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Design a Dynamic State Observer in Active Power Filter For Power Quality Improvement

A. Suresh Kumar* and P. Suresh**

ABSTRACT

This paper design a dynamic state observer for extraction of harmonics in distortion waveform from supply side due to usage of non linear load. The shunt active power filter inject the negative harmonics to the supply side for improvement of the power quality. A state observer estimates the state variables based on the measurement of the output over a period of time. Separate observer have been provide for voltage and current signal. The pole assignment study for improve the steady state response of the system. The error in the magnitude and phase of the extracted the components, due to the deviation of the signal from the central frequency of the observer. The well known control strategy of using a large feed back around the noise signal can be employed to reduce its effect at the output, exhibiting low total harmonics distortion under non linear load. The simulation study was conducted using MATLAB, considering the dynamic extraction of harmonic in source side of non linear load.

Keywords: Shunt active power filter; state observer; Non linear load; Pulse width modulation.

1. INTRODUCTION

Reliable and quality of power has become one of the most critical issues in this world. Harmonics is one of the problems associated with power quality. While using of nonlinear loads such as diode/ thyrister and rectifiers, harmonics are introduced in the transmission line currents, which degrade the power quality in power transmission/distribution systems. Traditionally passive filters have been used to attenuate the harmonic distortion and compensate the reactive power, but they are bulky, detune and can resonate with supply impedance. The active power filters (APF) are powerful tools for compensation of current harmonic, reactive power and unbalance of nonlinear fluctuating loads.

Alternatively, active filters can be used, to maintain the power quality (PQ). There has been an increasing interest in harmonic detection and extraction algorithms over the last decade. Large frequency deviations from the nominal value of 50 or 60 Hz can substantially degrade the performance of the harmonic filters. Conventionally, the extraction of individual harmonics has been based on the fast Fourier transform (FFT) [1]. It is offline accurate and efficient under stationary conditions. The loss of accuracy, under time-varying conditions and the noise sensitivity of FFT, has been discussed in [2] and [3]. A number of algorithms based on least-square techniques [4]; Kalman filtering [5]; Parseval's relation and energy concept [6]; artificial neural networks (ANNs) [3], [7]; adaptive infinite impulse response line enhancer [8]; and non recursive procedures [9] and state estimation techniques [10] have been proposed to extract and measure harmonics under time-varying conditions.

The THDv in industry should not exceed 5% as per the guidelines given in the IEEE Standard 519-1992. LC compensators have been considered to minimize the expected value of the total voltage harmonic

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[*] Assistant Professor, Department of Electrical and Electronics Engineering, SRM University, Kattankulathur–603 203, kancheepuram Dt., Tamil Nadu, India, *Email: sureshkumarask2@gmail.com*

[**] Assistant Professor, Department of Electrical and Electronics Engineering, SRM University, Kattankulathur–603 203, kancheepuram Dt., Tamil Nadu, India, *Email: suresh.au95@gmail.com*

distortion while maintaining the power factor at a specified value [11]. Fixed passive filters may not perform well, particularly when the operating frequency drifts far away from the set resonance frequency.

Alternatively, active filters can be employed [12], [13]. Series as well as shunt compensation for the elimination of distortion can be used when non-linear loads are connected to an inverter. However, improper use of shunt compensators may sometimes increase the distortion in voltage and current in a feeder [14]. The quality of the network voltage affects the operation of a grid connected inverter. The inverter current will show heavy distortion when connected in parallel to a poor quality voltage source [15].

A survey of PWM technique is available in [16] and an interesting procedure for eliminating harmonics in PWM inverter has been reported in [17].

Many control methods have been proposed for obtaining pure sinusoidal output with good voltage regulation and fast dynamic response. The availability of low cost microprocessors led to many discrete-time methods, such as repetitive control, sliding mode control [18], and deadbeat control to improve the performance. To get zero steady state error in the output voltage and fast response, a combination of virtual inductor, capacitor and a resistor were used in [19], while the internal model control scheme (IMC) was employed in [20]. The control methods presented in [21], [22] employ two feedback control loops. The inner loop is used for current control and the outer loop is used for voltage control. Some of these methods have specifically considered the reduction in distortion due to non-linear loads.

A state observer method based on the space-domain approach for single-phase shunt active power filters to eliminate harmonics is analyzed in this project. Different compensating current references can thus, be accurately and easily obtained by adopting the proposed method. Simulation results were obtained using MATLAB simulink. The develop simulink model for compensated and uncompensated condition. Use this method to reduce the THD value and power factor also obtain near unity, so power quality is improved.

2. SYSTEM DESCRIPTION

The shunt SAPF was used widely. Figure 1 shows the topology of SAPF, which has used to cancel the current distortion. The performance of SAPF strictly depended on the features of the current-detection algorithms and controllers. Many papers on current-detection algorithms have been published, and some algorithms have been applied in practice.

