Harmonic Compensation of Controlled & Uncontrolled Loads by using Sahf

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***Abstract*—In this paper ,three phase shunt active harmonic filter is used for harmonic compensation of controlled & uncontrolled loads by using phase locked loop techniques with new synchronized pulse generator. The circuit model consists of a standard shunt SAHF with IGBT inverter used for harmonic elimination of controlled & uncontrolled loads. PLL is used for generating a sinusoidal output & Synchronized pulse generator is used for giving firing pulse to controlled converter used as one of a Non-Linear load. The SAHF uses a PLL with adaptive filter to generate a reference sinusoidal source current which is in-phase with load current and has the same RMS gain as the load current. Hysteresis switching is used for Current control. In Hysteresis switching method, a hysteresis band is formed & within the band, the shunt line current tracks the reference current In this way Hysteresis Switching is used for producing the reference signal for the IGBT inverter & also the synchronized pulse generator is used for generating firing pulse for 3-phase controlled rectifier used as one of non-linear load.**

Keywords—Shunt Active harmonic filter (SAHF), IGBT inverter, Series Inductor, Phase locked loop (PLL), Hysteresis Switching (HS), Point of common coupling (PCC), Synchronized pulse generator.

I. INTRODUCTION

Many industrial & Domestic load posses non-linear behavior, examples are Controlled and Uncontrolled rectifiers, welding transformer, switched mode power supply (SMPS), arc furnaces, various motor drive applications etc. All these Nonlinear loads cause distortion in voltage and current waveforms due to presence of various orders of Harmonics reactive power and resonance problems, higher transformer and line losses, over-voltages, over-heating, Electro Magnetic Interference (EMI) problems, and other Power Quality Issues. All these undesirable effects result in reducing system stability [1] -[3]. Traditionally various types of Passive filters alone have been used to eliminate the harmonics due to their lower cost and higher efficiency. However, these filters have multiple drawbacks including fixed compensation affecting sometimes the voltage regulation at the PCC at fundamental frequency. Therefore, Active Harmonic Filters (AHF) or Active Power Line conditioners(APLC) are recently used for solving these power quality problems in many Industrial applications . The classification of AHF is Shunt Active harmonic filter, Series Active Harmonic filter, combination of both or with passive & active filters together called Hybrid Active harmonic filter[4]. The Shunt AHF is suitable for current based & reactive power compensation. The Series AHF is suitable to suppress voltage harmonics, voltage flicker & to decrease voltage unbalance. The combination is called Unified Power Quality Conditioner which is the best solution for Active filtering[6]. All these type of AHF has ability to compensate all the harmonics and reactive power and after compensation keeps the system balanced irrespective of the load; i.e., nonlinear and or balanced and unbalanced [5][7-11].

In this paper, we proposes SAHF of which most significant part is PLL & HS used to estimate the reference current and control the dc-bus capacitor voltage of the inverter. A PLL is feedback system that fixes relation between output phase and input phase that are synchronized or locked, that's why the name called "Phase Locked Loop". The hysteresis switching current control technique has been the most suitable technique for all the applications of VSI in SAHF , the used active power Filters in this paper. The present hysteresis band current controller having property of unconditioned stability, high speed response, and good accuracy [12-14].The proposed shunt active harmonic filter is validated and investigated for two nonlinear loads in which one is controlled load & another one is uncontrolled load. The used one of controlled non-linear load getting a firing pulse from Synchronized 6-pulse generator.

II. PROPOSED CONTROL STRATEGIES

Proposed methodology uses PLL & HS controlled shunt AHF to reduce the harmonic and unbalance problems from the combination of controlled & uncontrolled non-linear loads. The shunt AHF with IGBT inverter & HS is installed at the Point of Common Coupling (PCC). The three-phase shunt active harmonic filter is a three phase current controlled "voltage-source inverter (VSI)" with a mid-point earthed, split capacitor in the dc bus.

