come near each other causing arching, transients in voltage or voltage sag/swell. Various power quality problems are listed and described in the following section **[1].**

Problems related to power quality can be classified as **[6]**:

- Waveform Distortion
  - Harmonics
  - Inter harmonics
  - Notching
  - Noise
- Transients
  - Impulsive transients
  - Oscillatory transients
- Short Duration Variation
  - Voltage sag or dip
  - Voltage swell
  - Interruption
- Long Duration Variation
  - Under voltage
  - Overvoltage
  - Interruption

II. Case Study

1. Active Power Filter

The Active Harmonic Filter concept uses power electronic devices in conjunction with passive elements to introduce current components, which cancel the harmonic components of the non-linear loads. APF's are also used to eliminate voltage balance, to regulate terminal voltage, to suppress voltage flicker, and to improve voltage balance in three-phase system. This wide range of objectives is achieved either individually or in combination, depending upon the control strategy, configuration and requirements which have to be selected appropriately. AF's can be classified according to converter type, topology, and the phases number exist. The converter type can be either CSI or VSI bridge structure. The topology may be Shunt and Series, or it may be a combination of both. The third classification is based on the number of phases, such as single-phase and three or four-wire (three-phase) systems.

2. Simulation of Ideal Shunt APF

To illustrate the functioning of shunt APF (shunt compensator) we have considered the three phase distribution system shown in figure 1 i.e all the currents and voltages that are indicated in this figure are instantaneous quantities. Here a three phase balanced supply (V_{sa}, V_{sb},V_{sc}) is connected across a star (Y) connected load. In addition it is assumed that the load is drawing a 5th harmonic current of magnitude 0.05 p.u. The loads are such that the load currents (I_{1a}, I_{1b}, I_{1c}) may not be balanced, may contain harmonics and dc offset. In addition to this the power factor of the load may be poor. So design a shunt compensator that does not draw any real power to the load, that is entire amount of real power must come from supply only and the purpose of the shunt compensator is to inject currents in such a way that the source currents are harmonic free balanced sinusoidal and their phase angle with respect to the source voltages has a desired value.

$V_{sa} = \sqrt{2} \sin \omega t$ $\quad Z_{1a} = 6.0+j3.0$ (1)

$V_{sb} = \sqrt{2} \sin (\omega t -120^0)$ $\quad Z_{1b} = 3.0+j1.5$ (2)

$V_{sc} = \sqrt{2} \sin (\omega t +120^0)$ $\quad Z_{1c} = 7.5+j1.5$ (3)

Load = Non-linear

Load currents contain 3rd and 5th harmonics in addition to fundamental.

$I_a = \Sigma (I_m / n) * \sin (n\omega t- \phi_n)$ (4)

Where n=1,3,5

$I_b = \Sigma (I_m / n) * \sin \{ n(\omega t-120^o)- \phi_n \}$ (5)

Where n=1,3,5

$I_c = \Sigma (I_m / n) * \sin \{ n(\omega t +120^o)- \phi_n \}$ (6)

Where n=1, 3, 5

Transforming the voltages and currents into α-β-0 frame we get

$V_o = 0$ (7)

$V_\alpha = \sqrt{3} / 2 * V_m * \text{Sin}\ \omega t$ (8)

$V_\beta = -\sqrt{3} / 2 * V_m * \text{Cos}\ \omega t$ (9)

$I_o = (I_m / \sqrt{3}) * \text{Sin}(3\omega t - \phi_3)$ (10)

$I = \sqrt{3} / 2 *(I_m)*\{ \text{Sin}(\omega t - \phi_1) + (1/5) * \text{Sin}(5\omega t - \phi_5)\}$

$= -\sqrt{3} / 2 *(I_m) *\{\text{Cos}(\omega t - \phi_1) + (1/5) * \text{Cos}(5\omega t - \phi_5)\}$

i.e. 3^{rd} harmonic current is present only in the zero sequence.

$P = V_\alpha I_\alpha + V_\beta I_\beta$ (11)

$Q = V_\alpha I_\beta - V_\beta I_\alpha$ (12)

The above equations clearly demonstrate that there are two components of real & reactive power present in a system when loads contains harmonics.