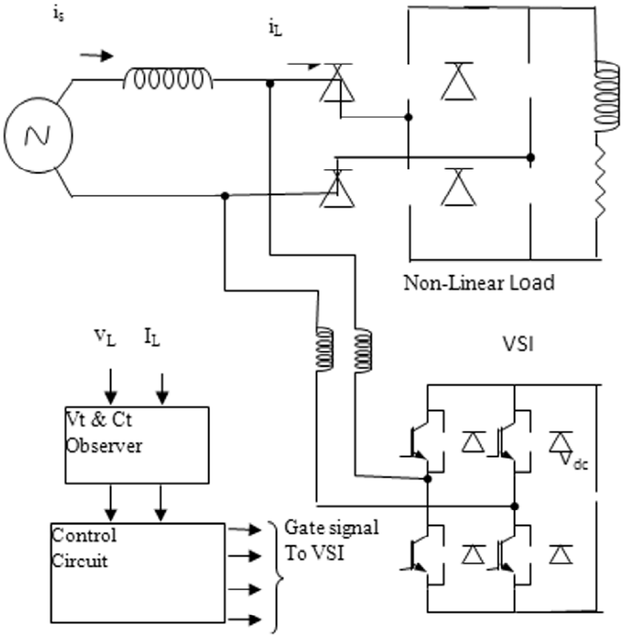

Figure 1: Single Phase Shunt Active Power Filter

However, usually one algorithm was only appropriate is some situation but not in all situation. Hence, a proposed dynamic state observer current-detection algorithm of SAPF for harmonic elimination, power factor correction, and balancing of nonlinear loads was proposed. The figure 1 represents as the single phase source was connected to the non linear load side. shunt active power filter inject in between source and load side. RL load was connected to the inverter side. I_s, I_L, were represent as the source and load side current. Similarly V_s, V_L were represented as the source and load side voltage. V_{dc} was represented as the dc side capacitor voltage. This current detection algorithm to generate the current references was used. This current references and voltage source inverter (VSI) output current references were compared and then inputted to the current controller. This controller generated the pulse signal. This signal was input gate signal to VSI.

2.1. State Observer

In practice all the state variables are not available for feedback. Possible reasons include. Non-Availability of sensors, Expensive sensors, Available sensors are not acceptable (due to high noise, high power consumption etc.,). The method are available to estimate unmeasurable state variables without differentiation process. Estimation of unmeasurable state variables is commonly know as Observation. If the state observer absorbs all the state variables of the system, regardless of whether some state variables are available for direct measurement, it is called a full-order state observer.

An observer estimates fewer than n state variables represent in figure 2, where n is the dimension of the state vector, is called a reduced-order state observer or, simply, a reduced –order observer .if the order of the reduced-order state observer is the minimum possible, the observer is called minimum-order state observer.

A state observer estimates the state variables based on the measurements of the output over a period of time. The system should be "observable". Let Unknown parameter of the system

$$\begin{pmatrix} x1 \\ \dot{x}2 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ -w^2 & 0 \end{pmatrix} \begin{pmatrix} x1 \\ x2 \end{pmatrix} \tag{1}$$

Known parameter of the system

$$\begin{pmatrix} \dot{\hat{x}}1 \\ \dot{\hat{x}}2 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ -w^2 & 0 \end{pmatrix} \begin{pmatrix} \hat{x}1 \\ \hat{x}2 \end{pmatrix} + \begin{pmatrix} k1 \\ k2 \end{pmatrix} e \tag{2}$$

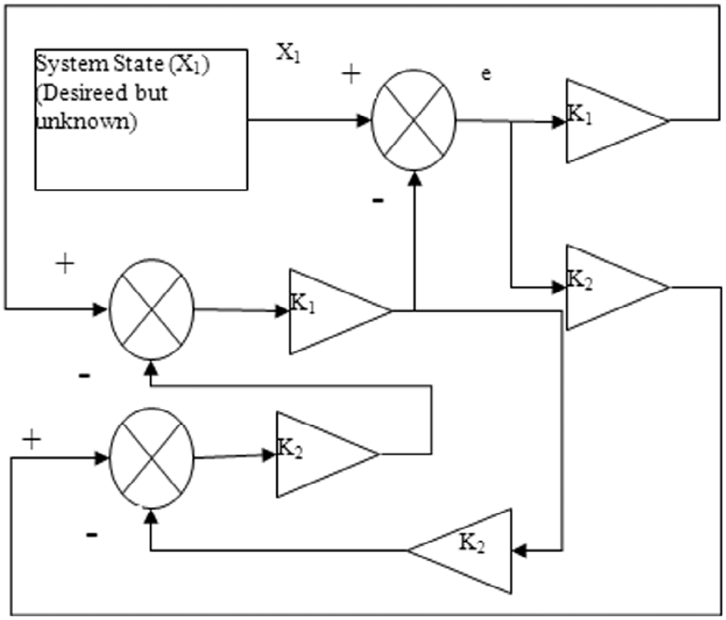

Figure 2: State observer block diagram

Subtract equation (1) and (2) We get

$$\begin{pmatrix}\dot{e}1\\ \dot{e}2\end{pmatrix}=(A)\begin{pmatrix}e1\\ e2\end{pmatrix}-\begin{pmatrix}k1\\ k2\end{pmatrix}e \tag{3}$$

