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Shunt Active Power Filter based on SRF theory and Hysteresis Band Current Controller under different Load conditions

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Abstract: *Recently nonlinear loads are widely used by industrial, commercial and residential consumers. The current drawn by these loads contain harmonics, which leads to reduction in power quality of the entire electrical power system. In electrical power system harmonics appear in the current signal due to this type of nonlinear loads . For this reason shunt active power filters are connected in parallel with the load for mitigation of harmonics and there by improving power quality.The concept of shunt active power filter is to inject the harmonic current of same magnitude but in opposite phase with the original harmonic current. The current controlled or voltage controlled, voltage source inverter (VSI) is the basics of an active power filter. In this paper a current controlled VSI is used with fixed band type hysteresis current control as the method of controlling the VSI. Here Synchronous Reference Frame (SRF) theory based method is used for the generation of reference current signals for the controller. This paper investigates the effectiveness of the proposed method by simulating in MATLAB/simulink for harmonics currents elimination under different load conditions.*

Keywords: *Power quality, Shunt active power filter(SAPF) ,Synchronous reference frame (SRF)theory, Voltage source inverter(VSI)*

I. Introduction

In recent years,quality of power delivered to industrial, commercial and domestic consumers is an important concern due to rapid rise in the usage of harmonics producing nonlinear loads including adjustable speed drives, power electronics converters, switched mode power supplies, arc furnaces etc. The term quality of power or electric power quality is used to express the purity in voltage and current waveforms. Quality reduction of electric power mainly occurs due to the power line disturbances like sag, swell, notches, unbalance and harmonics, where harmonics is the major power quality problem that is seen in the distribution side of power system network. Harmonics is the term used to express the distortion of voltage and current waveform. Harmonics are injected in to the circuit due to intensive use of nonlinear loads. These nonlinear load draws short pulses from the source supply and which combines with source impedance resulting in distortion of voltage and current waveform. Overheating, failure of components, interference to communication lines are the major problems associated with harmonics.

There are different methods to reduce harmonics in an electric power transmission network including use of line reactors, isolation transformer, phase shifting transformers, passive filter and active power filter. Use of harmonics filters, which are based on the filtering of unwanted frequency component is an effective and commonly used method, But the use of passive filter is limited due to large size, resonance problem and can compensate only fixed value of reactive power. Limitation of passive filter can be overcome by using active power filters, which may be series active power filter or shunt active power filter. Due to nonlinear loads harmonics mainly occurs in current signal, so in this paper a shunt active power filter is used.

Shunt active power filter (SAPF) is a power electronics converter that can inject current having same magnitude and opposite phase with that of original harmonics current. Core of a SAPF is a voltage source inverter (VSI).This VSI can acts as controlled current source and can provide required compensation. Controlling of this VSI is done by using fixed band hysteresis current controller. Synchronous reference frame theory based method is used for producing reference current required for the hysteresis band controller. Simplicity, good static and dynamic performance, reference current generation are independent of source voltage are some of the dominating advantages of SRF theory over other methods of reference current generation. Shunt active power filter is simulated using MATLAB /Simulink under different load conditions and results are compared.

II. Shunt active power filter

Shunt active power topology is most popular topology for current harmonics elimination due to easy implementation and good performance. Shunt active power filter (SAPF) behaves as a three phase controlled current source and it generates compensation current in phase opposition to the harmonics current that depends on the reference current generation [1]. It works in a closed loop manner so that it senses the load current variation continuously to generate the required compensation current. Schematic diagram of SAPF is shown in figure 1

