Mitigation of Current Harmonics Using Single Phase and Three Phase Shunt Active Filter with P-Q Technique

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Abstract: This paper presents a single phase and three phase shunt active filter designed to minimize power quality problems in electrical system. The use of Power electronic circuit in a wide range of applications has resulted in distorted current in the power system. For example:- generation of current and voltage harmonics. Due to the use of non-linear loads such as UPS, SMPS, speed drives etc... Causes the generation of current harmonics in the electrical circuit which leads to the distortion of load waveform, voltage fluctuation, voltage dip, heating of equipment etc. They draw reactive power components of current from the AC mains, hence causing disturbance in supply current waveform. One of the effective method to reduce harmonic in power system is the use of Shunt Active Power Filter (SAPF). This Paper gives detail performance analysis of SAPF undercurrent control strategy instantaneous reactive power theory (p-q) method. In this method a reference current is generated for the filter which compensate harmonic current component in power system. A current controller known harmonic current controller is used provide corrective gating sequence of the IGBT inverter and thus helps to remove harmonics component.

Keywords – shunt active filter, Instantaneous Reactive Power Theory, Hysteresis Current controller.

INTRODUCTION

Power quality has become a major concern for industrial and household customers, due to the harmonic distortion introduced by the nonlinear loads. The power quality problems in single phase systems is more due to the use of nonlinear loads. Harmonics are generated in power system due to non-sinusoidal current drawn by nonlinear loads through switching action of onboard power conversion circuits. In modern power systems the requirement for reactive power compensation is becoming more and more rigorous. Due to the drastic growth in the technology of power electronics the usage of nonlinear loads increased due to this rapid growth of power quality management was also required. Non-linear loads draw non-sinusoidal currents, from ac mains and cause a type of voltage and current distortion called a Harmonics.

The problem of harmonics can be mitigated by use of filters in the power circuit. Filters are mainly of two types Active Filters and passive Filters. Passive filters involve passive element and are simple to implement but do not respond efficiently to dynamics of power distribution system.

The basic principle of active power filter (APF) is to cancel specific harmonic components caused by nonlinear loads with the use of power electronic technologies. Active filters are mainly of three types: shunt APF, series APF and hybrid APF. Among various types of active power filters in this paper we are dealing with shunt active filter.

SHUNT ACTIVE POWER FILTER

The shunt active filters are used in the power electronic circuit to compensate current harmonics and reactive power. Shunt active filter compensates current harmonics by injecting complementary current that are produced by nonlinear loads.

The shunt active filter shown in the Fig. 1 is a current controlled voltage source inverter (VSI), which is connected in parallel with the load.