Let $y = c^t X$ where $c^t = [1, 0]$

The value of E become

$$\begin{pmatrix}e1\\ e2\end{pmatrix}=(E)$$

$$\left(X-\widehat{X}\right)=(E)$$

Substitute the value of e in below equation

$$\begin{aligned} e &= y-\widehat{y}\\ &= c^t\left(X-\widehat{X}\right)\\ e &\Rightarrow c^t E \end{aligned}$$

Let $\dot{E}$ become the error dynamics

$$\begin{aligned} \dot{E} &= AE - Kc^t E\\ &\Rightarrow \left(A-Kc^t\right)E\\ \dot{E} &= BE \end{aligned}$$

Above equation gives the system is autonomous, for this system to be stable all the Eigne values must be in the LHS of the “S” plane. Find the value of B to find the roots of the system

$$B=\begin{pmatrix}0 & 1\\ -w^2 & 0\end{pmatrix}-\begin{pmatrix}k1\\ k2\end{pmatrix}\begin{pmatrix}0 & 1\end{pmatrix}$$

$$B=\begin{pmatrix}0 & 1\\ -w^2 & 0\end{pmatrix}-\begin{pmatrix}k1 & 0\\ k2 & 0\end{pmatrix}$$

$$\Rightarrow\begin{pmatrix}-k1 & 1\\ -w^2-k2 & 0\end{pmatrix}$$

To calculate the roots of the system with the help of the (4) equation

$$(sI-B)=0$$

$$\Rightarrow\begin{pmatrix}s & s\\ s & s\end{pmatrix}\begin{pmatrix}1 & 0\\ 0 & 1\end{pmatrix}-\begin{pmatrix}-k1 & 1\\ -w^2 & 0\end{pmatrix}=0$$

$$\Rightarrow\begin{pmatrix}s & 0\\ 0 & s\end{pmatrix}-\begin{pmatrix}-k1 & 1\\ -w^2 & 0\end{pmatrix}=0$$

$$\Rightarrow\begin{pmatrix}s+1 & -1\\ w^2+k2 & s\end{pmatrix}=0 \tag{4}$$

$$s^2 + sk1 + \left(w^2 + k2\right) = 0 \tag{5}$$

To make the system stable the condition are below

$$\begin{cases} k1, & k1 > 0 \\ w^2 + k2, & w^2 + k2 > 0 \end{cases}$$

To get the value of roots trial and error method takes placebelow, in that consider *w* by changing the value of w the location of the pole in the *s* plane also vary.

$$\left(s + w + jw\right)\left(s + w - jw\right) = 0$$

$$\Rightarrow s^2 + 2ws + w^2 + w^2$$

$$\Rightarrow s^2 + 2ws + 2w^2 \tag{6}$$

By comparing the equation (5) and (6) we get the roots are given below

$$\therefore k1 = 2w;\ k2 = w^2$$

This the above roots are on LHS of the "*S*" plane, so system become stable If the roots nearer to the origin of the *S* plane the response of the system become slow but the waveform become sinusoidal.

If the roots faraway to the origin of the *S* plane the response of the system faster but the waveform has distortion.

2.2. Modelling of State Observer and Stability of the controller.

1) Pole assignment of state feed back

Observability means the estimation of initial state of the state variables based on finite Input-Output observations. Estimation of state variables depends on the real part of the closed loop poles assumed. Pole placement technique is used for calculating the observer feed-back gains (D) [*d*01, (*d*11, *d*12)]. System is considered as an oscillator generating a signal of frequency ω rad/s. State space model for this is

$$X =^{\cdot} AX$$

$$Y = c^T X$$

Where,

$$A = \begin{bmatrix} A_0 & 0 \\ 0 & A_1 \end{bmatrix}; A_0 = 0; A_1 = \begin{bmatrix} 0 & \omega \\ -\omega & 0 \end{bmatrix}$$

$$X = \begin{bmatrix} \chi_{01} \\ \chi_{11} \\ \chi_{12} \end{bmatrix};\ C^T = \begin{bmatrix} 1 & 1 & 0 \end{bmatrix}$$

The model designed for estimating the state variables, otherwise called as observer represented in state space model as

$$\dot{\hat{X}} = A.\hat{X} + D\left(y - C^T \hat{X}\right)$$

where *e* is the error in output from system as well as model.

