Simulation & Analysis of Series Active filter for Power Quality Improvement

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Abstract

Today major voltage related problem like voltage sag/swell, Voltage harmonics, unbalanced voltage in the electrical industry, Due to the increasing number of nonlinear load had dropped a serious power quality problem known as disturbance in power system. This paper deals with modeling and simulation of a Series Active Filter (SAF) for mitigation of voltage related problem. In this paper a three-phase three wire series active filter under distorted load conditions, the power quality problems are compensate through a synchronous reference frame (SRF) and hysteresis controller based control method. The proposed SAF system can improve the power quality at the point of common coupling (PCC). The simulation results based on MATLAB Simulink are discussed in detail to support the SRF and hysteresis controller based control method presented in the paper.

Keywords: *Series Active Filter (SAF), Synchronous Reference frame (SRF), Power quality*

I. INTRODUCTION

Modern power system is a complex network where many generating station and load centers are interconnected through long power transmission and distribution network. Now a day distribution system is facing poor power quality at the load ends. Today industrial processes are based on a large amount of power electronics devices such as programmable logic controllers, adjustable speed drives. A power electronics converters behaves as a nonlinear load and very sensitive to disturbance. Due to increasing number of highly nonlinear load such as computer power supplies, furnaces, power converters at domestic, commercial and industrial level which produce undesirable effect in the power system. Poor power quality may result into leads to low power factor, low efficiency, overheating of transformer and so on. Voltage disturbance become very expensive for the industrialists in terms of loss of production, loss of raw materials, and damage of material. The most common form of power quality disturbance is the voltage sag, which accounts 70% of all power quality disturbances. Voltage sags that occurs during the operation of the equipment will causes a reduction in life span and equipment will causes a reduction in life span and efficiency of the devices. Typical distribution system the wide spread use of non-linear loads results in a drop of the quality of a voltage waveforms at the point of common coupling of various loads. The weakening quality of electric power is mainly because of current and voltage harmonics due to wide spread application of power electronics converters, zero and negative sequence components originated by the use of single phase and unbalanced loads, voltage sag, voltage swell, voltage interruption etc. Voltage sag is the most occurring power system problem today that can cause electrical equipment to fail or shut down. The power generated at the generating station is a purely sinusoidal in nature. Conventional power quality mitigation equipment use Passive elements and do not always respond correctly as nature of power system condition change. Therefore, it is very important to maintain a high standard of power quality. A number of topologies have been proposed[1]. The latest generation of power semi-conductor devices Active Power Filter is used. With improvements in power and control circuits, active filters are appropriate a good alternative passive filters. Active power filters as an efficient and economical way of eliminating harmonics in the power system. One modern solution that deals load supply voltage imperfections is the Series Active Filter (SAF). Series Active Power Filter was introduced by the end of the 1980 and operates mainly as a voltage regulator. The series connected filter protects the consumer from an inadequate supply voltage quality. The series active filter is modeled in the stationary abc frame and then the model and then the model is transformed to the rotating dqo frame with the aim of reducing the control complexity.

II. SERIES ACTIVE FILTER

The series active filter injects voltage components in series with the supply voltage and therefore can be regarded as a controlled Compensating voltage sags and swells on the load side. The Series Active Filter is connected series with the mains, using a suitable transformer. The main purpose of a SAF is to compensate for supply voltage power quality issues such as, sags, swells, unbalance [1][2].

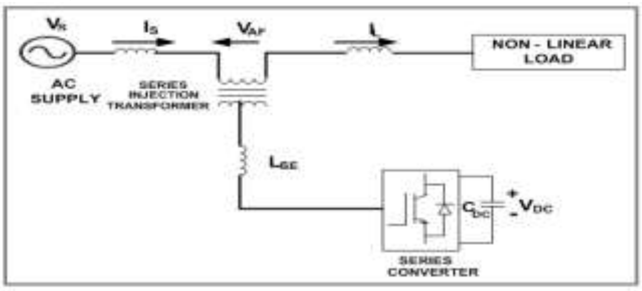

Figure 1. Line diagram of Series active filter

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Figure 1 shows a system arrangement of a single-phase or three-phase series active filter is mainly used for compensate various types of voltage related problems. The series active filter is controlled on the basis of the following manner:

- The controller detects the instantaneous supply current is.
- The series active filter applies the compensating voltage V_{AF} across the primary of the series injection transformer. This compensating voltage is significantly reducing the supply harmonic current i_{sh} when the feedback gain K is set to be enough high[3].

