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PI Controller Based Shunt Active Power Filter for Harmonic Reduction

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Abstract
The active power filter is an advanced power electronic device, which can be used for compensating harmonics and improving power quality. The different types of active power filters are: shunt active power, series active power and hybrid active power filters. Among the three types, The shunt active power filter injects a suitable compensating current at point of common coupling so that the harmonics present in the line are cancelled out and the sinusoidal nature of voltage and current waveforms are restored. A PI controller based control algoritham is developed to control the three phase shunt active power filter to compensate harmonics produced by the nonliner load to improve power quality. The instaneous p-q theory is used for extracting the harmonic current. Also a PI controller is developed to maintain a constant DC voltage across the capacitor of DC bus side of the inverter. The three phase shunt active power is developed by using MATLAB/SIMULINK. The proposed shunt active power can supress harmonics generated by the non liner load and it can maintain the THD value within the standard limit.

Keywords:*Three phase shunt active power, PI controller, p-q theory, power quality*

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INTRODUCTION

With the rapid development in semiconductor industry, power electronics devices have gained popularity in industries and also in household electrical appliances. Although these power electronics devices have benefited the electrical and electronics industry, these non-linear devices are the main source of harmonics in the power system. Harmonic is a sinusoidal component of a periodic wave and its frequency is an integral multiple of the fundamental frequency. These power harmonics are called electrical pollution which will degrade the quality of the power supply. They also cause disturbance to other consumers and interference in nearby communication networks, low system efficiency and poor power factor. The active power filter based on power electronics technology is a viable solution for power conditioning to suppress the harmonics in the power system.

BACKGROUND

Power Quality

The power quality issue is defined as "any occurrence manifested in voltage, current, or frequency deviations that results in damage, upset, failure, or misoperation of end-use equipment."

Power electronic are the most important cause of power quality problems such as harmonics, interharmonics, notches, and neutral currents etc. Harmonics are produced by rectifiers, advance system designs, soft starters, electronic ballast for discharge lamps, switched-mode power supplies, and HVAC using ASDs. Equipment affected by harmonics includes transformers, motors, cables, interrupters, and capacitors (resonance).

Overview of Harmonic

Harmonic content in the electrical system will cause a waveform of voltage or current in the electrical system to be distorted. This situation is very critical because it will interfere with other electrical systems. Harmonic analysis is the process of calculating the magnitude and phase angle of fundamental and harmonic waveform. Set of sine waves with the lowest frequency f Hz, while all other frequencies equal to multiples of f (2f, 3f, 4f, 5f…). By definition, the lowest frequency sine wave refers to the base and all the high frequency waves known as harmonics. For example a series of sine waves containing frequency of 50, 100 and 150 Hz consists of the following components, 50 Hz (fundamental frequency), the second harmonic, 100 Hz (2x50 Hz) and third harmonic, 150 Hz (3x50 Hz). By performing harmonic analysis, non-sinusoidal wave can be represented by a series of sinusoidal wave containing multiples of the fundamental frequency of the harmonic components.

Harmonic Standards

An important component in addressing harmonic problems is in defining limits to harmonic voltage and current distortion. For harmonic current limits, IEC and IEEE use two principally different approaches. The IEC standard set limits to the amount of emission of individual equipment, whereas the IEEE harmonic standard limits the emission per customer. Under the IEEE standard the responsibility lies with the customer who may decide to install filters instead of buying better equipment. Under the IEC standards the responsibility lies with the manufacturers of polluting equipment. The difference can be traced back to the aim of the documents: the IEEE standard aims at regulating the connection of large industrial customers, whereas the IEC document mainly aims at small customers that do not have the means to choose between mitigation options. The IEEE 519 standard provides guidelines for harmonic current limits at the point of common coupling between the facility and the utility. Harmonic current injection at the PCC determines how one facility might affect other power users and the utility that supplies the power. As the ratio between the maximum available short circuit current at the PCC and the maximum demand load current increases, the percentage of the harmonic currents that are allowed also increases.