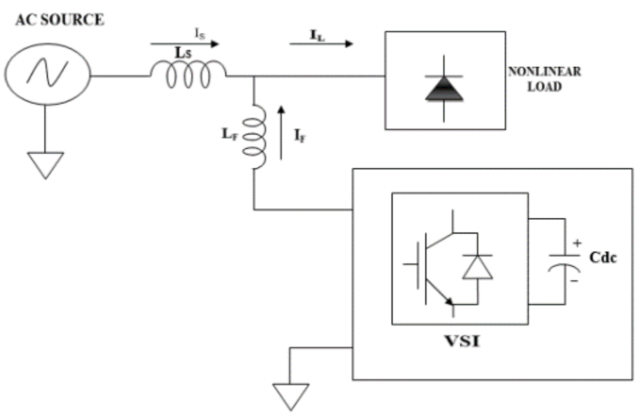


Fig 1: Block diagram of single phase shunt active filter

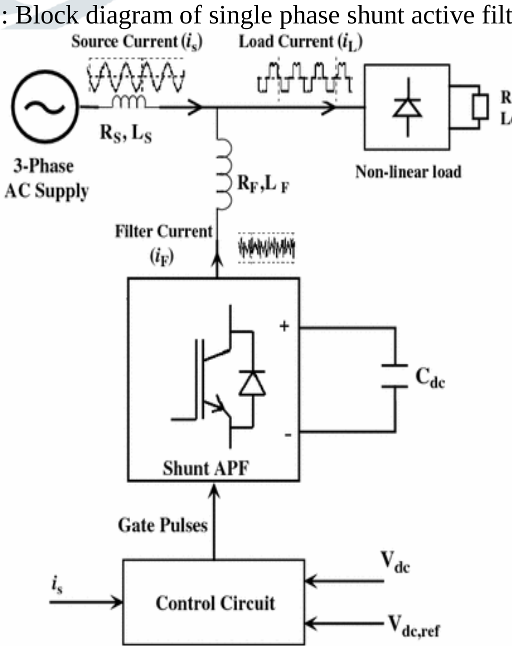


Fig 2: Block diagram of 3 phase shunt active filter

By using right control scheme, APF can additionally enhance device power factor. Thus, by means of the effect of active power filter, voltage assets see the nonlinear load virtually as resistor.

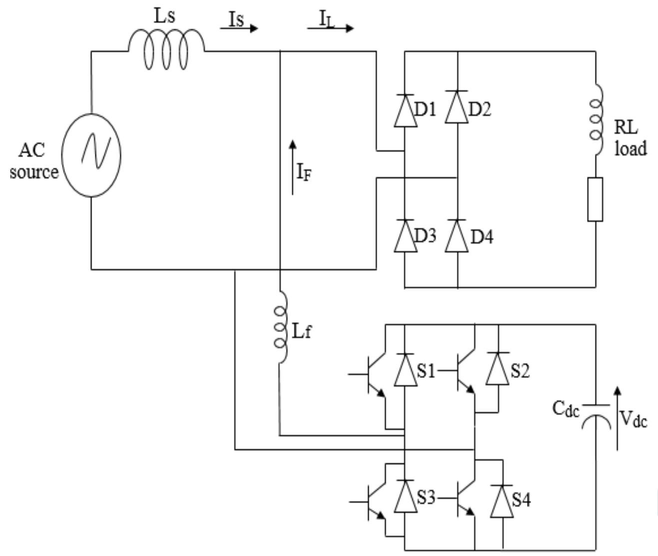


Fig 3: circuit diagram of single phase shunt active filter

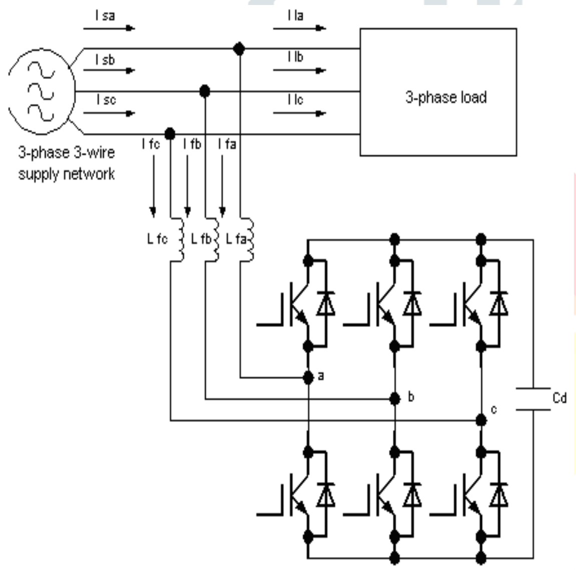
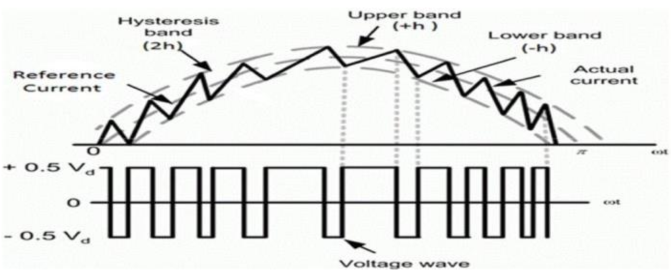