III. CONTROL STRATEGY OF SERIES AF

The conventional synchronous reference frame (SRF) based method can be used to eliminate harmonics presents in supply voltage or current. The SRF method is based on a-b-c to d-q-0 transformation which also known as park transformation. Figure 2.shows the a-b-c to d-q-0 transformation. The reference frame transformation is formulated from a three-phase a−b−c stationary system to the direct axis (d) and quadratic axis (q) rotating coordinate system so it is also known as d-q method [16][17].

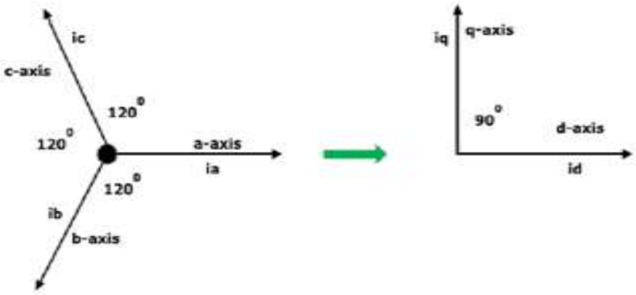

Figure 2.a-b-c to d-q-0 transformation (park transformation)

In the SRF method the transformation angle (ωt) presents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase ac voltage. In the SRF method d-q-0 axes are rotate synchronously with supply voltages.

The proposed control strategy is aimed to compute mainly the three phase reference voltage at the load terminal. The series active filter based on SRF method can be used to solve the voltage related power quality problems such as, voltage sag, voltage swell and voltage harmonics. The SRF method is used in series active filter for generating reference voltage signal. The supply voltages V_{Sabc} are transforming into d-q-0 which is given in equation below.

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(\omega t) & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ \cos(\omega t) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix}$$

Where, ωt is the transformation angle and V denotes voltages.

In the SRF ωt is a time varying angle that represents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase ac voltage. Synchronous Reference Frame method (SRF) is one of the most common and probably it is the best method. To implement the SRF method and for reference voltage calculation the phase locked loop (PLL) is used to generate the transformation angle (ωt) which presents the angular position of the reference frame. This transformation presents is known as park transformation[4]. Figure 3 shows the Control block diagram of d-q theory for generating voltage reference signal in SAF. The low pass filter is used to obtain the reference source voltage in dq coordinates.

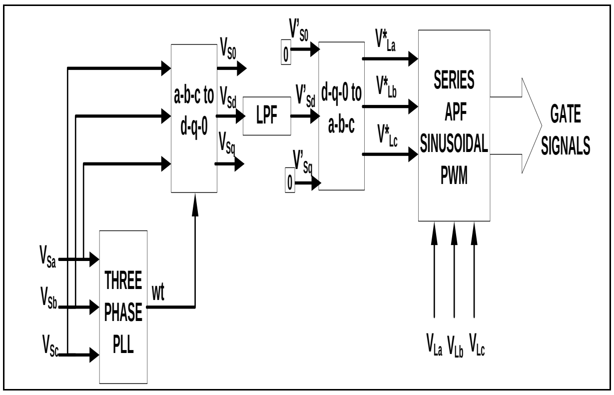

Figure 3. Control block diagram of d-q theory of Series APF

The inverse park transformation is used for generating reference voltage signal which is given in equation below is convert the reference load voltage (V'_{Labc}) are transform d-q-0 into a-b-c.

$$\begin{bmatrix} V'_{La} \\ V'_{Lb} \\ V'_{Lc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(\omega t) & \cos(\omega t) & \frac{1}{\sqrt{2}} \\ \sin\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \\ \sin\left(\omega t + \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix}$$

After generating reference load voltage (V^*_{Labc}) are compared with sensed load voltage (V_{Labc}) in sinusoidal pulse width modulation technique. This comparison between reference load voltage and sensed load voltage in sinusoidal PWM technique generate gating signals for series voltage source converter. In series voltage source converter as a switching device use insulated gate bipolar transistor (IGBT) which can compensate all voltage related problems, such as voltage sag, voltage swell and voltage harmonics.

IV. HYSTERESIS TECHNIQUE FOR SERIES ACTIVEFILTER

There are various types voltage-controlled pulse width modulation (PWM) techniques available among all of them hysteresis controllers offer inherent simplicity in implementation and excellent dynamic performance.