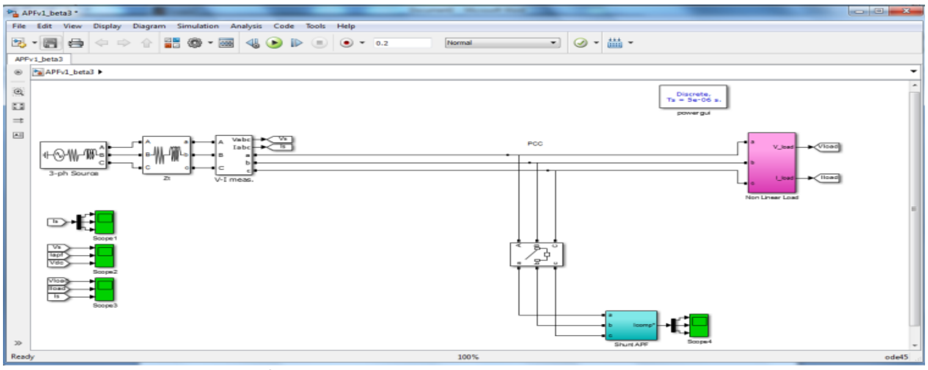

Figure 2.1: Shunt compensator for 3-phase, 3-wire system supplying Y connected load on open APF