Error differential equation is obtained as

$$\dot{E} = \left(A - DC^{T}\right)E$$

where E is the error in actual and estimated state variables. The roots of the error differential equation are the closed loop poles of the observer. Observer feed-back gains [d01, (d11, d12)] are designed using pole placement technique. The closed loop poles of the observer assumed to be equidominant at $s = -a\omega$ for DC component and $s = -a\omega \pm j\omega$ for the fundamental components. Transfer function model of the observer d-q model is 1/(1+ $sTob$), where $Tob = 1/(a\omega)$ time constant of observer decides the response time as well as filtering of the signal.

Figure 3 shows the state observer implement in the Orcad simulator. Selection of the pole has extremely important in the system response and also construe the system error. The state variables are represent as follows.

$$x_1 = \sin(\omega t)$$

$$\dot{x}_1 = x_2 = \omega\cos(\omega t)$$

$$\ddot{x}_1 = \ddot{x}_2 = \omega^2 \sin(\omega t)$$

$$\dot{\hat{x}}_1 = \hat{x}_2 + k_1 e$$

$$\dot{\hat{x}}_2 = -\omega^2 \hat{x}_1 + k_2 e$$

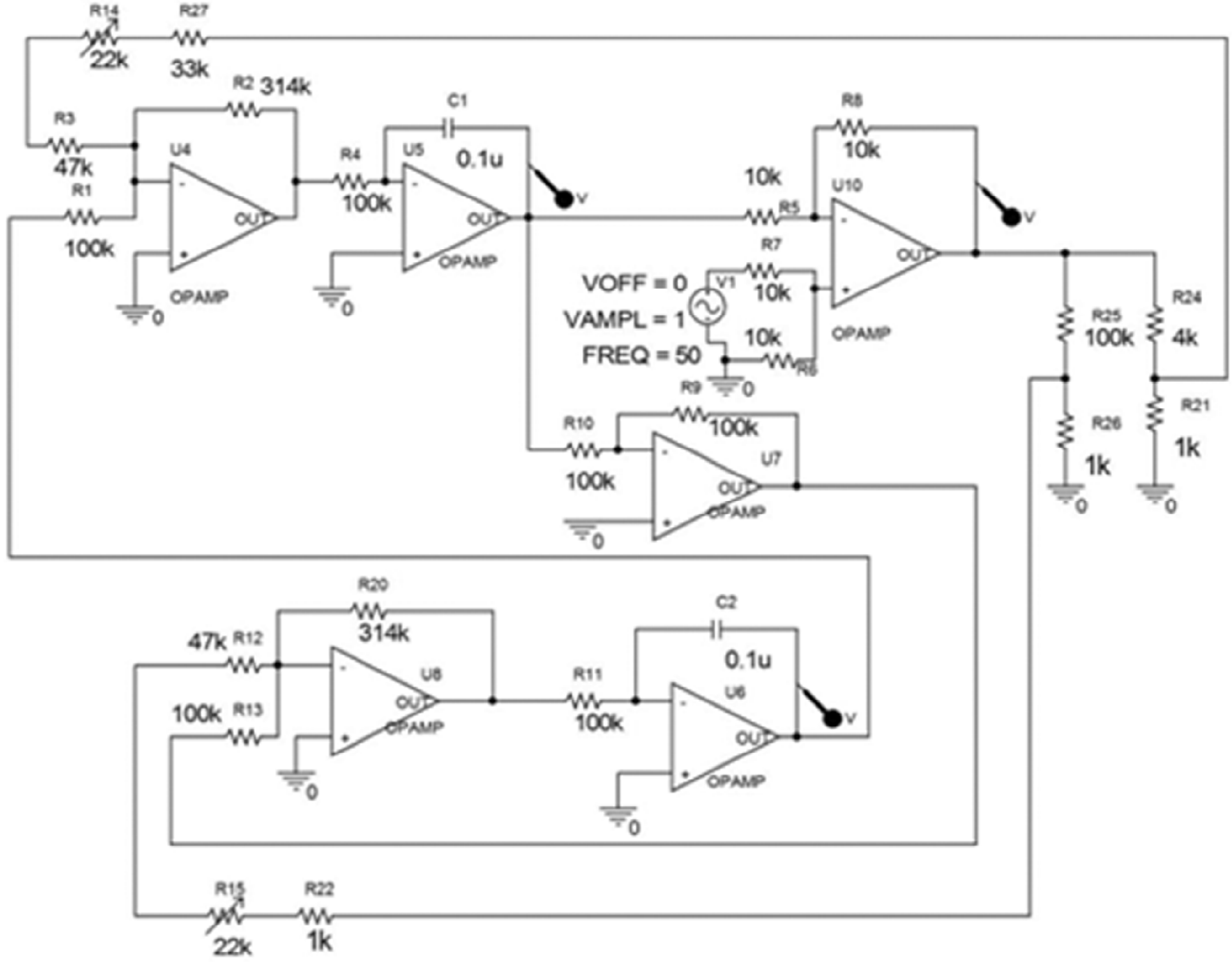

Figure 3: State Observer model Implement in Orcad simulator.