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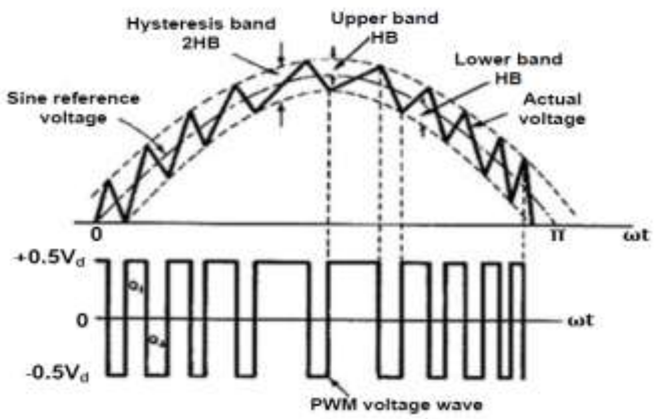

Figure 4. Hysteresis voltage control technique

Hysteresis-band PWM is basically an instantaneous feedback voltage control technique of PWM where the actual voltage continually tracks the command voltage within a hysteresis band. Figure 4. explains the operation principle of hysteresis band PWM for a half bridge inverter. The control circuit generates the sine reference voltage wave of desired magnitude and frequency, and it is compared with actual voltage wave. As the voltage exceeds an upper hysteresis band, the upper switch in half bridge is turned off and lower switch is turned on. As a result, the output voltage transition from $+0.5V_d$, and $-0.5V_d$, and the voltage starts to decay. In same way as voltage crosses the lower band limit, the lower switch is turned off and the upper switch is turned on. In comparison with other control technique hysteresis voltage control has a very fast response and simple operation but the disadvantage of this method is variable switching frequency[14].

The hysteresis band voltage control for series active power filter is used to generate the switching pattern of the inverter. There is various voltage control methods proposed for active power filter configurations; but the hysteresis voltage control method is proven to be the best among other voltage control methods, because of

quick voltage controllability, easy implementation and unconditioned stability. The hysteresis band voltage control is robust, provides excellent dynamics and fastest control with minimum hardware [15][18].

Figure 5. shows the comparison between the reference load voltage (V_L^*) and sensed load voltage (V_L) and the generating error is given to hysteresis band which generates switching instants of series voltage source converter. Figure 4. Shows the Simulink diagram of hysteresis voltage controller.

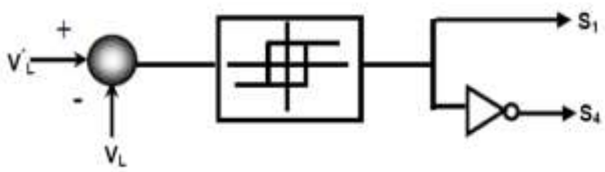

Figure 5. Control block of hysteresis band voltage control technique

The reference voltage to be injected by the series active filter is referred as V_L^* and the actual voltage of the series active filter is referred asV_L. The control scheme decides the switching pattern of series active filter in such a way to maintain the actual load voltage of the filter to remain within a fixed hysteresis band (HB) as indicated.

The switching logic is formulated as follows:

$$V_L = V_L^* - HB \qquad (1)$$

$$V_L = V_L^* + HB \qquad (2)$$

Where, V_L= actual load voltage

V_L^* = reference load voltage

HB = hysteresis band and S1, S2, S3, S4 are switches of voltage source inverter.

From above discussion note that the switching frequency of the hysteresis voltage control method described above depends on how fast the voltage changes from upper limit to lower limit of the hysteresis band. Therefore, the switching frequency does not remain constant throughout the switching operation, but varies along with the voltage waveform.

V. T0TAL HARMONICS DISTORTION (THD)

The total harmonic distortion, or THD, of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

When a signal passes through a non-ideal, non-linear device, additional content is added at the harmonics of the original frequencies. THD is a measurement of the extent of that distortion.