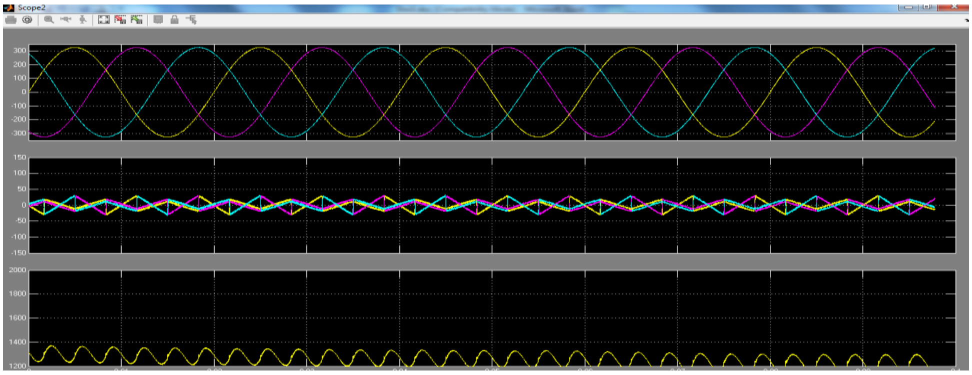

Figure 2.2: Final output after the execution of the programme on open APF

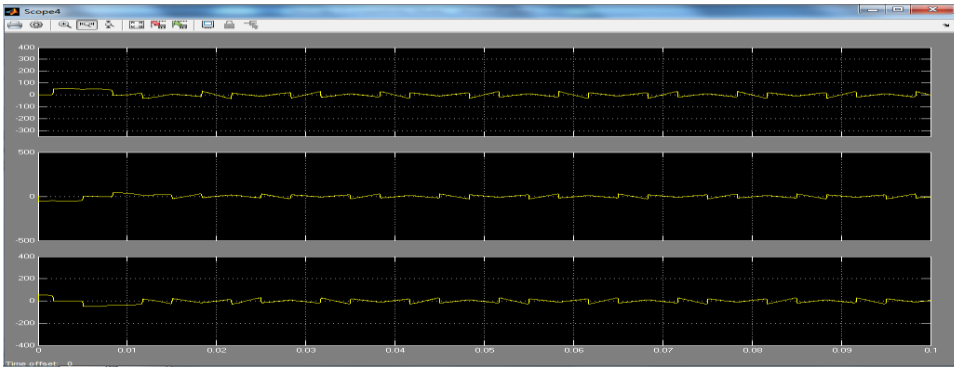

Figure 2.3: Scope 4 output for the current on open APF

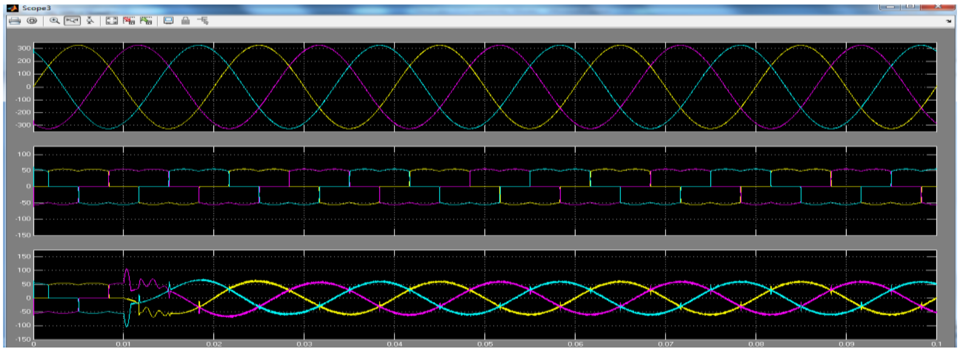

Figure 2.4: Final output after the execution of the program on open APF

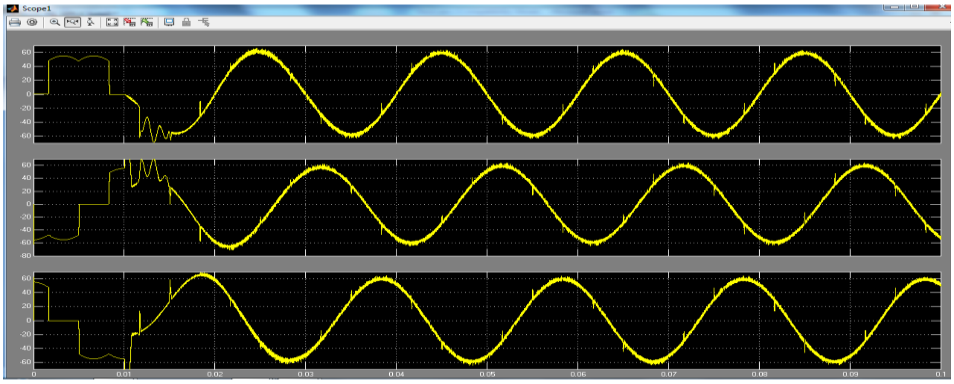

Figure 2.5: Scope 1 output for the current on open APF

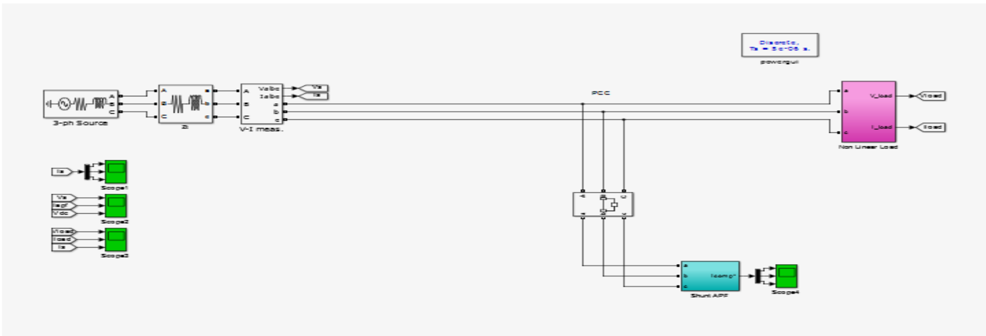

Figure 2.6: Shunt compensator for 3-phase, 3-wire system supplying Y connected load on Closed APF

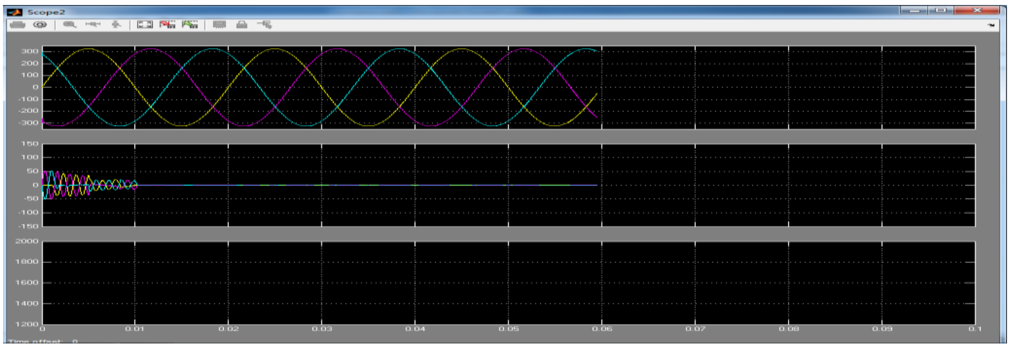

Figure 2.7: Final output after the execution of the program on Closed APF

3. Generating Solution Using Matlab Programs

Step 1:- Analyzing Problem

The current sources in this problem are connected in Y. The loads are such that the load currents (I_{la}, I_{lb}, I_{lc}) may not be balanced and contain harmonics and dc offset. The purpose of shunt compensator would be to inject currents in such a way that source currents (i_{sa}, i_{sb} , i_{sc}) are harmonic free balanced sinusoidal and their phase angle with respect to source voltages has a desired value.