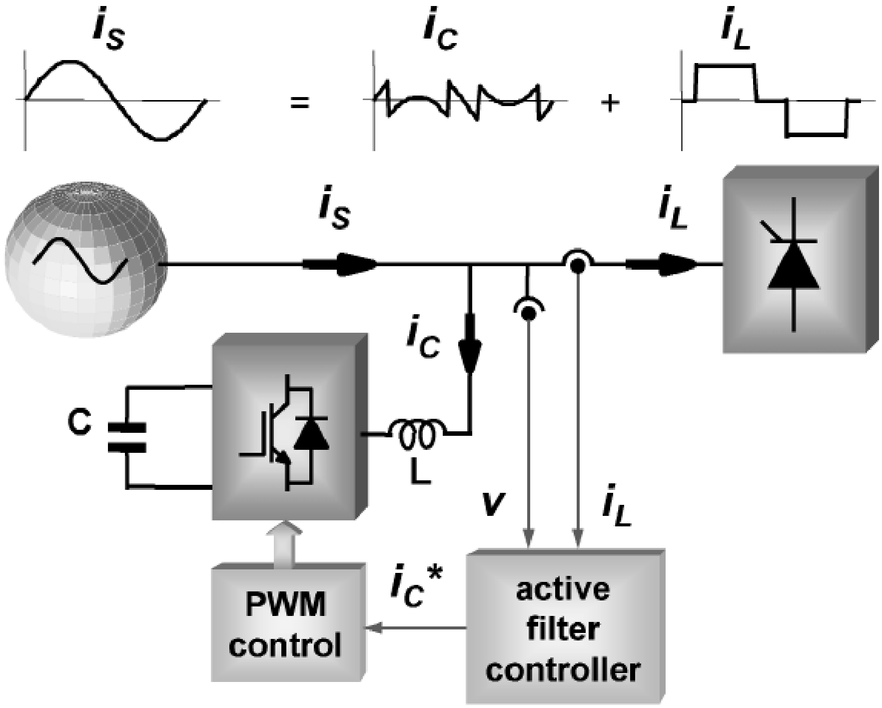


Figure 1. Schematic diagram of shunt active power filter

Figure shows that SAPF consists of two distinct main blocks
1) Active filter controller (Reference current generation block)
2) Pulse width modulated current controller(PWM controller)

Active filter controller is used for instantaneous monitoring of load current and there by the generation of reference compensating current. Synchronous reference frame theory is the most popular reference current generation method. By using this reference compensating current and source current, gate pulses required for the VSI is generated by PWM controller. PWM controller is responsible for power processing in synthesizing compensation current required for the entire system.

2.1 REFERENCE CURRENT GENERATION BY SRF THEORY

One of the simple reference current generation method is time domain based SRF method, in which three phase load current in a-b-c stationary frame is converted in to direct and quadrature axis components so that harmonic components in load current can be easily mitigated by a low pass filter(LPF). A schematic diagram of SRF method is shown in figure 2.

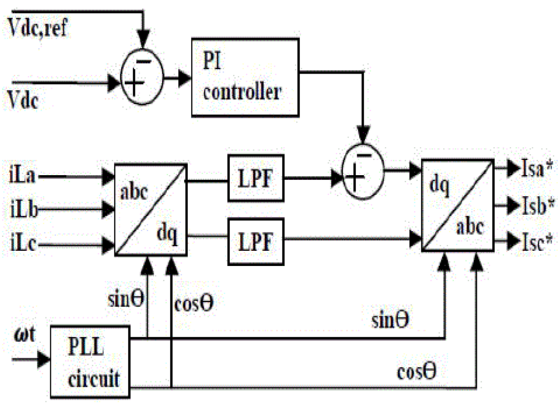


Figure 2. SRF method for reference current generation

SRF method requires phase locked loop (PLL), which provide fundamental frequency for synchronization purpose and this method also requires a PI controller for maintaining dc link voltage constant. Load current in a-b-c frame is converted in to 0-d-q frame component, which can be described by the equation 1

$$\begin{pmatrix} I_d \\ I_q \\ I_0 \end{pmatrix} = \frac{2}{3} \begin{pmatrix} cos\theta & \cos(\theta - 120) & \cos(\theta + 120) \\ sin\theta & \sin(\theta - 120) & \sin(\theta + 120) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} \begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix} \quad (1)$$

