Impact Factor Value 4.046 **e-ISSN: 2456-3463**
International Journal of Innovations in Engineering and Science, Vol 5, No.1, 2020
www.ijies.net

Design & Analysis of Synchronous Reference Frame Based Shunt Active Power Filter Using Matlab Simulink

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Abstract – *This paper presents the implementations of a new control algorithm for a three-phase shunt active power filter to regulate load terminal voltage, eliminate harmonics, and improve the power factor in systems with an uncontrolled rectifier and an AC controller as the non-linear loads. Different methods are used to control the active power filters. The reference current to be detected from the load current and processed by the active power filter controller is obtained from control algorithms, of Synchronous Reference Frame Theory (SRF Theory). The voltage source inverter (VSI) is the core of an active power filter. The system is modeled and simulated using MATLAB/Simulink simulation package with a shunt active power filter to compensate for the harmonics current injected by the loads.*

Keywords*- Shunt Active Power Filter, Voltage Source Inverter, Current controller, Non linear load, Synchronous Reference Frame, Total Harmonic Distortion.*

INTRODUCTION

The increasing number of power electronics based equipment has gravely impacted the quality of electric power supply. Harmonics are caused by both industrial and domestic loads. At the same time, much of the equipment causing the disturbance is quite sensitive to the harmonics themselves. A shunt active power filter (SAPF) is a device that is connected in parallel to a group of loads. The shunt active power filter cancels the reactive and harmonic currents drawn by the load so as to make the supply current sinusoidal. Thus, the resulting total current drawn from the ac main becomes sinusoidal. Shunt active power filters is the device which generates the same amount of harmonic as generated by the load but 180o phase shifted. The advantage of active filtering is that it automatically adapts to changes in the network and load fluctuations. They can compensate for several harmonic orders, and are not affected by major changes in network characteristics, eliminating the risk of resonance between the filter and network impedances. Another advantage is that they take up very little space compared to traditional passive compensators. One of the key issues for a proper implementation of an active filter is to use a good control algorithm. Control strategies are applied to active power filters for determining the reference compensation currents to maintain sinusoidal source currents supplied to nonlinear loads according to IEEE-519 standards. The design of an active power filter becomes a challenging task for meeting the strict requirements of critical loads. The use of computers in the 978-1-4799-3421-8114/$31.00 ©2014 IEEE design stage helps in the better understanding of the circuit behavior, selection of component ratings; design of closed loop controllers, and also to arrive at optimum solutions. Simulation is a powerful way to reduce development time and ensure the proper fulfillment of critical steps. This paper proposes a model of a three-phase three-wire shunt active power filter based on synchronous reference frame control strategy for the extraction of reference currents the voltage source inverter. There are two major parts of a shunt active power filter. The first one is the controller that determines the compensating current to be injected at the point of common coupling (PCC) and the necessary active component of the current required to be absorbed to maintain the D.C. bus voltage. Various techniques for calculating compensating current such as instantaneous reactive power theory, synchronous detection method, and synchronous d-q frame method are available. Secondly, there is a current controlled voltage source inverter. As the load harmonics may be complex, change rapidly and randomly, A shunt active power filter has to respond quickly with high control accuracy in current tracking. There are various current control methods proposed for such active power filter configurations, but in terms of quick current controllability and easy implementation hysteresis band current control method has the highest rating among other current control methods.

The main components of the above system are as follows.

01-Mains Supply

02- Nonlinear Load

03- Active Power Filter

a. Voltage Source Inverter

b. DC Link Capacitor

c. Interface Reactor

d. Reference Current Generator

e. Current Controller

The design of the APF controller is based on time-domain method that consists of three main tasks; to identity the harmonic content and form a synchronized reference APF current; to provide closed-loop control to force the current of the active filter to follow the reference current; and to regulate the capacitor dc voltage. The aim of the project is to investigate the performance of a three phase three wire shunt active power filter based on synchronous reference frame theory and with reference to elimination of current harmonics by off line simulation technique using MATLABI SIMULINK.