Step 2:- Writing Necessary Equations
Since the current is drawing 5th harmonics current of magnitude 0.05 per unit. The three load currents in per unit would be:

I_{1a} = 0.2108 Sin (ωt-26.57^0) + 0.05 Sin 5ωt (13)
I_{1b} = 0.4216 Sin (ωt-146.57^0) + 0.05 Sin 5(ωt-120^0) (14)
I_{1c} = 0.1849 Sin (ωt+108.69^0) + 0.05 Sin 5(ωt+120^0) (15)

Also applying KCL at common point of coupling we can write the following expression for the compensator currents.

$I_{f\beta} = I_{l\beta} - I_{s\beta}$, where β=a, b, c (16)

The three source currents for a mean power of 0.5282p.u or 0.1761 p.u per phase are given as

$I_{sa} = \sqrt{2}$ * 0.1761 Sin ωt = 0.249 Sin ωt (17)
$I_{sb} = \sqrt{2}$ * 0.1761 Sin (ωt -120^0) = 0.249 Sin (ωt -120^0) (18)
$I_{sc} = \sqrt{2}$ * 0.1761 Sin (ωt +120^0) = 0.249 Sin (ωt +120^0) (19)

Step 3:- Writing Programs and Generating Waveforms

III. Results & Discussions

The following figures shows the different waveforms which are the results of MATLAB programming when ideal shunt APF (shunt compensator) is used for harmonic elimination and power factor improvement for a 3-phase, 3-wire system supplying nonlinear loads. It can be seen in above graph that the load currents are distorted due to the presence of the 5th harmonic component.

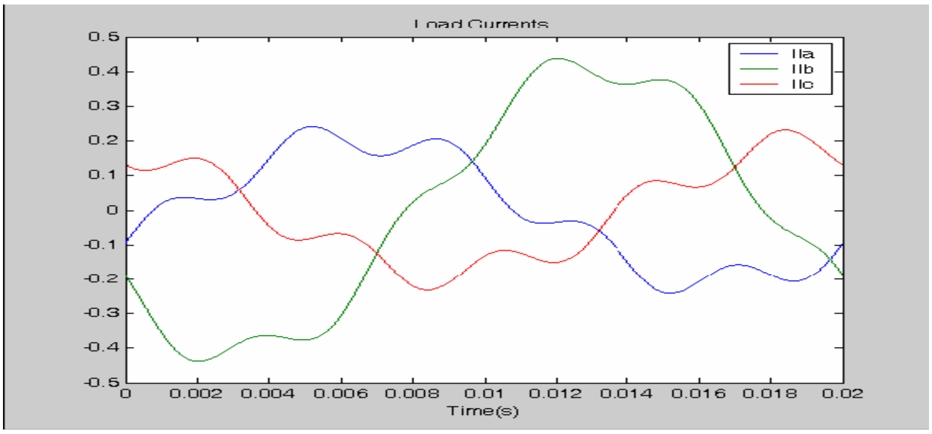

Figure 3.1: Load current waveforms

The waveform of instantaneous power is shown in fig. 3.2. It is obvious that the instantaneous power drawn from the source is constant even when the instantaneous power into the load is oscillating and distorted. Now it is clear that the average component of the power comes from the source while the oscillating component comes from the compensator. Also the compensator does not supply any real power i.e entire amount of real power comes from the supply source.