Direct and quadrature axis component consists of both dc component and multiple ac component, in which ac component is termed as the harmonics component .This harmonics components can be eliminated by using a LPF and steady state error of each harmonic component is eliminated using PI controller.

$$I_d = I_{ddc} + I_{dac} \quad (2)$$

$$I_q = I_{qdc} + I_{qac} \quad (3)$$

After elimination of harmonic component in direct and quadrature axis component, 0-d-q frame component is converted back in to a-b-c frame component to obtain reference compensating current.

$$\begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix} = \begin{pmatrix} cos\theta & \sin\theta & 1 \\ \cos(\theta - 120) & \sin(\theta - 120) & 1 \\ \cos(\theta + 120) & \sin(\theta + 120) & 1 \end{pmatrix} \begin{pmatrix} I_d \\ I_q \\ I_0 \end{pmatrix} \quad (4)$$

With the help of this reference compensating current and source current, gate pulses for the VSI is generated by using hysteresis band current controller.

2.2 PWM CURRENT CONTROLLER

Gate pulses for the VSI is generated by using hysteresis band current controller, which is a most suitable method for current controlled VSI [4] .Unconditioned stability, very fast response, and good accuracy are the dominating factor of this method. Schematic diagram of conventional hysteresis band controller is shown in figure 3.

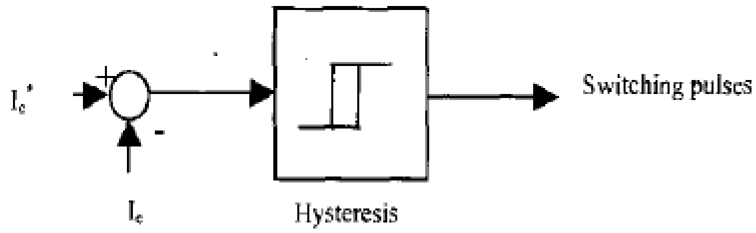


Figure 3. Hysteresis band current controller

This method asynchronously controls the switches of VSI, to change actual current to follow the reference current. When actual current exceeds the upper hysteresis band limit, corresponding switching of VSI forces the actual current to decrease and similarly when actual current is smaller than the hysteresis limit, corresponding switching of VSI, forces the current to increase. Voltage across the capacitor must be greater than the grid line voltage so as to make continuous increase and decrease of the actual current.

III. Simulink diagrams and output waveforms

Shunt active power filter under different load conditions are simulated using MATLAB\simulink .Output waveforms are observed and total harmonics distortions at different conditions are compared.

3.1 SIMULATION OF SHUNT ACTIVE POWER FILTER BY SRF THEORY

A three phase source is connected to a nonlinear load as three phase diode bridge rectifier is simulated using MATLAB\simulink. It is found that there is harmonics component in the Grid current. Simulink diagram and output waveforms are shown below.