Fig 4: circuit diagram of 3 phase shunt active filter

The shunt active filter which has a self-controlled dc bus has



a topology similar to a static compensator (STATCOM) used in power transmission system for reactive power compensation. Shunt active filters compensate harmonics of load current by adding equal yet opposite harmonic compensating current. The single and three phase shunt active filter consists of AC supply, DC bus capacitor (C_f), interfacing inductor (L_f), single three phase full bridge rectifier, single and three phase active filter, controller and load. The current injected by the filter compensates the harmonics the harmonics due to the non-linear load.

The compensation current (I_f) is obtained by subtracting load current (I_L) from source current (I_s).

Load current (I_L) consists of two components which are fundamental components (I_{Lf}) and harmonic (I_{Lh})

$I_L = I_{Lf} + I_{Lh}$

The compensation current (I_c) injected by active filter is taken equal to harmonic component of load (I_{Lh}).

$I_c = I_{Lh}$

The harmonic component of load current is supplied by active filter and therefore, source current (I_s) only has to supply fundamental current of the load

$I_s = I_L - I_c = I_{Lf}$

HYSTERESIS BAND CONTROLLER

The current control method for hysteresis is used to provide the IGBT inverter with the exact gating pulse and sequence by comparing the current error signal with the specified hysteresis unit. The fig. 5 shows the error signal is fed to the comparator of the hysteresis band where it is compared with the hysteresis band, the comparator output signal is then passed through the active power filter to produce the desired countervailing current following the reference current waveform.

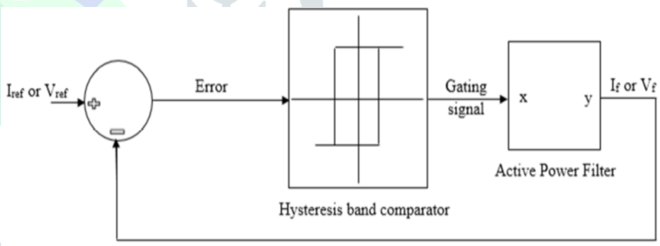


Fig 5: Hysteresis current control

The hysteresis band controller are used to generate pulses for the inverter switching action of the voltage source converter (VSC). There are various current control method but hysteresis control method has quick current controllability and easy implementation make hysteresis current control method much more superior to other current control methods.

It makes the compensation current from active filter to follow the reference current signal within the tolerance limit. The control scheme waveform is shown in fig.6

Fig 6: Hysteresis controller

The merits of using this control scheme are its appreciable dynamic performance and flexible control of peak to peak ripple current.

INSTANTANEOUS REACTIVE POWER THEORY

The single phase P-Q theory is used for harmonic compensation in the utility side. It is used based on the instantaneous power which is defined in time domain and used to get real time control in both transient and steady state condition. It has the ability to generate sinusoidal current in the utility side under conditions of voltage imbalance due of power quality problems. Thus, reference compensation current is derived from this principle, which will compensates for skewed voltages and current. This reference current can be used to control the switching of the converters and thus the harmonics are reduced in the power supply.

The P-Q theory, also known as instant reactive power theory, is commonly used in 3 phase 3 wire power systems and also applied to 4 wire systems. While this theory uses three current and three voltage signals, it can also be used for single phase active filter by duplicating two additional current and voltage signal by 120° angel shifting.

P-Q METHOD MATHEMATICAL MODELLING

The load current in phase "a" can be represented mathematically as shows in eq. (1). By assuming that eq. (1) and the load current for phase "b" as well as phase "c" can be expressed as eq. (2) and eq. (3).

$$i_a = \sum_{i=0}^{n} \sqrt{2I_i}\,\sin(w_i + \theta_i) \qquad (1)$$

$$i_b = \sum_{i=0}^{n} \sqrt{2I_i}\,\sin(w_i + \theta_i - 120^{\circ}) \qquad (2)$$

$$i_c = \sum_{i=0}^{n} \sqrt{2I_i}\,\sin(w_i + \theta_i + 120^{\circ}) \qquad (3)$$

Equation (1), (2) as well as (3) can be transformed into matrix form as shown in the eq. (4) and eq. (5) for load voltage and load current.