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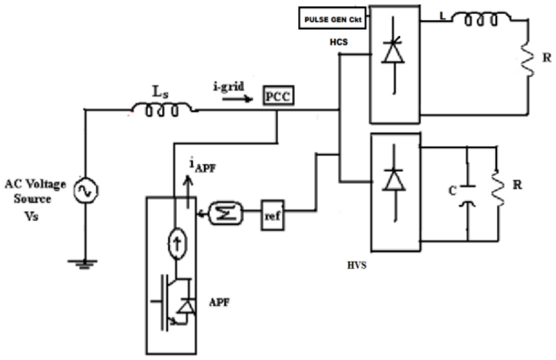

Figure1.Proposed Active Power Filter Configuration

It consists of two Non-linear loads in which one is Uncontrolled & another one is Controlled load. Both are phase-shifted by 30 degrees. For obtaining 30 degree phase shift in between two loads, the Controlled load is connected in Delta-Delta form and Uncontrolled load in Delta-Star form. The Delta-star connected uncontrolled rectifier is connected with Delta-Delta form Controlled load by a transition switch initially closed having transition time 5/60 sec to change the load output. The Active harmonic filter uses a PLL & HS to generate harmonic free output current which is in-phase and has the same RMS gain as the reference current. The current error in between the load current and the reference current is generated by the IGBT Bridge Inverter through hysteresis switching. The Proposed Control strategies uses two loads in which one is controlled & another one is uncontrolled loads. The controlled load gets firing pulse from Synchronized 6-pulse generator circuit.

III. SYNCHRONISED 6-PULSE GENERATOR, PHASE LOCKED LOOP (PLL) & HYSTERESIS SWITCHING (HS)

A) Synchronized 6-Pulse Generator:

The Synchronized 6-Pulse Generator block can be used to give firing pulse to fire each of the six thyristors of six-pulse converter. The input of the Generator having five inputs. Input 1 is the alpha firing signal in Degree. Input (2 to 4) are the phase to phase synchronizing voltages. Synchronizing voltages should be in phase with three phase voltages at converter AC terminal. AB, BC , CA are the line voltages. Input 5 allows us to Block the operation of Generator. The pulses are disabled when applied signal is greater than zero. The output of the block is a vector of six pulses which are individually synchronized on the six thyristor voltages. The pulses are generated by synchronized 6- pulse generator by an alpha degrees after increasing zero crossings of the thyristor commutation voltages.

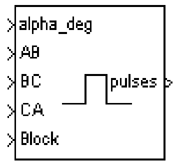

Figure2 .6-Pulse Synchronizing Generator

The figures below display the synchronization of the six pulses generated by pulse Generator for firing angle of 0 degree. The pulses are generated exactly at the zero crossings of the three line-to-line synchronization voltages AB, BC and CA.

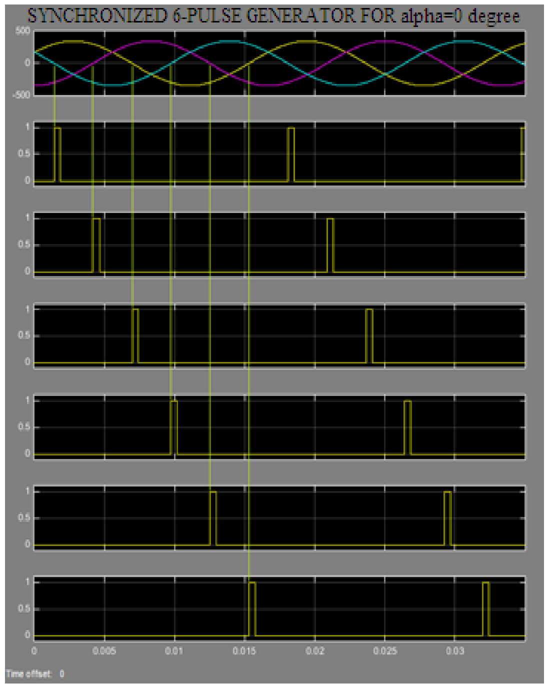

Figure3 .6-Pulse Synchronizing Generator for alpha=0°

The Synchronized 6-Pulse Generator block can be designed to work in double-pulsing mode. In this mode two pulses are sent to each thyristor of 6-pulse Generator, when the alpha angle is reached, first pulse is given, second pulse is given after 60 degrees later. The figures below shows the synchronization of the six pulses for an alpha 30 degrees and with double-pulsing mode. The pulses are generated 30 degrees after the zero crossings of the input supply voltage (line-to-line).