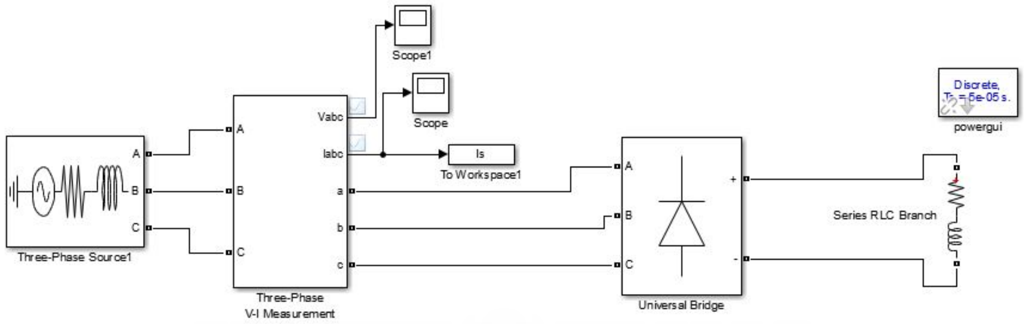


Figure 4. Simulink diagram of nonlinear load

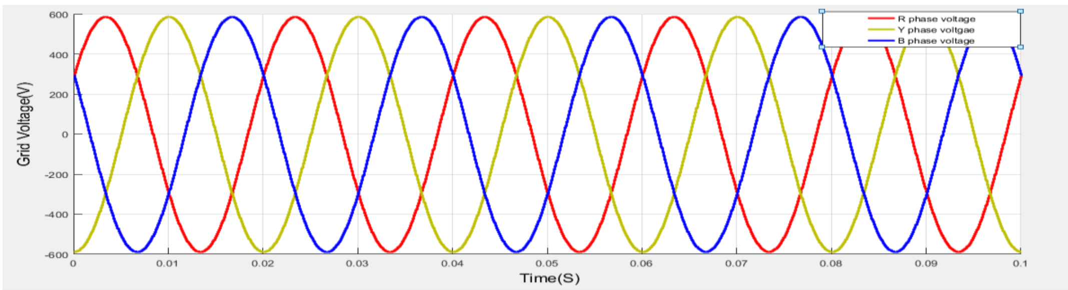


Figure 5. Grid voltage waveform before compensation

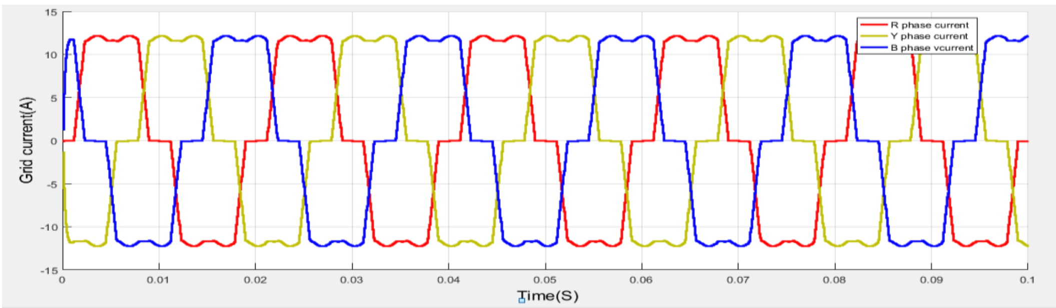


Figure 6. Grid current waveform before compensation

Fourier transform (FFT) analysis is done and it is found that Total harmonic distortion(THD) is 27.01% before compensation. Inorder to reduce the harmonics content in the grid current waveform, SRF theory based shunt active power filter using hysteresis band current controller is designed and simlulated using MATLAB\simulink. Output waveforms are shown below in figure