2) Stability analysis of controller

The stability analysis of the system based on the assign the poles, Figure 4 shows the output response of the state observer model. The input frequency has 50 HZ sinusoidal signal. The poles of the second order characteristics equation are 0.01 and 0.625. The output response of the observer get both sin and cosine signal. The poles are near to the orgin, so the response are quick.

The characteristic equation in the s-domain, obeyed by this error differential equation, has (2N + 1) roots, which are also defined as the observer poles. These closed-loop poles can be located on the left-hand side (LHS) of the s-plane. The closed-loop poles are assumed to be equidominant and located such that,

$s = -aj\omega_1$ for $m = 0$ and $S = (-aj\omega_1 \pm jm.\omega_1)$,

for $M = 1, 2, 3 \ldots\ldots\ldots N$

Where, ω_1 = Fundamental Frequency

The observer pole placement” makes the magnitude of the individual components in the error vector E vanish exponentially (i.e.,$|e_m(t)|$remains within the $e^{-1\omega_1 t}$ envelope. To sum it up, the output variables of the various blocks of the observer $\widehat{Y} = \left[\widehat{X}_0, \widehat{X}_{11}, \widehat{X}_{21}, \ldots\ldots \widehat{X}_{m1} \ldots\ldots \widehat{X}_{n1}\right]^t$ would tend to merge with the dc, fundamental component, and all of the harmonics of the signal to be analyzed, both in magnitude and in phase. The parameters in the vector D of the control system are set such that all of the observer poles are on the LHS of the s-plane. Since the extracted harmonics are sine waves, the individual blocks would be controlled oscillators, tuned to the various harmonics. The oscillations would be pure sine waves, only when the control signals for the blocks vanish as the error $e(t)$ tends to zero. For power applications, the fundamental tuned frequency is fixed nominally at $f = 50$ Hz or (60 Hz). The harmonic frequencies are fixed at (m.f) Hz, $m = 2, 3, 4 \ldots\ldots N$. The tracking of signals when the frequency drifts from the nominal value.