METHOLOGY

Shunt Active Power filter

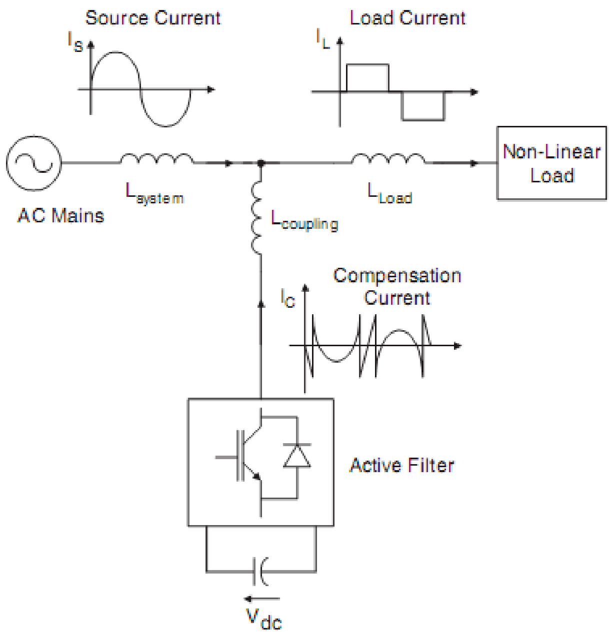

Fig. 01- Shut Active Power Filter

Shunt active power filter is a device that is connected parallel to the load to cancel the reactive and harmonic current injections. The shunt active power filter is a voltage source inverter driven to generate the currents that are equal but opposite to the harmonic currents in the current waveforms. The basic compensation principle of shunt active power filter is that it is controlled to supply a compensating current ic into the system, so that it cancels current harmonics on the AC side, and makes the source current in phase with source voltage as explained in above principle. Fig.2 shows different waveforms. Curve A is the load current waveform and curve B is the desired mains current. Curve C shows the compensating current injected by the active filter containing all the harmonics, to make mains current sinusoidal. In this way, by eliminating harmonics from power system shunt active power filter plays an important role in power quality improvement. It also helps in reactive power compensation, voltage regulation etc. Shunt active power filter is smaller, more versatile, more selective, better damped and less prone to failure problem.

Synchronous Reference Frame

Reference Frame transformation is the transformation of coordinates from a three-phase a-b-c stationery co-ordinate system to the 0-d-q rotating coordinate system as shown in Figure. This transformation is important because it is in 0-d-q reference frame the signal can effectively be controlled to get the desired reference signal. Transformation is made in two steps: In 1st transformation from the three-phase stationery coordinate system to the two-phase so-called α-β-o stationery coordinate system is done. Load currents and voltages at Point of Common Coupling (PCC) are transformed to 0αβ coordinates.

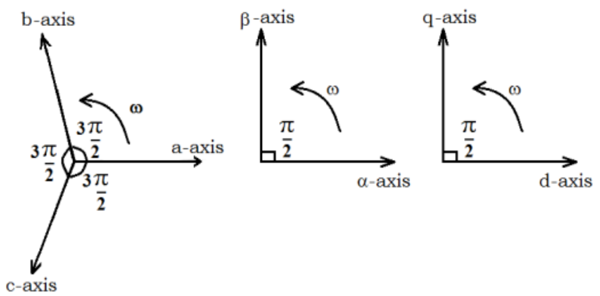

Figure 02:-Reference Frame Transformation

The axes a, b, and c are fixed on the same plane and are separated from each other by 120 degree, α-β-o are orthogonal axes with the α-axis being synchronized with the a-axis of a-b-c plane and β-axis being orthogonal to the α-axis. 0αβ in fig.2 is still rotating with the frequency of ω radians/second. To eliminate this frequency, a 2nd step is taken, in this transformation from the 0-α-β stationery coordinate system to the 0-d-q rotating coordinate system.