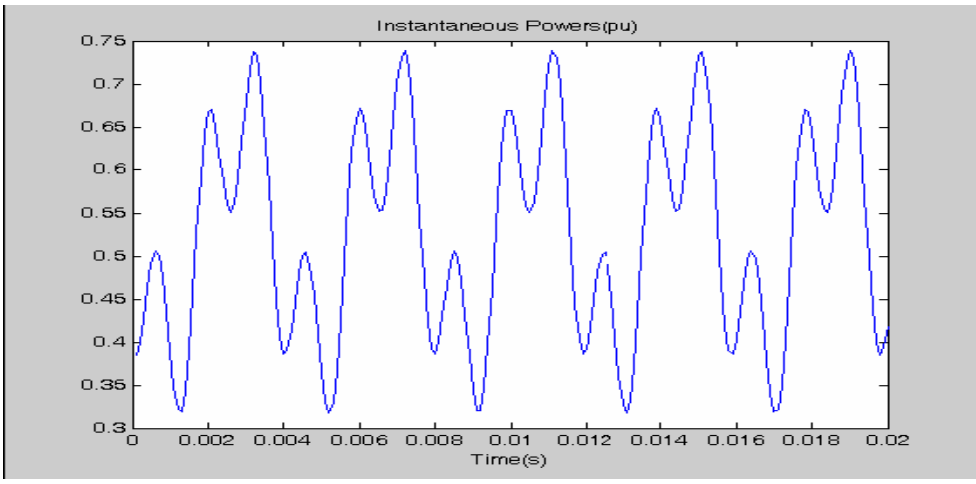

Figure 3.2: Instantaneous power

These compensator currents are injected into the system so that the source currents are harmonic free balanced sinusoidal and their phase angle with respect to the source voltages has a desired value.

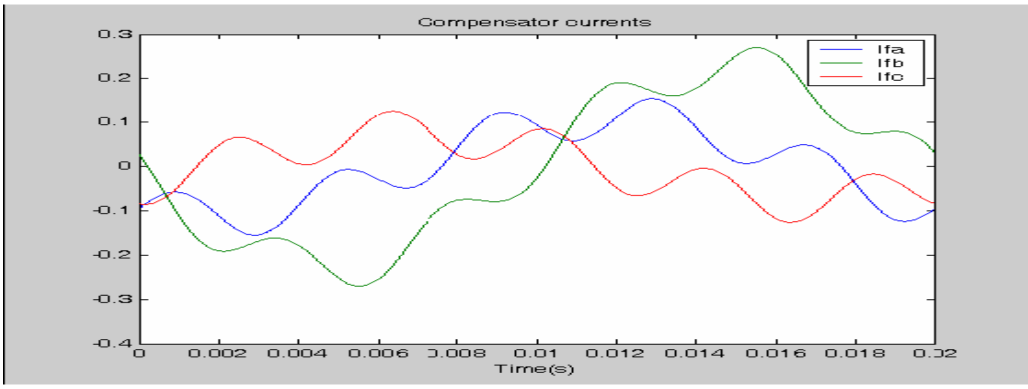

Figure 3.3: Compensator currents

The following fig. 3.4 shows the source currents being balanced with the compensator being switched after one cycle.

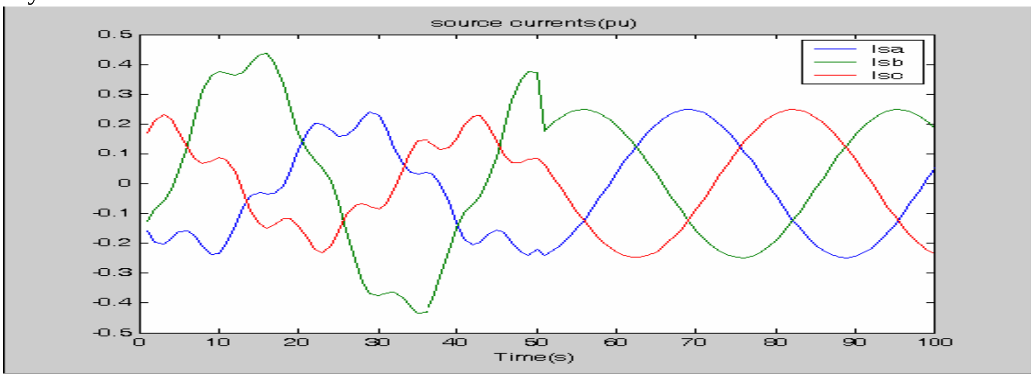

Figure 3.4: Source currents

The source voltage and current of phase-R are shown in Fig. 3.5 which clearly demonstrates that the source voltage and current are in same phase when the compensator being switched after one cycle.