The general equation for finding the THD is:

$$\%THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots\ldots\ldots\ldots\ldots + V_n^2}}{V_1}$$

Where,

$V_2, V_3, V_4, \ldots$ =Harmonic Or

V_1 =Fundamental Component

VI. SIMULATION MODEL

In this section, the simulation result of series APF is shown. The developed model of series APF

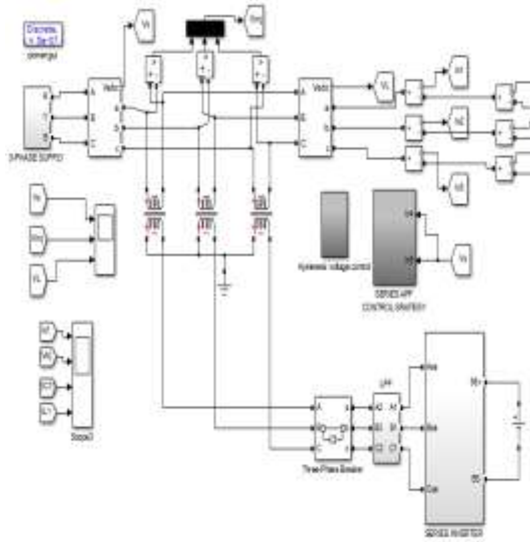

Figure 6. Simulation Model

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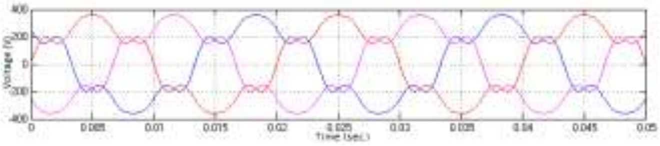
VII. SIMULATION RESULTS

Simulation results and FFT analysis of series active filter using synchronous reference frame control theory:



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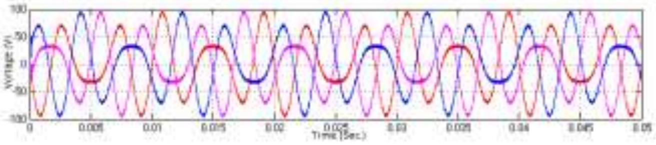

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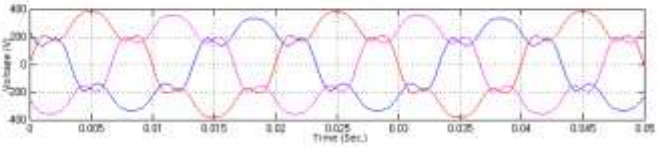

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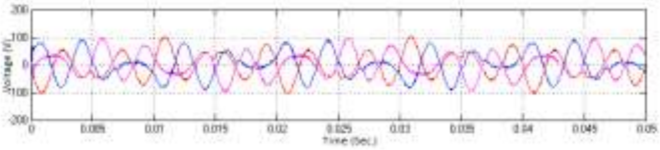

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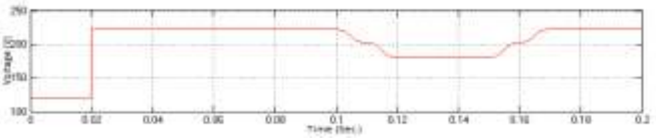

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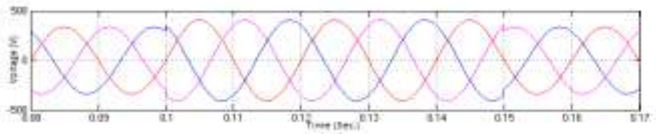

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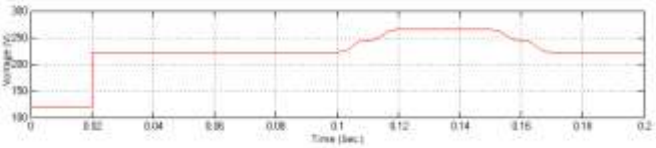

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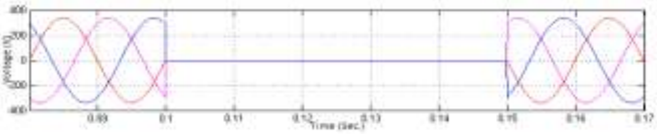

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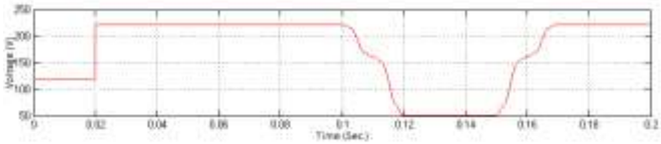