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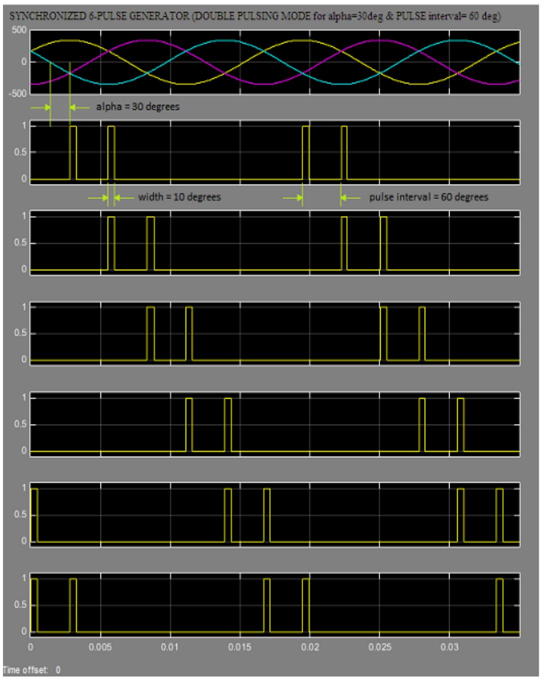

Figure4 .6-Pulse Synchronizing Generator for alpha=30°

B) PLL Introduction:

Various methods of synchronization techniques are presents today's. They are mainly classified as open-loop and closed- loop techniques. Open-loop technique directly estimates the phase angle of the input voltage and input current signals. In closed-loop methods, the estimation of the phase is adaptively updated through a loop mechanism having self locking tendency. PLL is Negative feedback control system where output frequency (*fout)* tracks with the input frequency (*fin)* and rising edges of input clock approaches align to rising edges of output clock.

Mathematical equation of frequency synthesizer-

$Vin(t) \propto \sin(2\pi fin(t))$ [phase locked loop]

$$Vout(t) = \sin(2\pi N fin(t))$$

When phase-Locked,

$\emptyset_{out} = N\, \emptyset_{in}$ $\quad f_{out} = N f_{in}$

C) Proposed PLL:

Proposed methodology of PLL for estimation of reference current is shown in figure 5. In proposed scheme of PLL the load current, input frequency and terminal voltage are the inputs. Firstly, the distorted three phase supply voltages are sensed and given to the proposed PLL which generates sine terms. The supply voltage is multiplied with a suitable gain of values K=1…N before being given as an input to the PLL.

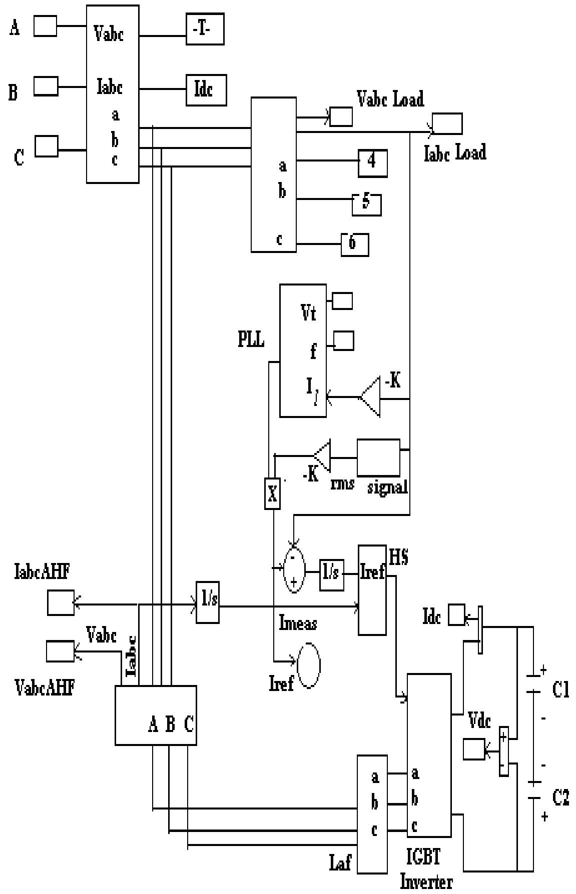

Figure 5. Simulation Model of Shunt Power Active Filter with Phase Locked Loop (PLL & & Hysteresis Switching (HS)