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} 1 \\ 1\angle 120^{\circ} \\ 1\angle 240^{\circ} \end{bmatrix} [i_a] \qquad (4)$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} 1 \\ 1\angle 120^{\circ} \\ 1\angle 240^{\circ} \end{bmatrix} [v_a] \qquad (5)$$

The instantaneous reactive power theory, consisting of the matrix transformation i.e. (Clarke transformation) for the 3 phase voltages in the a-b-c coordinates to the α-β-0 coordinates, and accompanied by the evaluation of the p-q theoretical components.

The instantaneous space vector, v_x and i_x are set on x axis, similarly for y axis v_y and i_y and for z axis v_z and i_z. These space vectors can be easily transformed into α-β-0 coordinate continues to follows:

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_\circ \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (6)$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_\circ \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (7)$$

The active and reactive can be written as

$$p = v_\alpha\, i_\alpha + v_\beta\, i_\beta + v_\circ\, i_\circ \qquad (8)$$

$$q = v_\alpha\, i_\alpha - v_\beta\, i_\beta \quad (9)$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (10)$$

Real and reactive power consists of two part they are oscillating part and mean part respectively and also known as AC and DC part. The equation for these two powers is written as

$$p = \bar{p} + \tilde{p} \qquad (11)$$

$$q = \bar{q} + \tilde{q} \qquad (12)$$

The instantaneous zero sequence power (p_o) is written as
$P_o = V_{o1} I_o = \bar{p}_o + \tilde{p}_o$

Where,
P_o = Mean value of the instantaneous zero series power
$\tilde{p}_o$ = Alternated value of the instantaneous zero series power
$\bar{p}$ = Mean value of instantaneous real power
$\tilde{p}$ = Alternated value of instantaneous real power
$\bar{q}$ = Mean value of instantaneous imaginary power
$\tilde{q}$ = Instantaneous imaginary power

The DC part can be calculated by using low pass filter, which is can remove the high frequency and give the fundamental component. From DC part active and reactive power, the α-β reference current can represented as

$$i_{\alpha\beta} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \qquad (13)$$

Where $\Delta = v_\alpha^2 + v_\beta^2$

The 3-phase reference current of APF is given through equation (14) earlier than the signal to be subtracted from load current. The subtracted 3-phase current can be used to produce PWM signal using hysteresis band controller. For signal phase shunt filter hysteresis band is used to drive the gate pulse.

$$i_{abc}{}^{*} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} i_{\alpha\beta}{}^{*} \qquad (14)$$

SIMULATION IN MATLAB

The single phase and 3 phase instantaneous P-Q theory for single phase and 3 phase shunt APF is simulated to evaluate its operation under supply voltage condition. The simulation study on single phase 230V 50Hz, feeding a single phase full bridge rectifier with RL load connected across the utility side. Similarly for 3 phase 415V 5oHz, feeding a 3 phase full bridge rectifier with RL load connected across the utility side The overall simulation of single phase and 3 phase is as shown in below figure.