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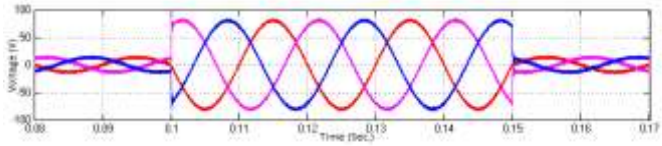

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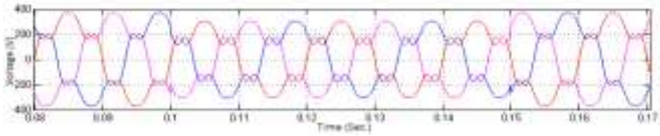

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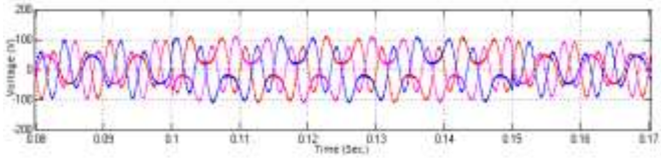

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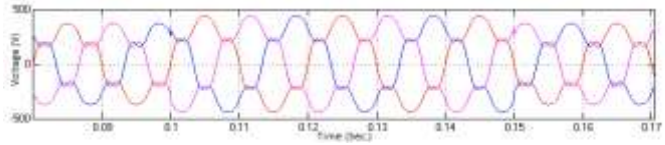

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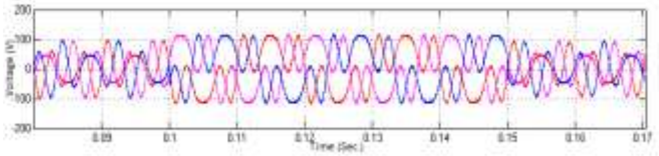

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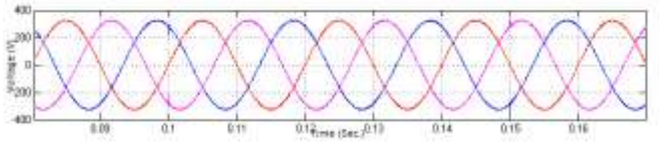

(p)

Figure 7. (a) Steady State Harmonics Voltage (b) Steady State Harmonics of Compensating Voltage (c) Unbalanced Harmonics Voltage (d) Unbalanced Harmonics of Compensating Voltage (e) Voltage Sag (f) Voltage Sag RMS Value (g) Voltage Swell (h) Voltage Swell RMS Value (i) Voltage Interruption (j) Voltage interruption RMS Value(k) Voltage Sag/Swell, Interruption of Compensating Voltage (l) Voltage Sag with Harmonics (m) Voltage Sag with Harmonics Compensating Voltage (n) Voltage Swell with Harmonics (o) Voltage Swell with Harmonics of Compensating Voltage (p) Load voltage

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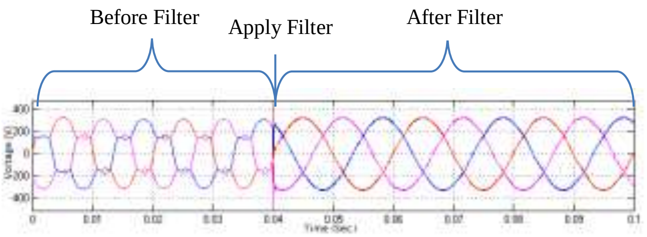

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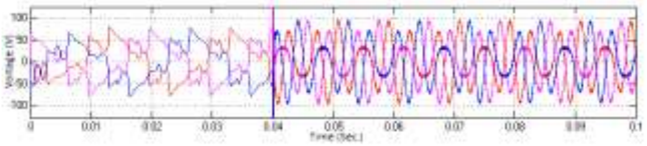

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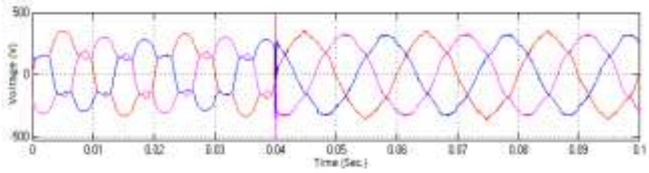

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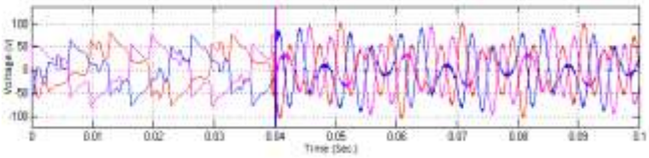