Here the load current is I_l , the load voltage is Vt, the Output signal of the adaptive detecting circuit is ω and the fundamental reference frequency is f which is in phase with ac source voltage. The input sinusoidal reference signal which is the fundamental component of the system voltage has the same frequency and phase with the desired fundamental components of load current and load voltage, accordingly, the dc component of the integrator output will tune until they are equal in magnitude. From the sampled load current and load voltage, the corresponding fundamental real components of the voltage and current are extracted.

$$I_f = I_l - kE_m \sin(wt)\,[K_0 + (1/w)RCt_0 IE_m \sin(wt)$$

$$I_f = I_l - kK_0 E_m \sin(wt) - kK_1 E_m \sin(wt)$$

Where

$$K_1 = \left(\frac{1}{w}\right) RCIE_m \sin(wt)$$

$$Vs = V_l - kE_m \sin(wt)\left[K_0 + \left(\frac{1}{w}\right) RCVsE_m \sin(wt)\right)$$

$$Vs = V_l - kK_0 E_m \sin(wt) - kK_1 E_m \sin(wt)$$

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Where

$$K_1 = \left(\frac{1}{w}\right) RCIE_m \sin(wt)$$

And

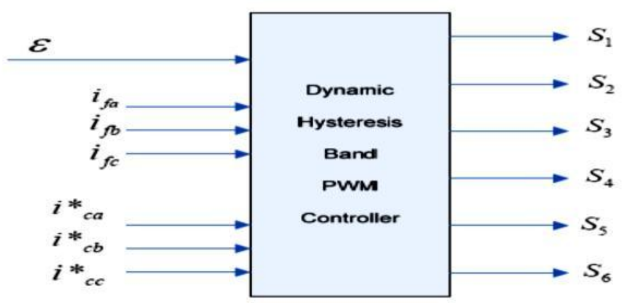
$I_L = I_P + I_Q + I_H$
$V_L = V_P + V_Q + V_H$

Where fundamental active component load current is I_P , fundamental reactive component of load current is I_Q , harmonic components in load current is I_H, fundamental active component of load voltage is V_P , fundamental reactive component of load voltage is V_Q, and the harmonic components in load voltage is V_H. Proportional coefficient is K_1 and the dc component of the integrator output is K_0.

$$I_f = I_l - kK_0E_m\sin(wt)$$
$$I_f = I_P + I_Q + I_H - kK_0E_m\sin(wt)$$
$$I_f = I_Q + I_H$$
$$I_P = kK_0E_m\sin(wt)$$

D) Introduction of Hysteresis Switching:

A dynamic hysteresis band PWM controller uses current control which is implemented through feedback modulation. A hysteresis band is formed, within which reference current is marked, the shunt line current tracks the reference current. The reference currents calculated by the controller is compared by the measured values of compensation currents. In this way, the command signals for the inverter semiconductor switches can be produced by comparing them. Figure 6 shows the principle of the dynamic hysteresis current controller technique for current control. Within the Hysteresis band, If the shunt line current exceeds the maximum current limit of the hysteresis band, the upper half switch of the inverter arm is turned off and the lower half switch is turned on. The result of that is, the current starts to decay. Within the hysteresis band if the current crosses the minimum current limit of the hysteresis band, the lower switch of the inverter arm is turned off and the upper switch is turned on. The result is that, the current gets back into the hysteresis band. In this way the shunt line current is forced to track the reference current within the hysteresis band.