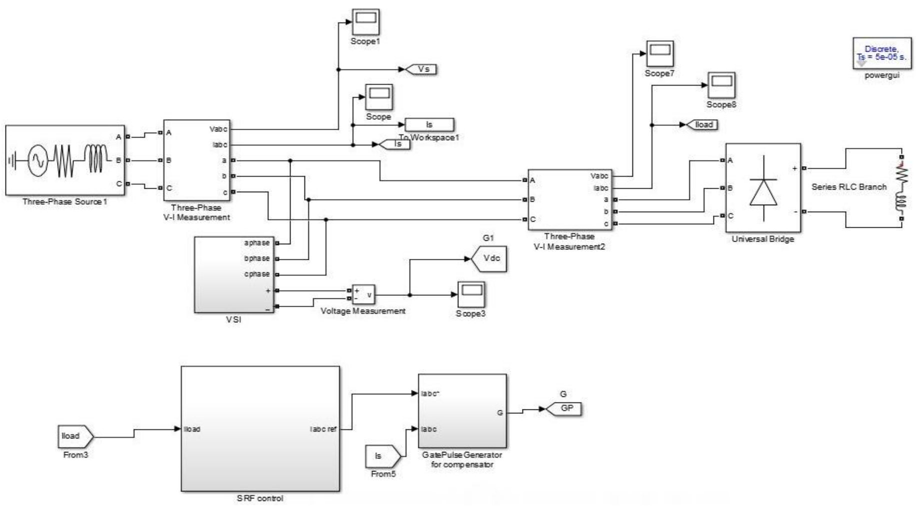


Figure 7. Simulink diagram of SRF theory based SAPF

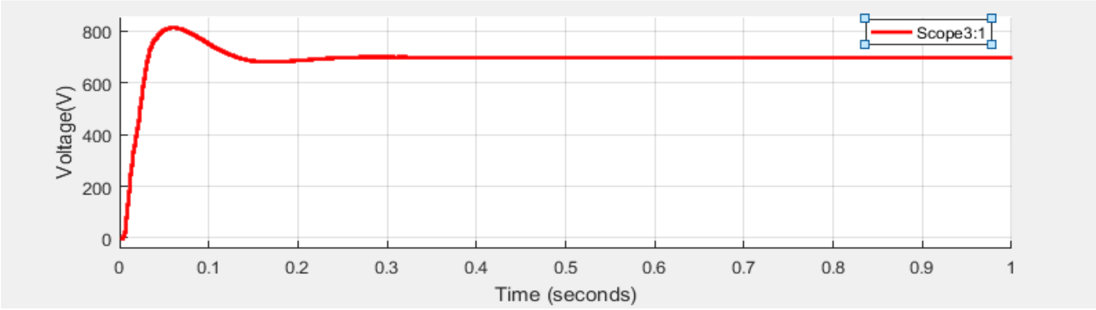


Figure 8. Voltage across input capacitor of VSI

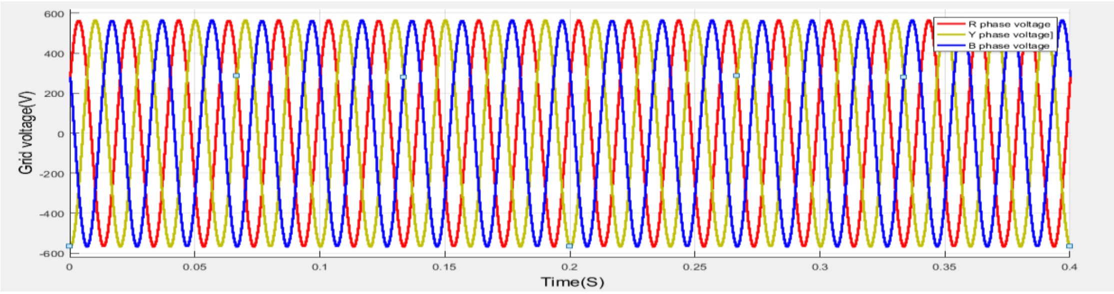


Figure 9.Grid voltage waveform after compensation

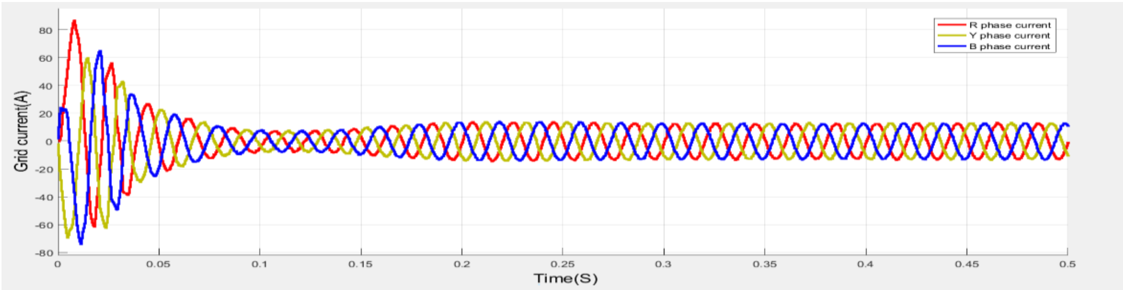
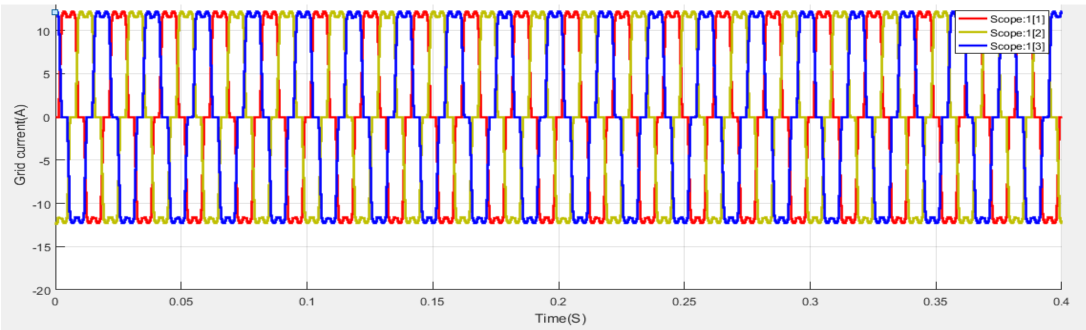


Figure 10 . Grid current waveform after compensation

Voltage across the capacitor became constant equal to reference voltage after some time and then after we get a purely sinusoidal current waveform on the grid. FFT analysis is done and it is found that THD is reduced to a value within the limit of IEEE.