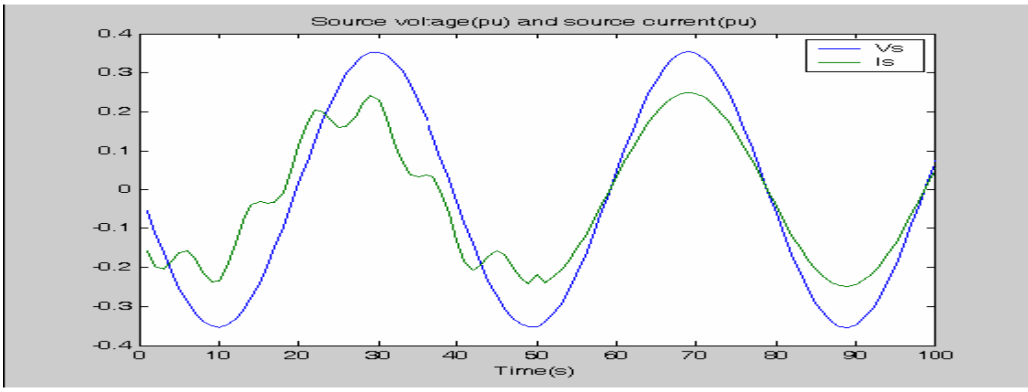

Figure 3.5: Source voltage & current

These results clearly demonstrate that the shunt APF (shunt compensator) balances the source currents, corrects their power factor to unity and eliminates harmonics from the source currents.

Results of MATLAB programs for simulation of shunt APF using p-q theory

The following figures shows the different waveforms which are the results of MATLAB programming for reference current generation scheme for the shunt APF (shunt compensator) using p-q theory to mitigate the harmonics and balances the source current. As already discussed in the p-q theory that the requirement of real power by the load is supplied by the source and the requirement of reactive power by the load is fulfilled by the compensator. Fig. 3.6 shows the waveform of active power required by the load and this active power is supplied by the supply source.

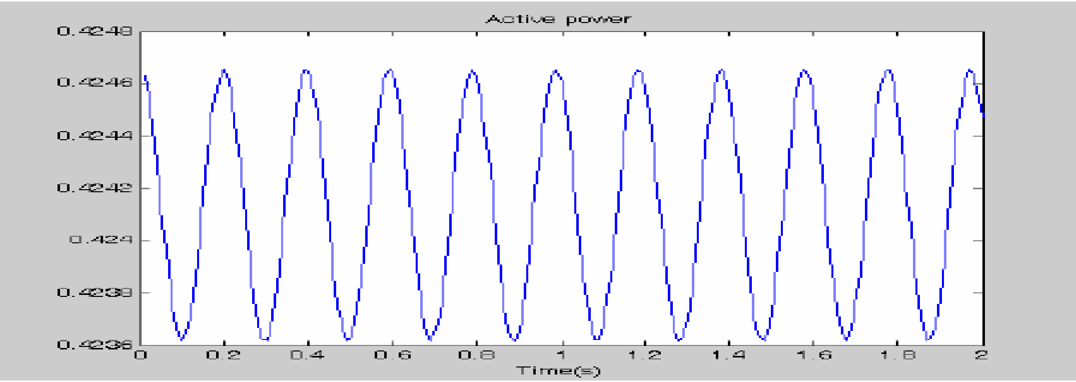

Figure 3.6: waveform of supplied Active power

Fig. 3.7 shows the waveform of reactive power required by the load and this entire reactive power requirement of the load is fulfilled by the compensator.