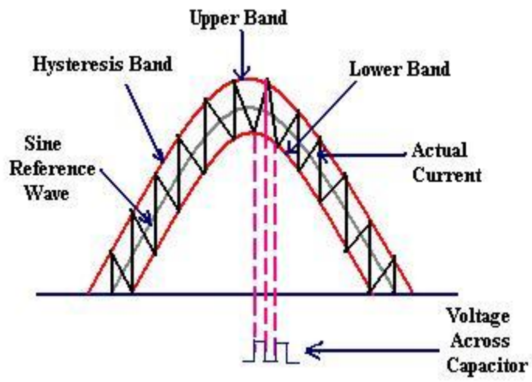


Figure 6. Hysteresis band PWM control

D) Proposed Control Scheme:

Figure 5 shows IGBT Inverter block diagram with PLL and HS which is implemented in simulink. Here, the two currents in which one is sensitive load currents "Iload" & the measured load currents "Imeas", are fed in to adaptive controller. The fundamental sinusoidal signals are obtained through the PLL using adaptive filters which is explained in figure 5. Let the load current I_l, and the current of active filter be the input to the shunt firing unit. The gate signal obtained from this unit is the input to the IGBT. The gate signal "Ig" is obtained by means of using hysteresis current controlling technique. For detecting the current to be compensated, reference current should be obtained. The root mean square (RMS) value of load current is used for improving the PLL value. Root mean square value (RMS) of load active current can be obtained by-

$$RMS(F(t) = \sqrt{\frac{1}{T}\int_{t-T}^{T} f(t)^2\, dt}$$

For the hysteresis controller the calculated value of currents is given along with the sensed three phases load current.

IV. SIMULATION RESULTS

Simulation Model is carried out on a Matlab /Simulink software R2013a. Figure 6 represents the simulation model of harmonic compensation of controlled & uncontrolled loads with SAHF. Figure 7 represents the Simulink model of controlled & uncontrolled loads without SAHF. Harmonics which are generated by non-linear loads is removed by PLL based Shunt Active Power Filter. Given model considers the harmonics due to non-linear (controlled & uncontrolled) loads and the disturbance presents in supply system also taken into consideration. Figure 8.1 represents the input current wave shape is non-sinusoidal which represents unbalanced supply. For given model, the Simulation time is 0.08 seconds. Figure 8.2 shows the 3 phase injected current waveform by ASHF at the point of common coupling. Figure 8.3 shows 3-phase load current waveform which is a combination of Controlled (delta-delta) & Uncontrolled (delta-star) loads. Table 1 shows simulation parameters.

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Table I System Parameters

SYSTEM	PARAMETERS		VALUE
SOURCE	VOLTAGE	Vs	4160*√3*√2 V
	FREQUENCY	f	50 Hz
	INDUCTANCE	Ls	$1x10^{-5}$ H
LOAD 1	CONTROLLED RECTIFIER (DELTA-DELTA)	THYRISTOR ON-RESISTANCE	$1X10^{-3}$ OHMS
		SNUBBER RESISTANCE	$1X10^{3}$ OHMS
		SNUBBER CAPACITANCE	$1X10^{-6}$ F
LOAD 2	DIODE RECTIFIER (DELTA-STAR)	RESISTANCE	$1X10^{-3}$ OHMS
		SNUBBER RESISTANCE	$1X10^{3}$ OHMS
		SNUBBER CAPACITANCE	$1X10^{-6}$ F
SAHF	SHUNT ACTIVE HARMONIC FILTER	LAF	$1X10^{-3}$ OHMS
		MAX.CURRENT	4000A
		FREQUENCY	50HZ
		DC BUS CAPACITANCE	$5X10^{-4}$ F
		VOLTAGE	440 V
SYNCHRONISING 6-PULSE GENERATOR	DOUBLE PULSING MODE	FREQUENCY	50 Hz
		PULSE WIDTH	10 degree
THREE PHASE BREAKER	(CLOSED)	TRANSITION TIME	5/60 Sec