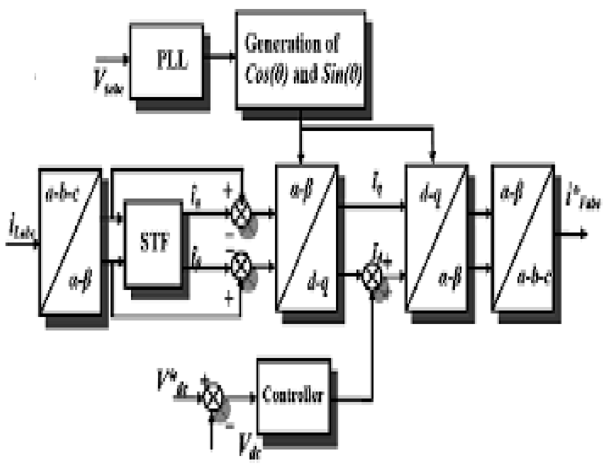

Figure 03: - Principle of Synchronous Reference Frame Method

The Synchronous Reference Frame method (SRF) is based on the fact that harmonics change their frequency in a rotating reference frame, and so they are better isolated with high pass filters. In this method the measured load currents are transformed into the rotating reference frame (d-q frame) that is synchronously rotating at the line voltage frequency using (1) and (2)

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{pmatrix} cos\omega_s t & -sin\omega_s t \\ sin\omega_s t & cos\omega_s t \end{pmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (2)$$

The line frequency components of the load currents become DC quantities and the harmonic components are frequency shifted by ωs in the d-q reference frame. A high pass filter in the d-q frame, with a cutoff at the line frequency can be used to extract the DC components. If the phase of the d-axis current is locked to the phase voltage, ea, of the a-b-c coordinates with a phase locked loop (PLL), and then the I_d^{dc} component represents the fundamental real current and I_q^{dc} represents the fundamental reactive component. By subtracting these quantities from Ild and Ilq, the harmonic content is obtained as shown in (3) and (4).

$$i_{dh} = I_{ld} - I_d^{dc} \quad \text{..........(3)}$$

$$i_{qh} = I_{lq} - I_q^{dc} \quad \text{..........(4)}$$

These quantities can then be used to develop the compensating quantities for the active filter by transforming back to α-β coordinates and then to a-b-c coordinates using (5) and an inverse transformation (6).

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{pmatrix} cos\omega_s t & -sin\omega_s t \\ sin\omega_s t & cos\omega_s t \end{pmatrix} \begin{bmatrix} i_{dh} \\ i_{qh} \end{bmatrix} \quad (5)$$

The compensating line currents can be obtained using

$$\begin{bmatrix} i^*{}_{ac} \\ i^*{}_{bc} \\ i^*{}_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} i^*{}_{c\alpha} \\ i^*{}_{c\beta} \end{bmatrix} \quad (6)$$

One of the most important characteristics of this method is that the reference currents are derived directly from the real load currents without considering the source voltages. The generation of the reference signals is not affected by voltage unbalance or voltage distortion, therefore increasing the compensation robustness and performance. Reference frame rotates synchronous with fundamental currents. Therefore, time variant currents with fundamental frequencies would be constant after transformation. However, harmonics with different speeds remain time variant in this frame. Thus, currents would be separated simultaneously to DC and AC parts. AC part of d axis and whole current in q axis are used for harmonics elimination and VAR compensation. Zero current is produced due to a three-phase voltage imbalance or waveform distortions which have not been considered in this paper. Finally, compensatory currents are determined by adverse Park transformation on d and q axis to be injected to the network after tracing and reconstruction. Synchronous d-q-0 reference frame based compensation algorithm is shown in figure