This means that larger power users are allowed to inject into the system only a minimal amount of harmonic current (as a percentage of the fundamental current). Such a scheme tends to equalize the amounts of harmonic currents that large and small users of power are allowed to inject into the power system at the PCC. Limiting the voltage distortion at the PCC is the concern of the utility. It can be expected that as long as a facility's harmonic current contribution is within the IEEE 519 limits the voltage distortion at the PCC will also be within the specified limits.

Table 1: *Harmonic Current Limits for General Distribution Systems(120–69,000 V).*

Isc/IL	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h	THD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20–50	7.0	3.5	2.5	1.0	0.5	8.0
50–100	10.0	4.5	4.0	1.5	0.7	12.0
100	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Table 2: *Voltage Harmonic Distortion Limits in Percent of NominalFundamental Frequency Voltage.*

Bus Voltage at PCC (kV)	**Individual harmonic Voltage Distortion (%)**	**Total Voltage Distortion THD (%)**
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

Sources of Harmonics

The main sources of harmonics are fast switching associated with power electronic devices, conventional sources such as electrical rotating machines and transformers and modern electronic equipments. Nowadays, due to the application of advanced technologies in industrial sectors such as power semiconductor system which are designed using phase controlled or uncontrolled rectifiers, inverters, AC voltage controllers, cycloconverter and converters, the harmonics are generated. They produce large harmonic currents of 3rd, 5th, 7th, 9th etc. harmonics.

The conventional sources such as electrical rotating machines, transformers and reactors produce current and voltage components with high frequency content. In general the rotors of AC machines have defects such as couple unbalance, angular misalignment, bad shaft, mechanical looseness. All these anomalies criteria produce harmonics in rotating machines. The nonlinear characteristics of the iron core transformer generate odd order harmonics current due to non-linear character of the flux density and magnetic field intensity.

The adjustable speed drives used for speed control applications generates large harmonic currents. Fluorescent lights use less electrical energy for the same light output as incandescent lighting but produce substantial harmonic currents. The use of personal computer has resulted in harmonic current generation proliferation in commercial buildings.

Harmonic Indices

The two most commonly used indices for measuring the harmonic content of a waveform are the Total Harmonic Distortion (THD) and the Total Demand Distortion (TDD). Both are measures of the effective value of a waveform and may be applied to either voltage or current. The THD is a measure of the effective value of the harmonic components of a distorted waveform. That is, it is the potential heating value of the harmonics relative to the fundamental. It is defined as the ratio of the root mean square of the harmonic content to the rms value of the fundamental quantity, expressed as a percent of the fundamental. This index is expressed as:

$$THD = \frac{\sqrt{\sum_{h>1}^{h_{max}} M_h^2}}{M_1}$$

Where;M_h is the rms value of harmonic component h of the quantity M. In some applications the harmonics is expressed by another term called Total Demand Distortion (TDD). It is defined as the ratio of the root mean square of the harmonic current to the rms value of the rated or maximum demand fundamental current, expressed as a percent. It is defined as follows:

$$TDD = \frac{\sqrt{\sum_{h>1}^{h_{max}} I_h^2}}{I_L}$$

Ik is the rms value of harmonic component k, IL is the peak or maximum demand load current at the fundamental frequency component measured at the point of common coupling.

Harmonic Extraction Methods

The effectiveness of active power filters in reducing the harmonic contents of the supply currents strictly depends on the ability of the algorithm used to extract the reference compensation current from the load current. A number of methods have been developed and analyzed for the generation of reference current. They can be divided into time and frequency domain methods.

Frequency Domain Methods

In the frequency domain approach, the Fourier transform is applied to the distorted voltage or current signals to extract the compensating signals. The Fast Fourier Transform (FFT) method calculates the magnitude and phase of the load current[1], Then the component corresponding to the fundamental active current is removed. Finally, the reference current is obtained by taking inverse FFT for the remaining frequency components.
Recent approaches are based on expressing signals in terms of wavelets. Wavelet transformhas the advantage of using a variable window size for different frequency components. This allows the use of long time intervals to obtain more precise low frequency information and shorter intervals for high frequency information.