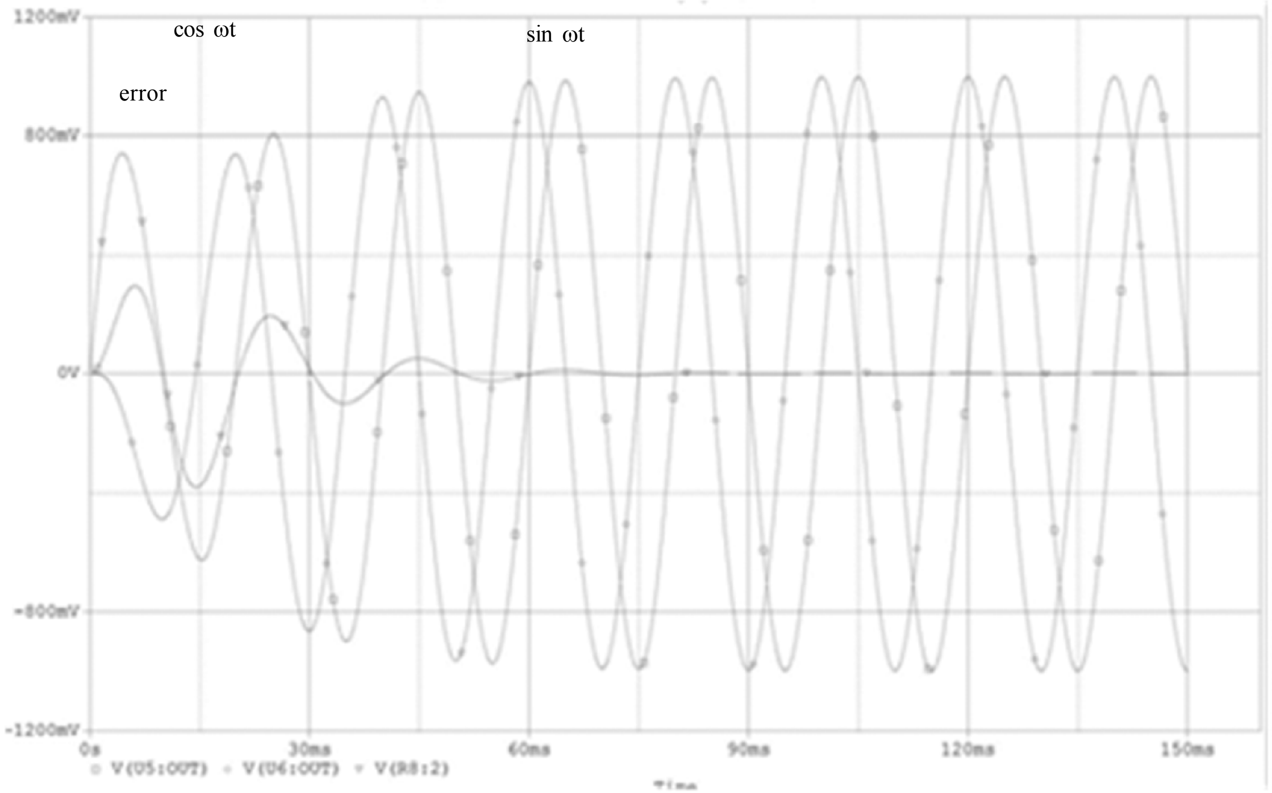

Figure: 4. State Observer Output Response

3. SIMULATION RESULT

3.1. Simulation Model of Proposed System

The figure 5 shows the matlab simulink diagram of the system. The input source connected as 220V and 50 Hz frequency connected to the single phase rectifier with 50&! resistance and 200µF capacitive load. The rectifier act as a non linear load. The input current source THD value has 59.54% due to the non linearity for the system. The shunt active power filter parallel injected to the source side

Simulation results of the continuous and the discrete composite observer, designed for a central frequency of 50 Hz, with automatic correction for frequency drift are presented in this section. By adding to the fundamental, the odd harmonics, a square wave-like input signal was generated. The factor a = 0.5 was chosen for the observers.

The observer figure 6 has matlab simulink model obtained the fundamental value and create the error, that error represent the harmonics in the signal. The controller used as the both voltage and current observer and generate the signal across it. The control signal compare with reference signal and generate the PWM