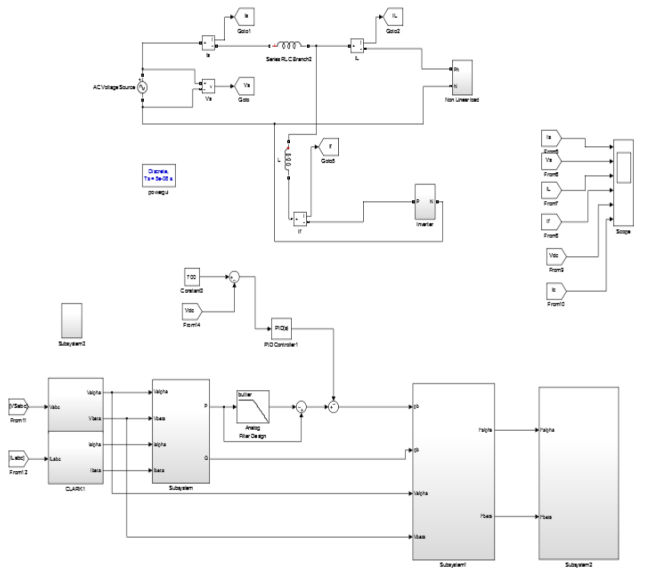


Fig 7: Simulation of single phase shunt active filter

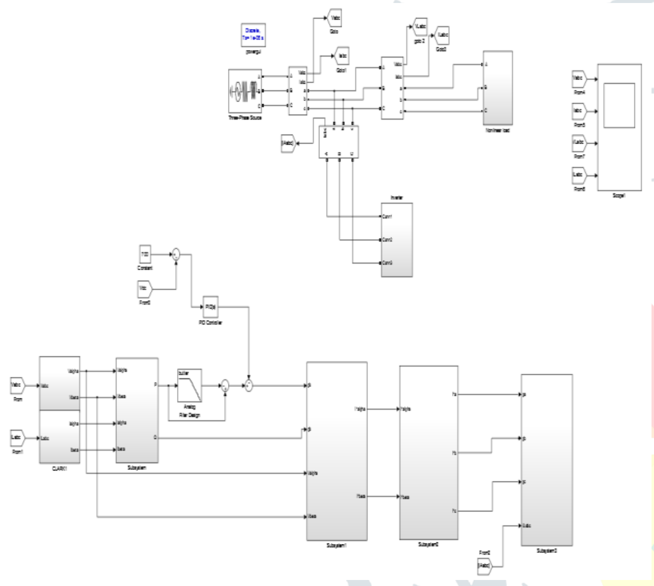


Fig 8: simulation of 3 phase shunt active filter

Single Phase and 3 phase Shunt APF comprises of a solitary stage IGBT based full bridge converter with an energy storage capacitor at the dc side. The APF is associated with purpose of regular coupling (PCC) through an interfacing inductor. The dc voltage of energy vitality stockpiling capacitor is contrasted and the reference voltage. The reference signal created from the correlation is taken care of to pre-tuned PI compensator and the yield signal accomplished from the compensator increased with unit size voltage source reference signal gives the reference principal current. The reference signal is given to hysteresis controller so that it generates gating pulses for the IGBT inverter.

The non-linear block comprises of single phase full bridge converter with RL load connected across it. It consists of 4 diodes during first half cycle diode 1 and diode 4 conducts and other two will be in off state. During second half cycle diode 2 and 3 will conducts similarly for 3 phase full bridge rectifier it consists of 6 diodes, during first cycle D1 and D6 conducts next cycle D2 and D3 and D4 and D5 in the last cycle and it its circuit diagram for both the cases is shown in fig 9 and fig 10.

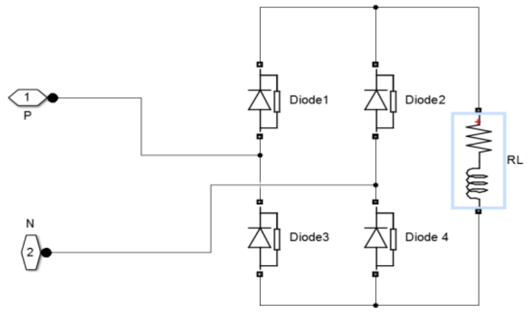


Fig 9: single phase Full bridge diode rectifier with RL load

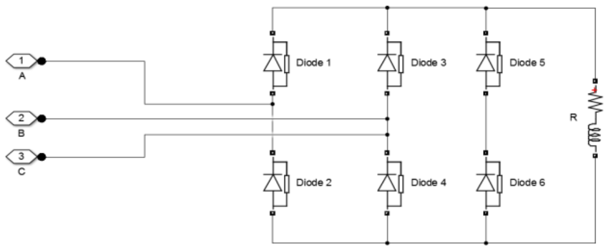


Fig 10: 3- phase Full bridge diode rectifier with RL load

The inverter block consists of 4 IGBT switches for single phase, similarly for three phase inverter block consists of 6 IGBT along with capacitor its voltage and current are measured and interfacing inductor at the point of PCC connected and its operation is similar to diode bridge rectifier but it consists of switches it requires a gating pulse to turn on.