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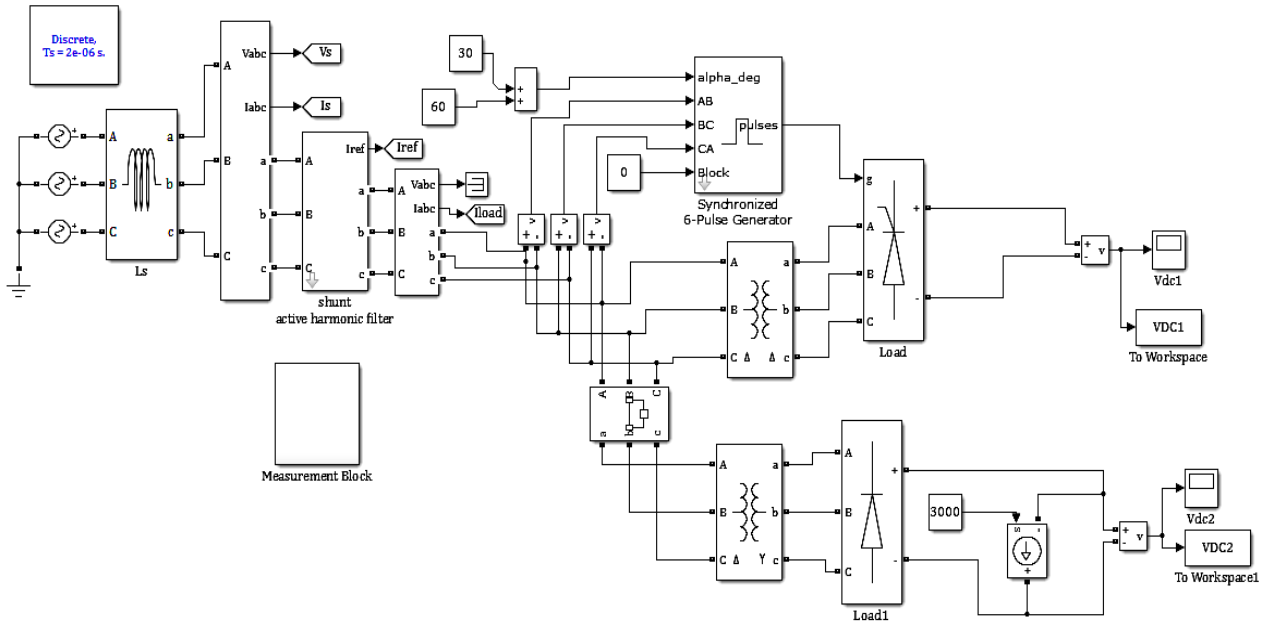

Figure 6. Simulink Model of Harmonic Compensation of Controlled & Uncontrolled Loads with SAHF