3.2 SIMULATION OF SAPF UNDER DIFFERENT LOAD CONDITIONS

Simulation of SAPF under different load conditions are done and waveforms are analysed.The loads used are1).Three phase diode bridge rectifier with R load, 2)Three phase diode bridge rectifier with RLload, 3)Three phase diode bridge rectifier and unbalanced R load, 4) Three phase diode bridge rectifier and capacitive load.Output waveform and THD after compensation are shown below



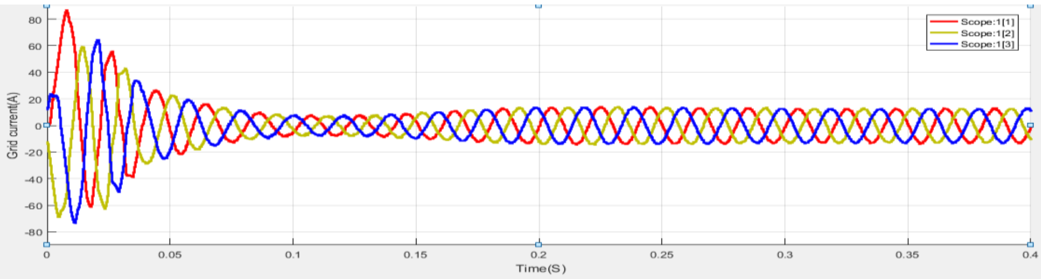


Figure 11. Grid current waveform of system with nonlinear R load (a) .Grid current before compensation (b) .Grid current after compensation