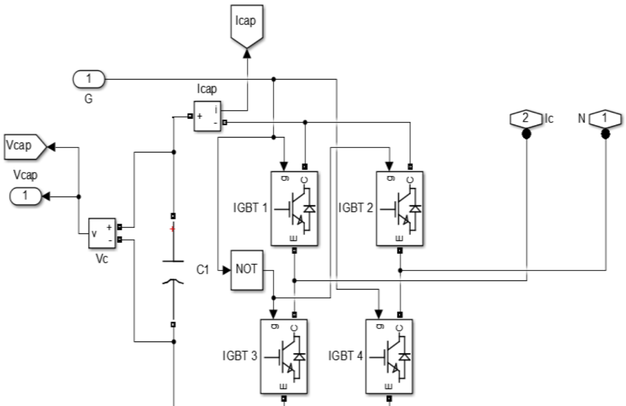


Fig 11: Single phase IGBT based full bridge inverter

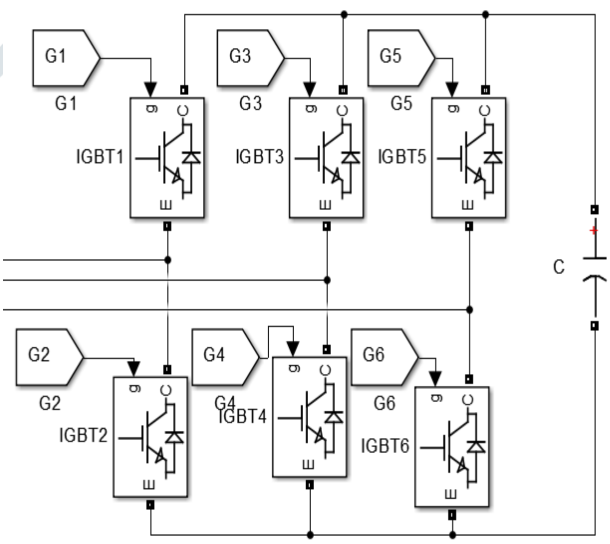


Fig 12: single phase IGBT based full bridge inverter

The reference current is generated by using the P-Q theory as it is developed for 3-phase system it can be used for 1-phase system by duplicating other two signals.

The reference current once given to the hysteresis band controller it generates proper gating signal for the inverter block i.e. for IGBT switches to turn on. The waveforms obtained during simulation is as shown in the below fig and THD can be taken so that harmonics is reduced by using the single phase shunt active filter as harmonic elimination method. The waveform of single phase shunt active filter is shown.