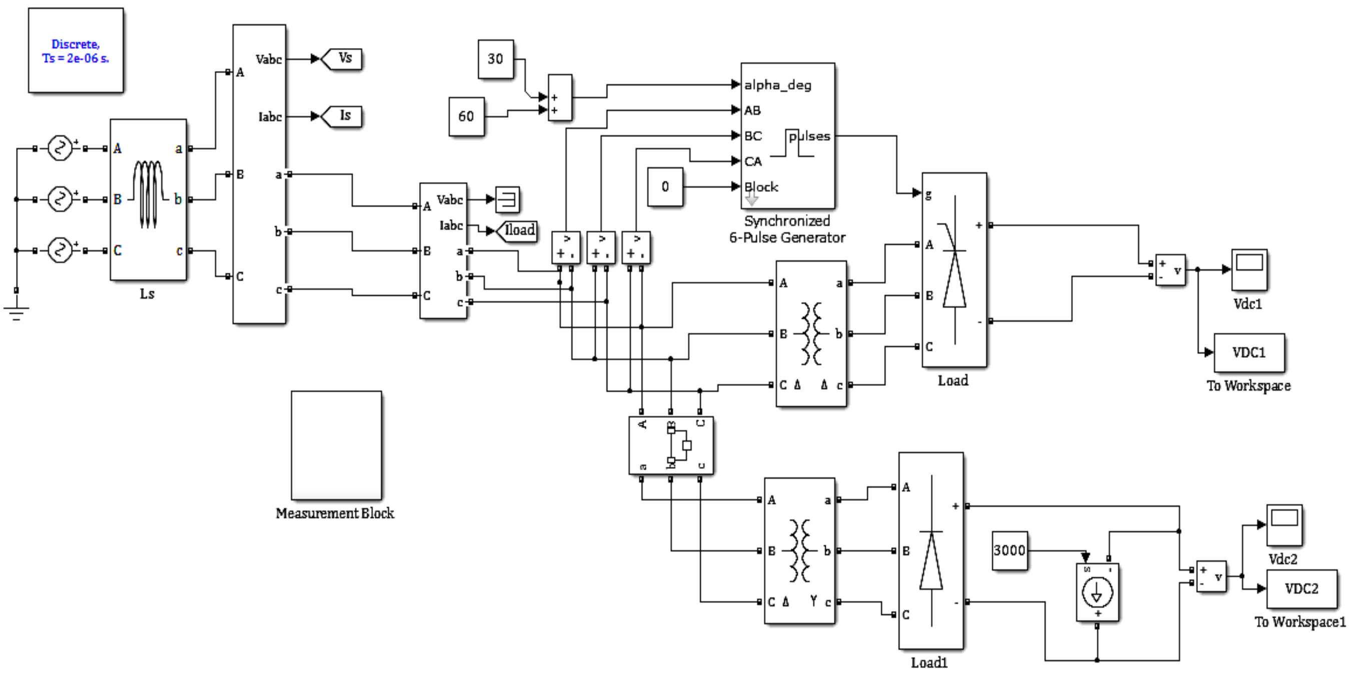

Figure 7. Simulink Model of Controlled & Uncontrolled Loads without SAHF

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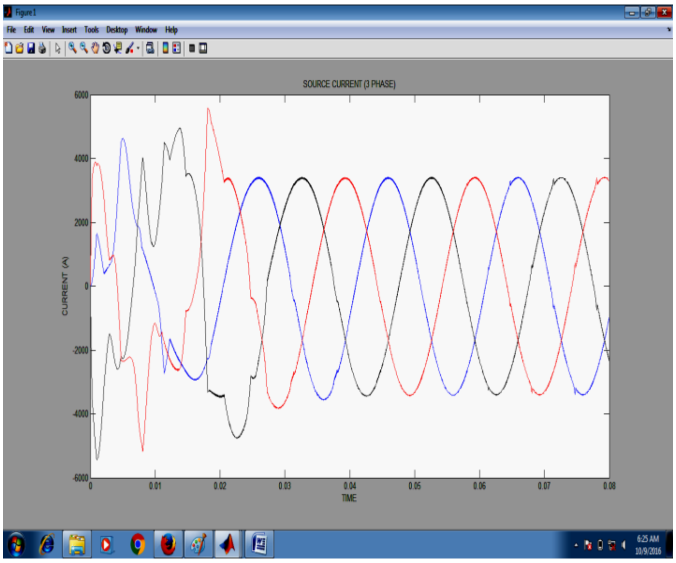