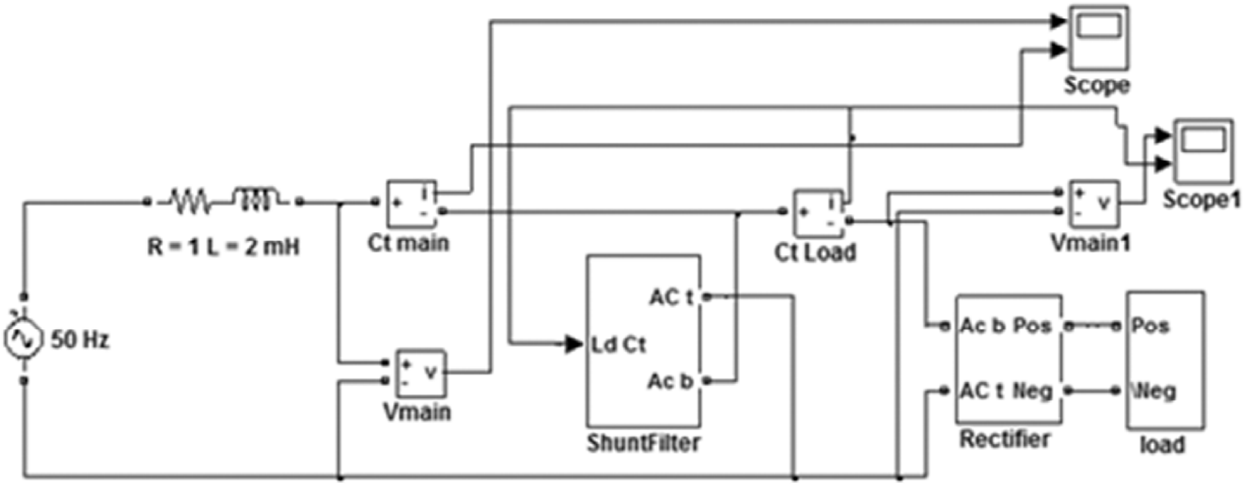

Figure 5: Matlab Simulink diagram of the System

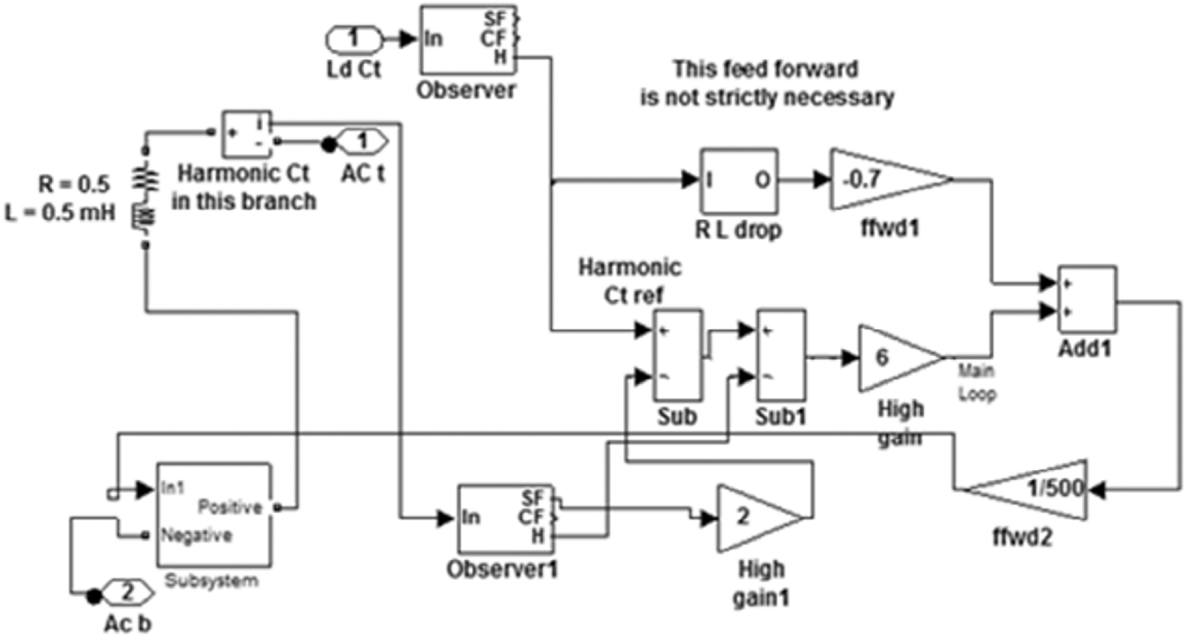

Figure 6: Matlab Simulink diagram of the System

signal. Pulses are given to the single phase voltage source inverter. The dead zone block limit for the positive and negative sequence. The voltage source inverter four switches were control by the given gate signals.

3.2. Simulation Result

The simulation result was show the voltage and current wave form for both source and load side shown in figure 7 and 8. The source side of the wave form achieve the pure voltage and current wave form which has compare to the uncompensated system. The voltage and current has obtained the 200v and 10A.. The source side response were very quick because of use of dynamic state observer.

The FFT tool were very use full for analysis the spectrum response. The figure 9 and 10 shows the THD value for the source side voltage and current wave form. The THD values were less compare with un compensated system. That value satisfied the IEE 519–1992 standard.