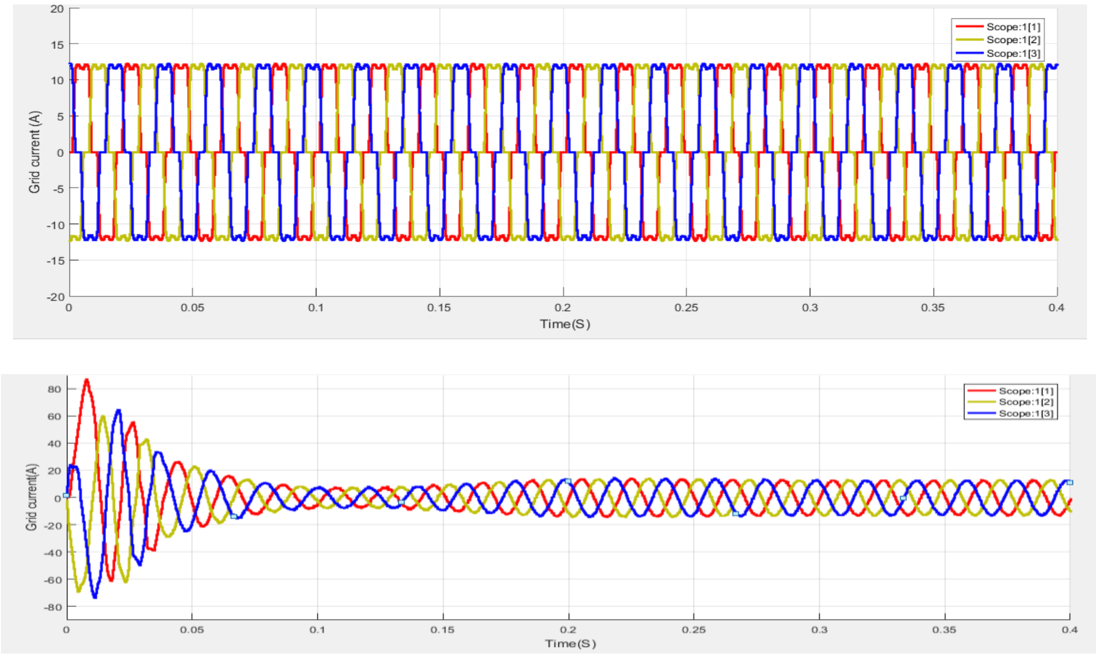


Figure 12. Grid current waveform of the system with nonlinear RL load. (a) .Grid current waveform before compensation. (b).Grid current waveform after compensation

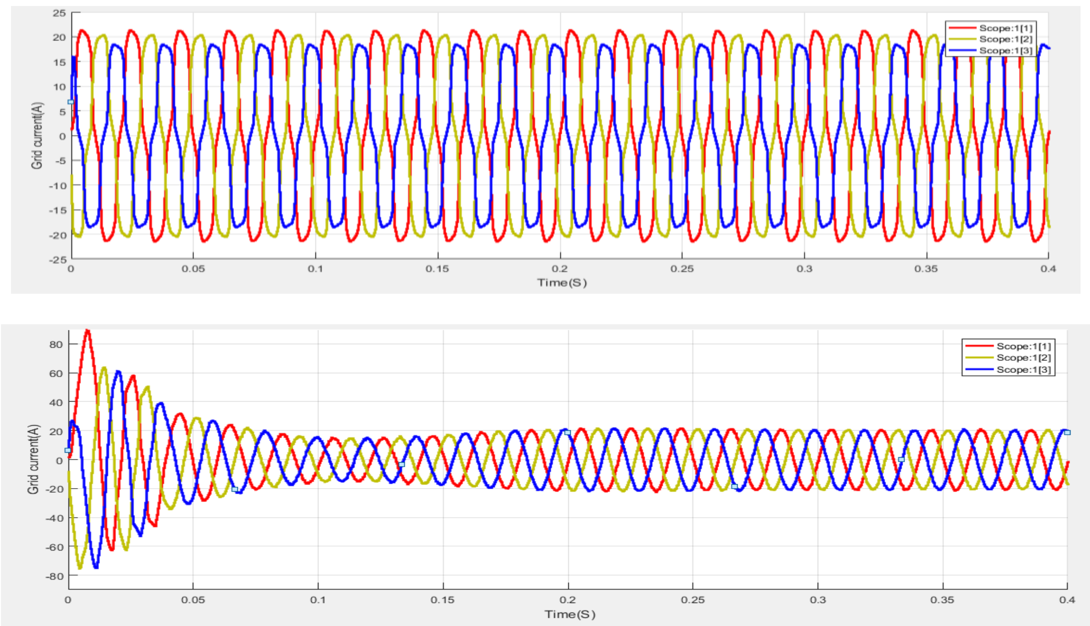


Figure 13. Grid current waveform of the system with nonlinear load and unbalanced load. (a). Grid current waveform before compensation. (b).Grid current waveform after compensation