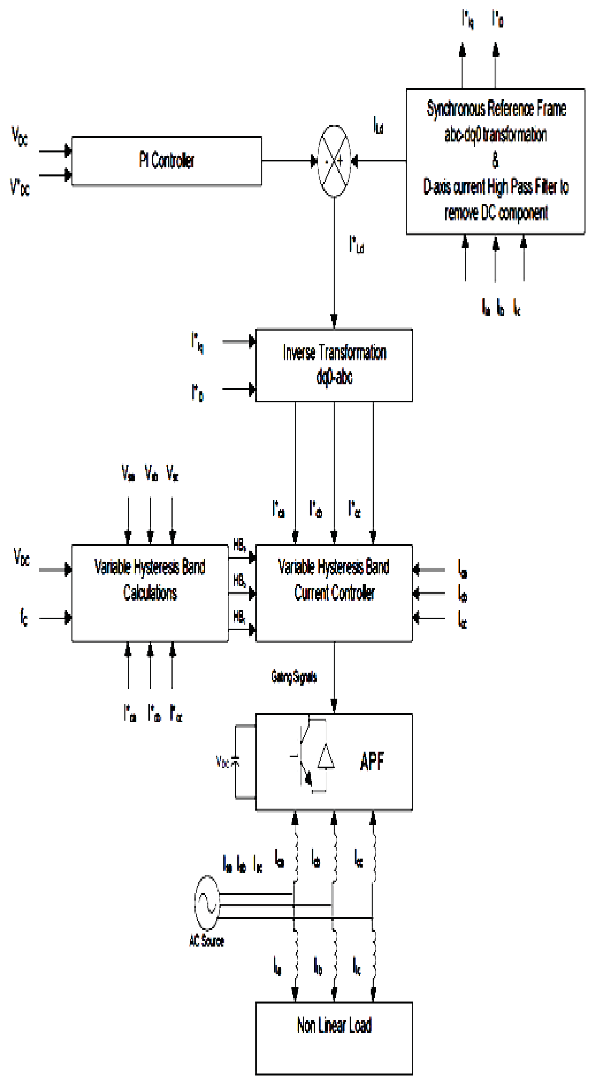

Figure 04:- Synchronous d-q Frame Algorithm

MODEL DESIGN & SIMULATION

During the development process of the shunt active power filter simulations were performed, which allowed the study of its behavior under different operation conditions, and permitted the tuning of some controller parameters together with the optimization of the active filter components values. The proposed model of three phase three wire shunt active filter for suppression of current harmonics has been simulated using MATLAB and its tools Power System Block set and Simulink for balanced normal sinusoidal supply. The proposed system uses two control loops namely dc link voltage control loop (outer loop) and current control loop (inner loop). The inner current control loop ensures that the current supplied by the inverter follows the reference current calculated from the samples of load current. The dc capacitor voltage is regulated by the outer voltage control loop, which ensures the transfer of sufficient real power from the ac source to compensate for the inverter losses and to maintain dc voltage across the capacitor equal to a reference value. The design specifications and the circuit parameters used in the simulation are indicated in table given below.

Table 1.Design specifications & circuit parameters

Source Voltage	Vsa,Vsb,Vsc	127 V rms
System frequency	f	60 Hz
Inverter DC Voltage	Vdc	450 V
Dc side capacitance	Cdc	1500 μF
Ac side inductance	LC	1.0 mH
Ac side resistance	RC 0.1 Ω	RC 0.1 Ω
Rectifier load Resistance	RL	5 Ω
Rectifier side Inductance	LL	1 Mh
Proportional constant	Kp	0.25
Integral constant	Ki	0.005
Switching frequency	Fc	12 kHz