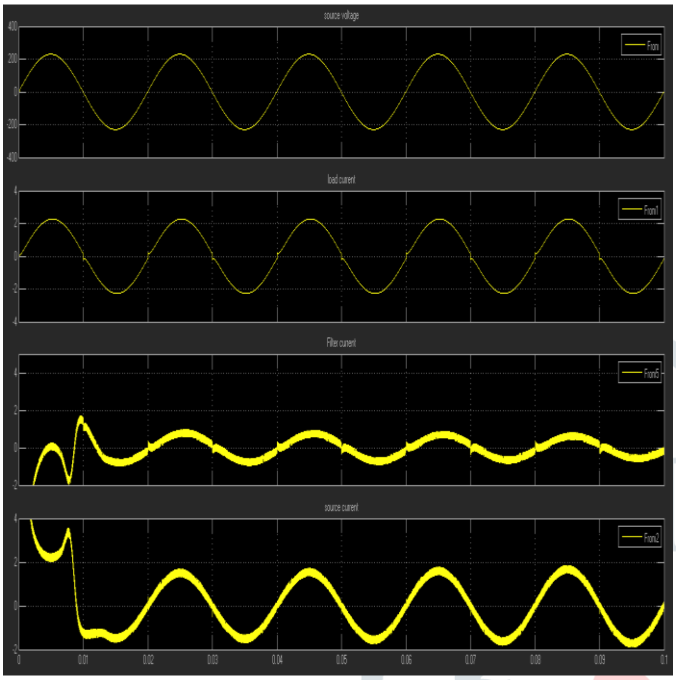


Fig 13: Single phase waveform

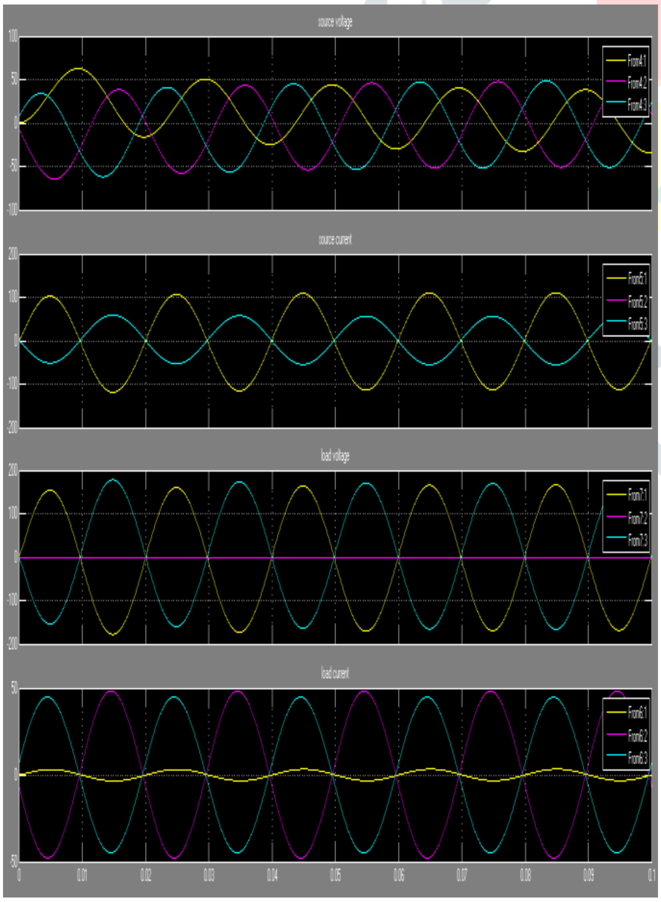


Fig 14: Three phase waveform

The single phase source voltage, current source, load current and filter current waveforms obtained after the implementation shunt active filter is shown in fig 12.

The 3 phase source voltage , source current, load current and load voltage waveforms obtained after the implementation shunt active filter is shown in fig 13.

The waveform obtained after simulation in all the cases in seen in the above figures and total harmonic distortion is obtained is compared with before and after the implementation of single phase and three phase shunt active filter.