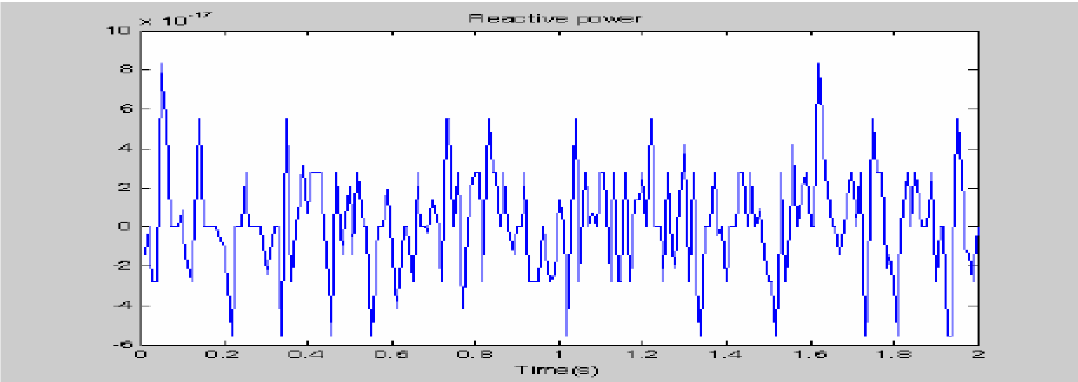

Figure 3.7: Reactive power

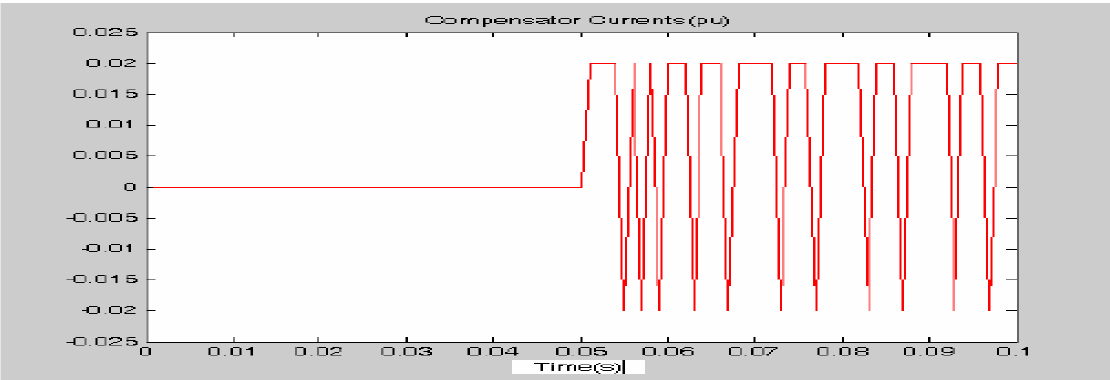

Figure 3.8: Compensator current supplied in circuit after one cycle

Fig. 3.9 shows the source currents which are balanced and harmonics free after one cycle when the compensator is switched on and supply its current.

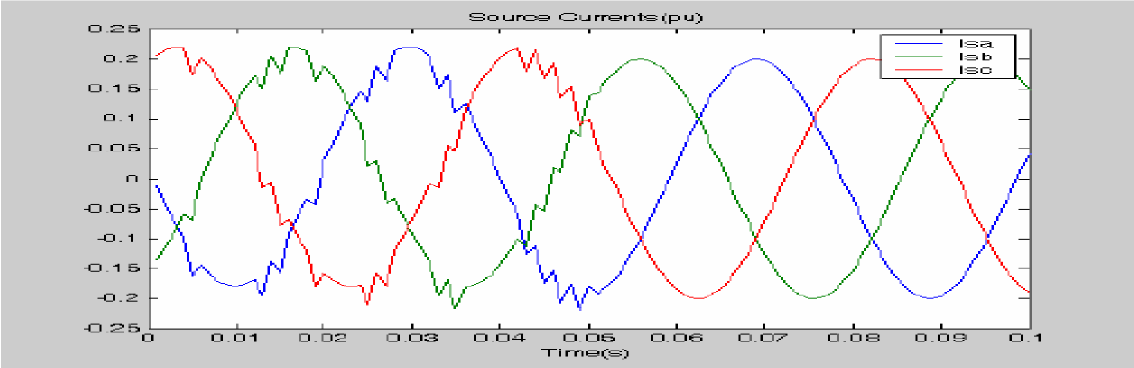

Figure 3.9: Source current waveforms

These results clearly demonstrate that the shunt APF (shunt compensator) on the basis of p-q theory supplies the entire reactive power and balances the source currents and mitigate the harmonics from the source currents.

IV. Conclusion

In this paper, an attempt is made to find out various power quality problems and among these problems most prominent and frequently occurring problem harmonics is analyzed. In this Paper, different types of active power filters with their control strategies are explained in detail. Then an ideal shunt APF using VSI converter configuration is realized, simulation of ideal shunt APF for 3-phase, 3-wire distribution system supplying non-linear loads is carried out to filter harmonics and to improve power factor using MATLAB 13a. In addition to this simulation of shunt APF for 3-phase, 3-wire distribution system using p-q theory has been carried out to eliminate harmonics. In this work, the real power exchange from converter is minimal just to provide losses in the converter and oscillating part of the load active power. The power handling capacity of the active power filter can be increased by connecting an energy storage device in place of capacitor. All the above work can be carried out with shunt APF, series APF or hybrid filter.

The main concentration of this work is to reduce harmonics. This work may further be extended for voltage regulation, power factor correction and load balancing of non-linear loads, in addition to the harmonics elimination for 3-phase, 3-wire and 3-phase, 4-wire distribution system.

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