Figure 7: Source Side voltage and current waveform

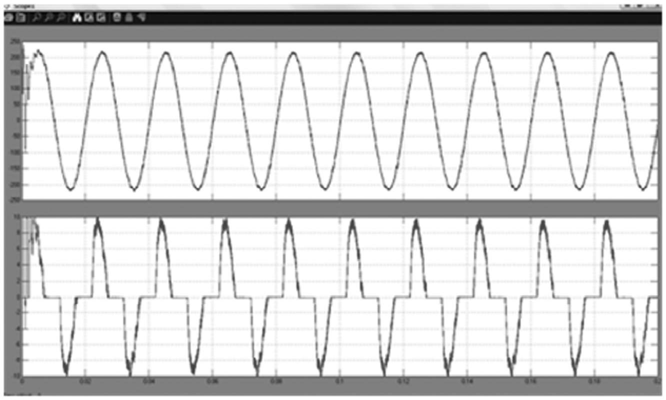

Figure 8: Load Side voltage and current waveform

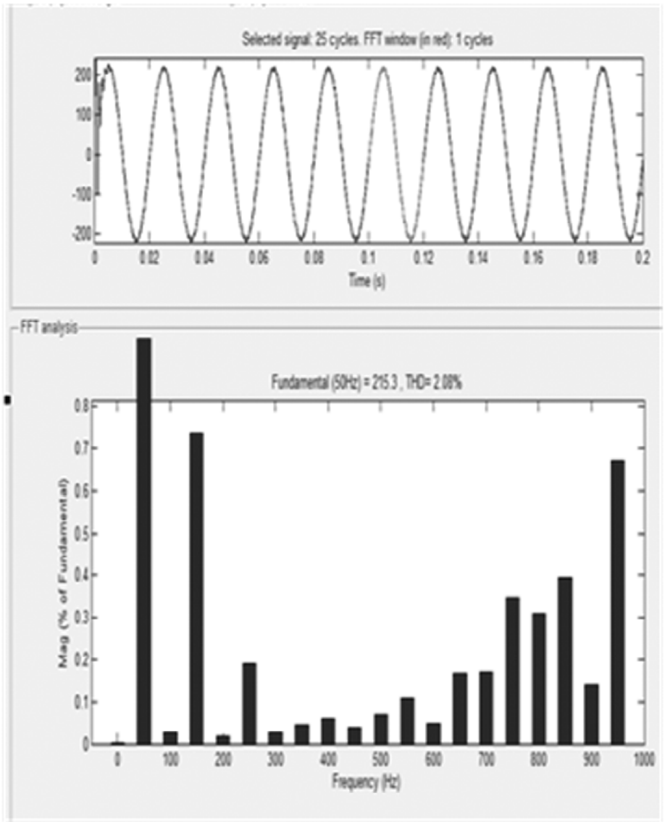

Figure 9: Source Voltage FFT analysis

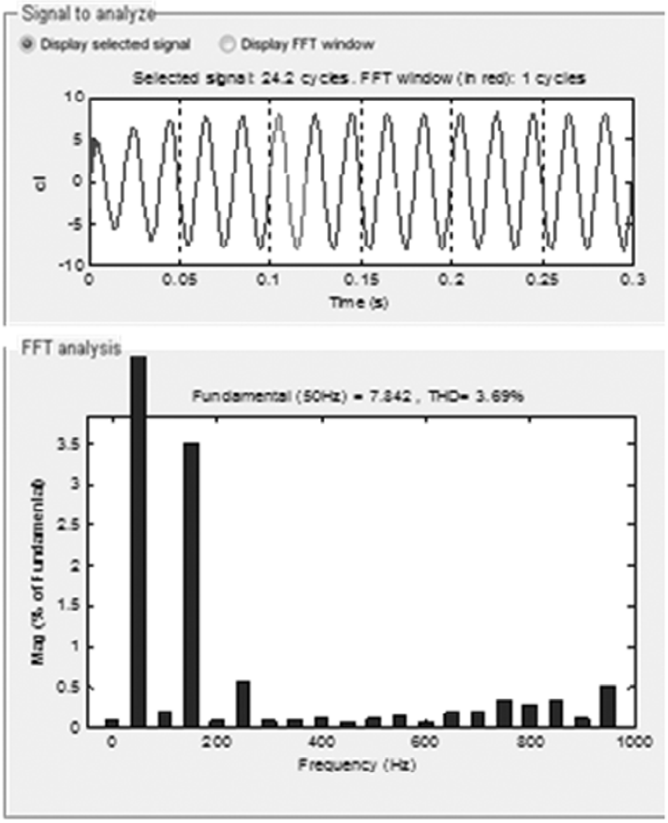

Figure 10: Source Current FFT analysis

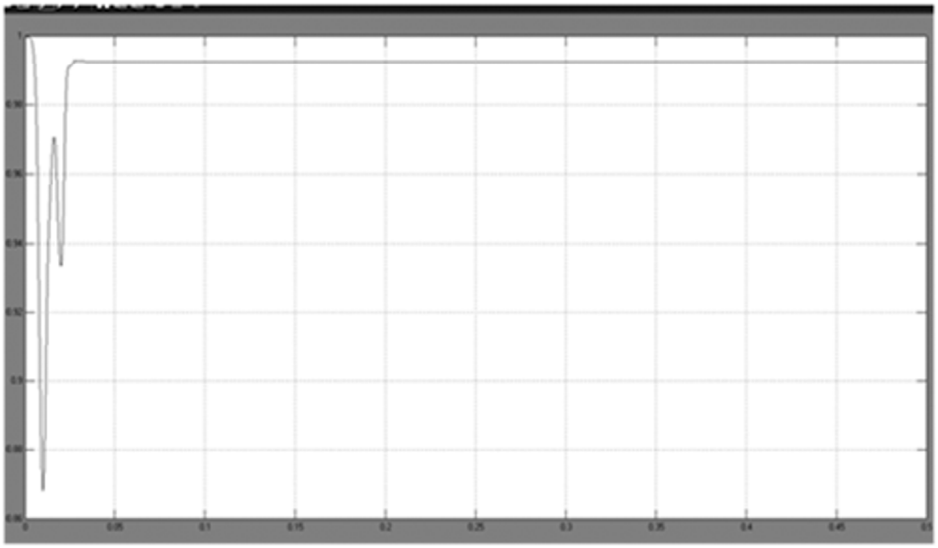

Figure 11: Power Factor

The power factor were very important in one of the power quality improvement. The system response of power factor shown in figure 11. That power factor were to maintain the near unity.

4. SIMULATION RESULT AND DISCUSSION

The system compare with the both compensated and uncompensated response. The controller used as both voltage and current observer. The controller has rapid response for selection of the poles. The Table 1.1 represent the total harmonic distortion (THD) and power factor value for compare with both compensated and uncompensated system. The THD value rapidly reduced the source current and also reduced in source voltage. The power factor also improved in good manner.

Table 1
Comparisons

Description		*Un Compensated*	*Compensated*
THD	Voltage	10.51 %	2.08%
	Current	59.54 %	3.69%
Power Factor		0.9	0.99

5. CONCLUSION

The observer for extracting harmonic from periodic waveform has been presented. The transient response depends on observer pole position. Harmonics in the output voltage waveform of inverters supplying non-linear loads can be reduced by employing a local harmonic feed back. For achieving this, a simple observer consisting of a single block can be used for estimating the fundamental and the harmonic content. In addition, the local harmonic feedback gives rise to an enormous improvement in the quality of the waveform, making up for any possible short coming in the feed forward scheme. It was found in the simulation and experimental studies that for a given pole position and harmonic feed back “h,” the use of composite observer shows a faster response. The use of the proposed observer in shunt active power filter has reduced the harmonic and improve the power factor for source of nonlinear load.

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