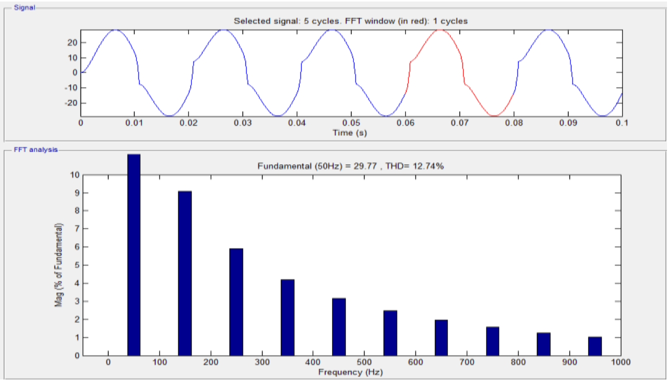


Fig 15: THD before SAPF for Single phase

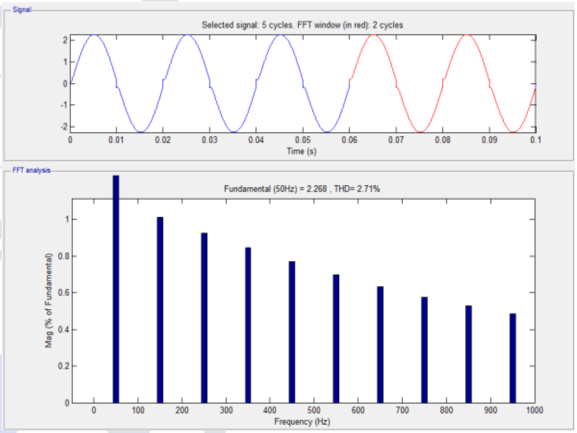


Fig 16: THD after SAPF for Single phase

From the fig 14 and 15 it is cleared that the THD of single phase shunt active filter is reduced, so that the power factor the system can be improved by using shunt active filter.

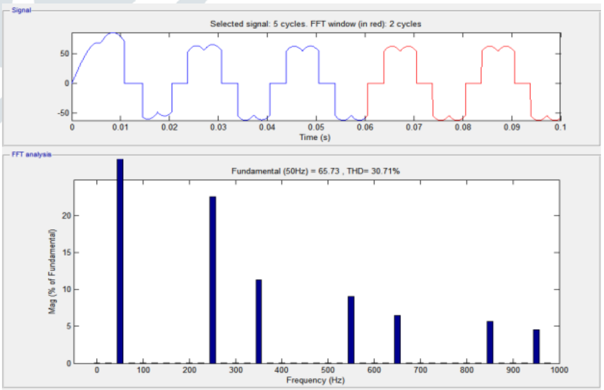


Fig 17: THD before SAPF for Three phase

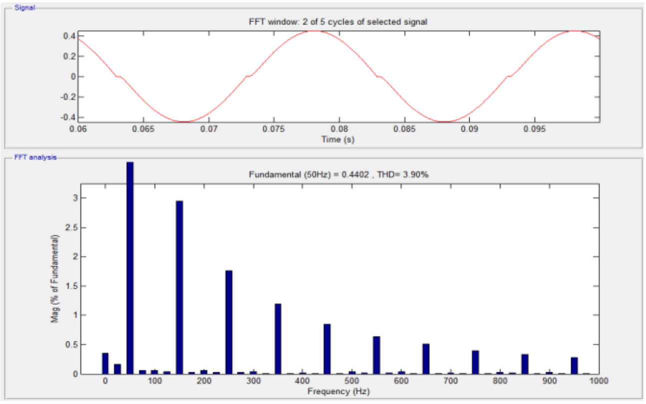


Fig 18: THD after SAPF for Three phase

From the fig 16 and 17 it is cleared that the THD of Three phase shunt active filter is reduced, so that the power factor the system can be improved by using 3 phase shunt active filter.

CONCLUSION

In modern days the increase in usage of non-linear load facing of harmonics and power factor issues in the electrical system. Many approaches can be used to eliminate harmonics from electrical circuit; one of the techniques is active power filter. This paper proves that PQ theory can be implemented to control single phase and three phase active filter, which the theory widely used to control three phase active power filter. Simulation result obtained before and after compensation form shunt active filter is observed. Before compensation the harmonics component in source current was 12.74% which was reduced to 2.71% after compensation for single phase and for 3 phase THD is reduced from 30.71% to 3.90%. PI control based shunt active filter is implemented for harmonic compensation of nonlinear load current. After the results are obtained it is found that shunt active filter is able to mitigate the current harmonics by eliminating the harmonic component in current.

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