(d)

Figure 8. Operational performance of Series Compensation (a) Balanced Voltage Condition Transformer Injected Voltage (b) Balanced Voltage Condition Load Voltage (c) Unbalanced Voltage Condition Transformer Injected Voltage (d) Unbalanced Voltage Condition Load Voltage

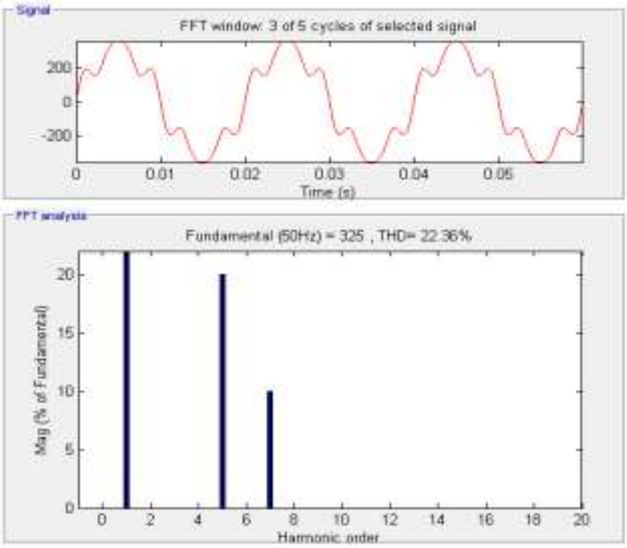

Figure 8. THD=22.36% of Source voltage

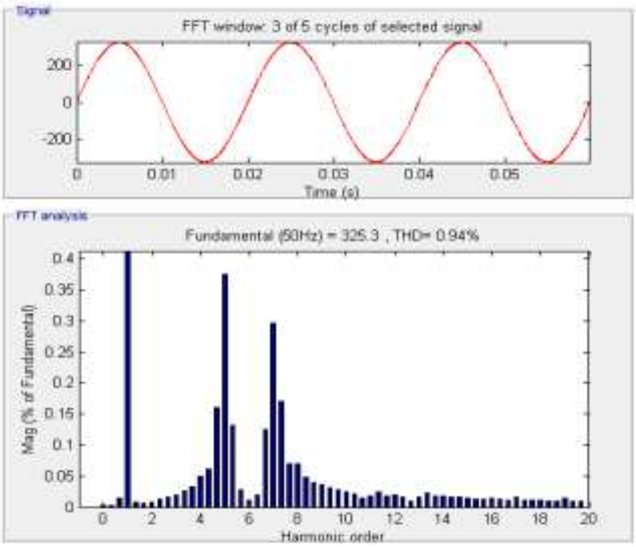

Figure 9.THD=0.94% of Load voltage

Table 1.Simulation results and THD level of voltage waveforms at the PCC

System Voltage Condition	Phase	Before Series Compensation		After Series Compensation	
		Voltage THD (%)	RMS	Voltage THD (%)	RMS
Balanced Voltage (V)	A	22.36	235.5	0.94	230
	B	22.36	235.5	1.09	230
	C	22.36	235.5	1.07	230
Unbalanced Voltage (V)	A	20.76	252.8	4.19	237.5
	B	22.36	235.5	5.91	230
	C	24.22	218.3	5.00	221
Voltage Sag with Harmonics Distortion	A	21.45	235.5	1.40	229.6
	B	21.45	235.5	1.46	229.6
	C	21.45	235.5	1.41	229.6
Voltage Swell with Harmonics Distortion	A	21.45	235.5	1.40	229.4
	B	21.45	235.5	1.46	229.4
	C	21.45	235.5	1.41	229.4

VIII. CONCLUSION

This paper describes a SRF based control strategy used in SAF, which mainly compensate voltage related power quality problems like voltage harmonics, voltage sag/swell, interruption & voltage sag/swell with harmonics. The series active filter mitigated the voltage related problem of the circuit. The investigation of series active filter with compensation technique based on SRF and hysteresis based theory. It was observed that the proposed control scheme of the SAF has a fast response and is able to maintain the voltage level. A voltage compensation technique based on SRF technique had been studied for series active power filters and a Simulink model is designed. By using the SRF technique which is one of the control techniques of Active Filter to compensate the voltage sag which are shown by the results and THD analysis.

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