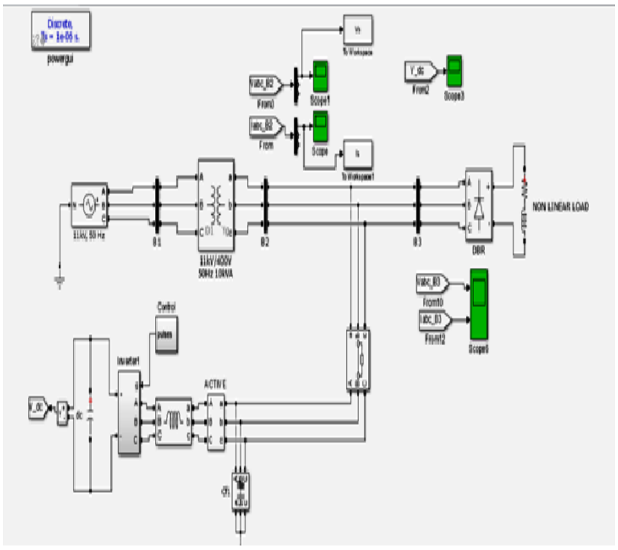

Figure 05:- Simulation of Synchronous Reference Frame

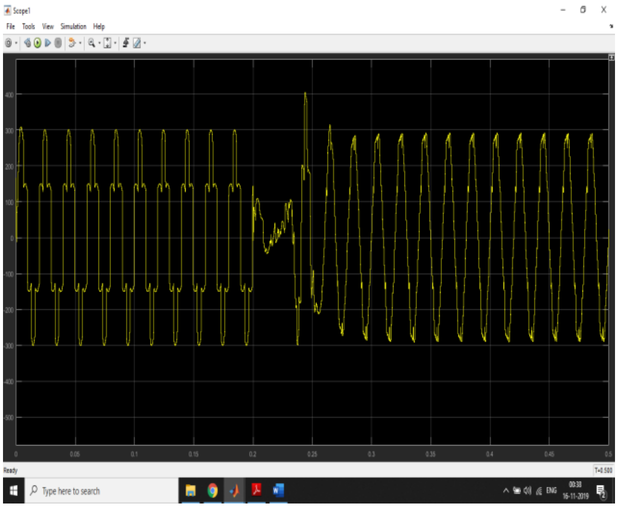

Figure 06:- AC Source Voltage

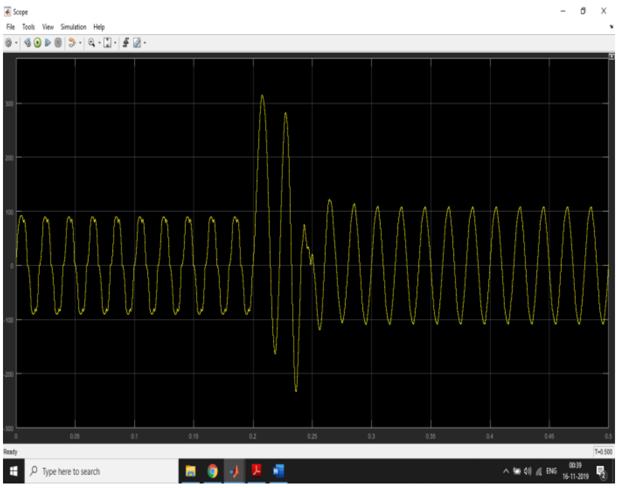

Figure 07:- AC Source Current

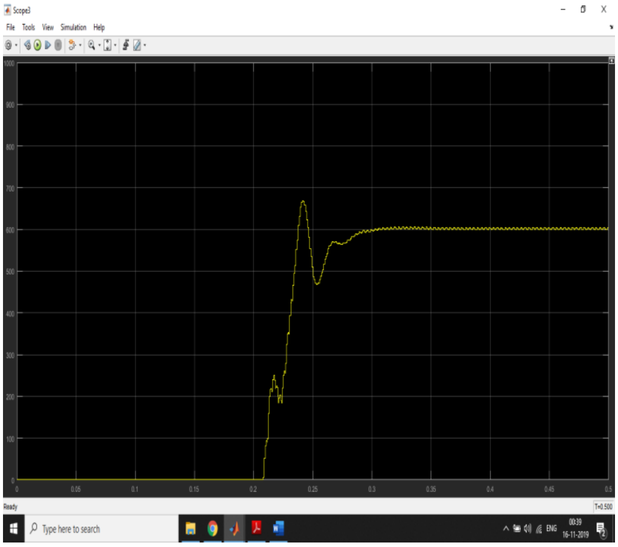

Figure 08:- DC Voltage of Capacitor

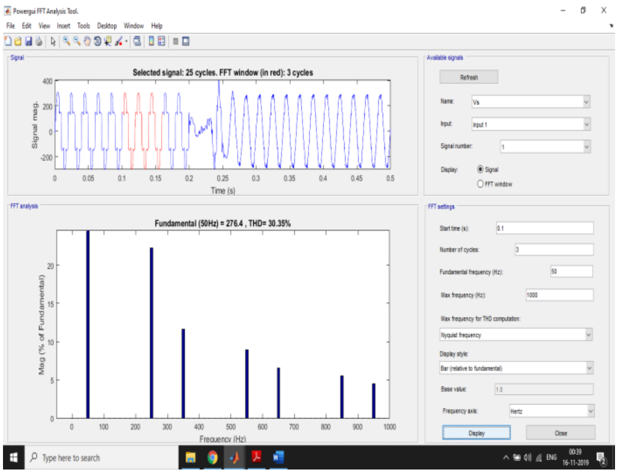

Figure 09:- Total Voltage Harmonics Distortion

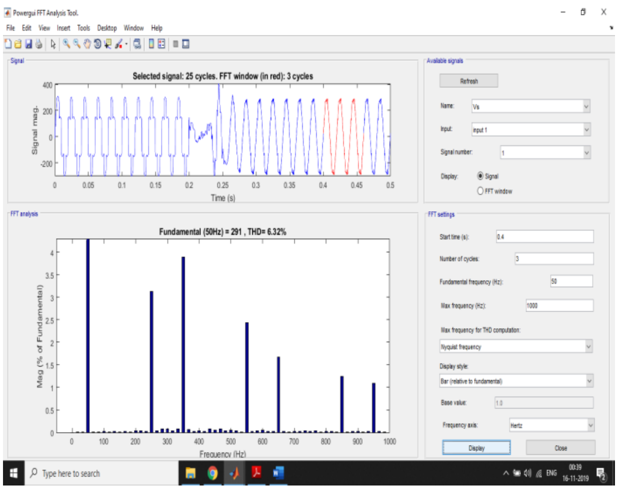

Figure 10:- Total Voltage Harmonics Distortion

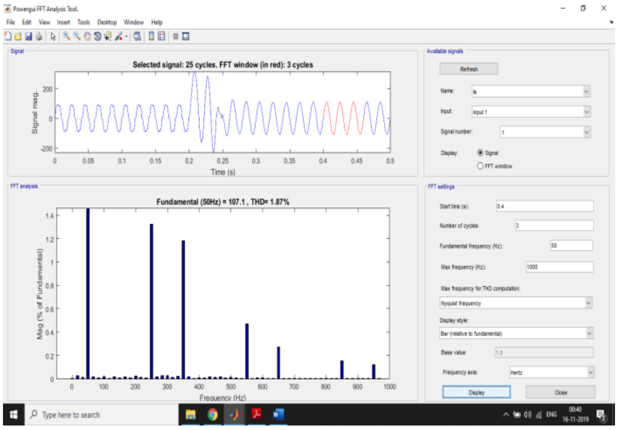

Figure 11:- Total Current Harmonics Distortion

CONCLUSION

It is observed that's synchronous reference frame theory based active power filter can be used for elimination of harmonics for a three phase three wire system supplying a non linear load and is quite effective for harmonic and keeping the utility supply line current sinusoidal. A PI voltage controller results in good dynamic performance of the active power filter system, and steady state condition is reached within a cycle of the AC mains. The THO is also computed in load current as well as in supply current. The THO is 22.79% before harmonic compensation in load current and 1.71% in supply current after harmonic current compensation using adaptive hysteresis band current controller which is quite below the 5% limit defined by IEEE-519 standard. The simulation results demonstrate the validity of the proposed model for active power filters to compensate current.

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