Figure 8.1 3 phase Source Current Waveform

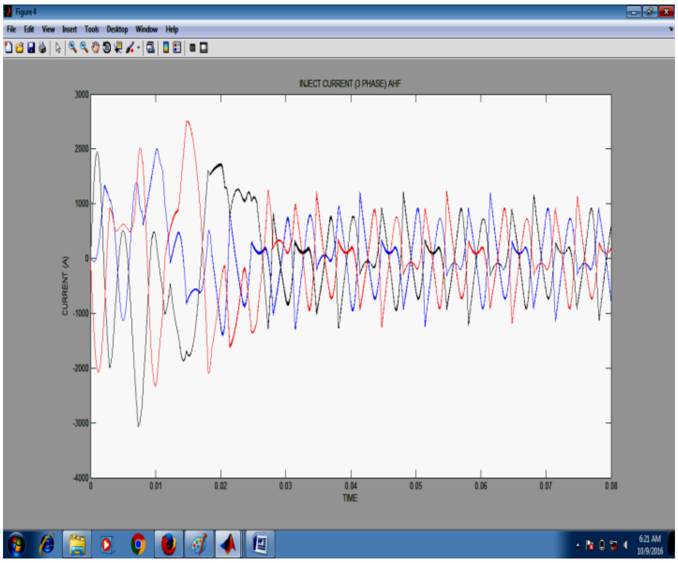

Figure 8.2 3 phase injected current waveform

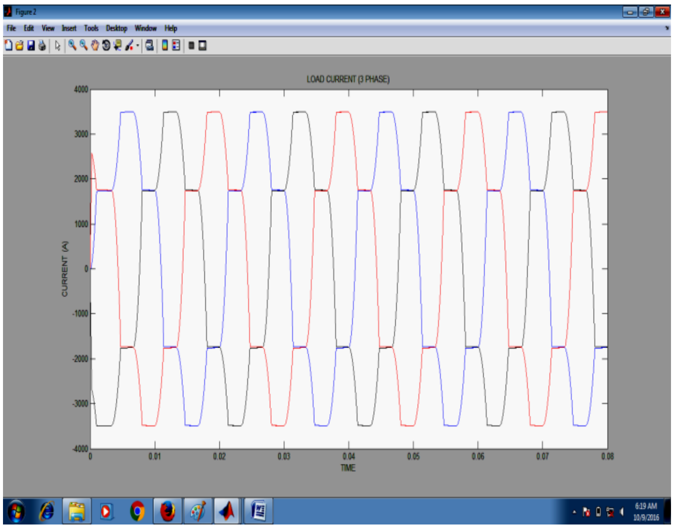

Figure 8.3 3 phase Load current waveform

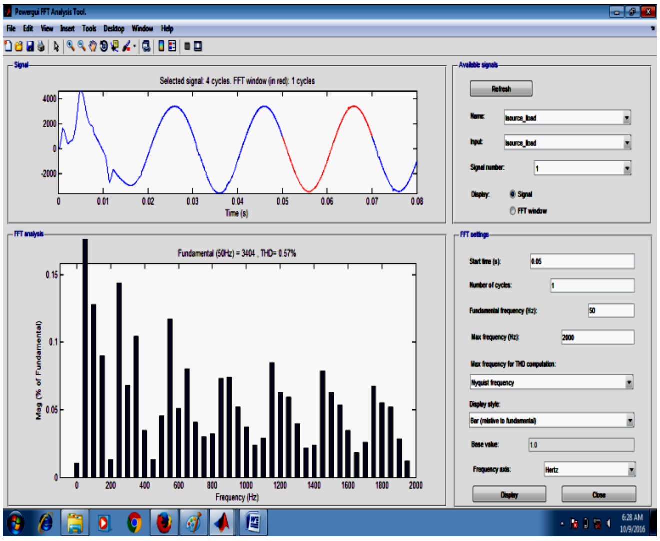

Figure8.4 FFT waveform of Non-Linear loads with SAHF (THD 0.57%) with fundamental freq 50 Hz

V. FFT Analysis

The Fast Fourier Transform (FFT) is used to measures the order of harmonics with the fundamental frequency at 50 Hz of the source current and also considers THD (total harmonic distortion) presents in selected signal. The FFT analysis of the system with and without the use of Shunt Active Filter is shown in Figure 8.4 & 8.5. The figure 6 shows the Non-linear loads directly connected with supply system that means without the use of Active Filter. In that case supply current having a THD of about 21.22% which is shown in figure 8.5. When Active Filter is used, the THD is reduced up to about 0.57% which is shown in figure 8.4.

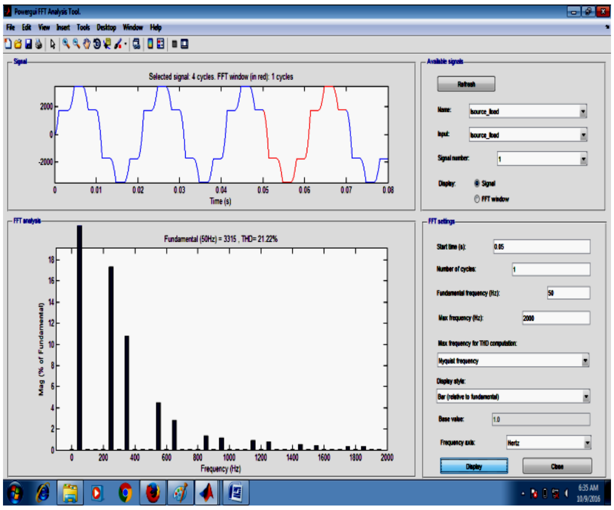

Figure 8.5 FFT waveform of Non-Linear loads without SAHF (THD 21.22%) with fundamental freq 50 Hz

VI. CONCLUSION

This project proposes the implementation of a three-phase shunt active harmonic filter with phase locked loop having a combination of controlled & uncontrolled loads. Simulation result shows, this system provides unity power factor operation of non-linear loads with harmonic current sources, harmonic voltage sources, reactive, and unbalanced components which reduces the harmonics from 21.22% to 0.57%.

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