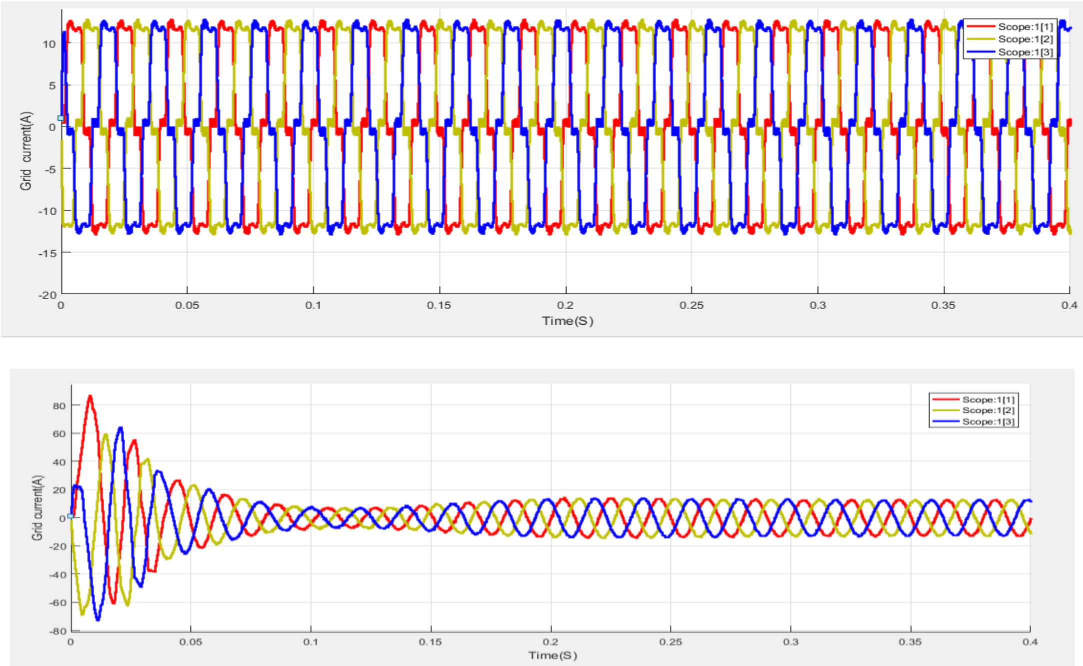


Figure 14. Grid current waveform of the system with nonlinear load and capacitive load . (a).Grid current waveform before compensation. (b). Grid current waveform after compensation.

Shunt active power filter based on SRF theory and hysteresis band current controller is simulated with different load and FFT analysis is done. Obtained THD values are given in table below

Loads	THD before compensation	THD after compensation
Nonlinear R load	21.54%	3.55%
Nonlinear RL load	21.50%	3.37%
Nonlinear RL load and unbalanced R load	12.47%	2.20%
Nonlinear RL load and C load	21.65%	4.08%

Table no.1 THD values at different load conditions

IV. Conclusion

Simulation of three phase system with three phase diode bridge rectifier with RL load as nonlinear load is done using MATLAB\simulink and it is found that harmonics components are present in the grid current waveform. Mainly 3^{rd} and 5^{th} harmonics are present and THD before compensation is found as 21.50%. Inorder to reduce the harmonics, a shunt active power filter based on SRF theory and hysteresis band controller is accurately designed and simulated using MATLAB\simulink. THD after compensation is found to be 3.37%. SAPF is also simulated with different load conditions and THD variations are observed. SAPF based on SRF theory can be used for the reduction of harmonics with any types of load including nonlinear load, unbalanced load, capacitive load.

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