The advantage of the frequency domain based method is that the magnitude of the frequency components is known. Hence by manipulation of the magnitudes, overloading of the shunt AF can be prevented. Furthermore, selective conditioning is made possible which is useful in some applications, where the focus is to reduce some specific harmonic component of the load current. However, the calculations involved are cumbersome and also the lack of information regarding the sequences, i.e. positive or negative-sequences, of the conditioning components makes the FFT method less practicable.

Time Domain Methods

Harmonic extraction methods in the time domain are based on instantaneous derivation of compensating signals in the form of either voltage or current signals from the distorted voltage or current signals. The various time domain methods include instantaneous “p–q” theory , synchronous d–q reference frame method,synchronous detection method, flux-based controller, notch filter method, P–I controller, and sliding-mode controller.

The instantaneous active and reactive power (p-q)[2], theory is based on transformation of voltage and current signals to derive compensating signals. The instantaneous active and reactive power can be computed in terms of transformed voltage and current signals. From instantaneous active and reactive powers, harmonics active and reactive powers are extracted using low-pass and high pass filters. From harmonic active and reactive powers, using reverse transformation, compensating commands in terms of either currents or voltages are derived. The first prototype based on this instantaneous power theory for active power filter was developed by Akagi and Nabae (1983) from Japan. This approach has been studied and extended into different approaches such as moving average p-q theory, extension p-q theory and single phase p-q theorem[3]. Aredes et al (2004) from Brazil had implemented this theory in control strategies for power line conditioners and active filters. For a three phase power system, the instantaneous reactive power theorem or p-q theorem is expressed as an instantaneous space vectors in voltage or current form. In the synchronous d–q reference frame and flux-based controllers, voltage and current signals are transformed to a synchronously rotating frame, in which fundamental quantities become DC quantities, and then the harmonic compensating signals are extracted. In the notch-filter-based method, the compensating commands are extracted using notch filters on distorted voltage or current signals. In P–I and sliding-mode controllers, either dc-bus voltage (in a VSI) or DC-bus current (in a CSI) is maintained to the desired value and reference values for the magnitudes of the supply currents are obtained. Subtracting load currents from reference supply currents, compensating commands are derived.

The main advantage of the time-domain methods is its fast response which is necessary for on line applications. But, the performance of these approaches may not be satisfactorily under noisy voltage or current conditions.

Current Control Strategies

Current control strategy is the heart of the active filter since it defines the converter switching frequency, the converter time response and the accuracy to follow the current references. The current control techniques for voltage source inverter can be categorized into linear and non-linear approaches [4]. Linear current controllers like PI, predictive and deadbeat controllers generate a desired voltage which is fed into a "sine-triangle" pulse width modulator to generate the switching signals for the inverter. Linear current controllers are characterized by a constant switching frequency, but have performance limitations caused by delays associated with the error calculation and PWM process. Non-linear current controllers are based on hysteresis strategies, in which measured currents are compared with reference currents on an instantaneous basis. The current error is then compared against a hysteresis band using a comparator to generate switching pulses for the inverter. Non-linear current controllers are characterized by widely varying switching frequencies but offer a good time response. Hence, for current control applications, hysteresis current control is often preferred. This method provides instantaneous current corrective response, automatic peak current limitation, simple implementation, good dynamic response and unconditional stability. But, they exhibit the following difficulties:

a) The control parameters such as the slope of the switching surface cannot be obtained readily from the component values in the power stage. They are usually designed by considering the converter's particular behaviors, such as the startup transients or the steady-state behaviors.
b) It requires several switching actions before settling to steady state after a large signal disturbance. Some design strategies are optimized for a particular transient performance, such as the startup process with one switching cycle. However, their respective control parameters cannot ensure similar performances for other types of large signal disturbances.
c) The switching frequency is dependent on the inverter operating conditions such as the magnitude of the DC voltage and grid voltages. This might increase the switching loss of the switches and losses of the output filter.
d) A hysteresis band is usually needed to define the switch function and it also determines the switching frequency. However, the magnitude of the hysteresis band is practically very small and difficult to control and also the slope of the reference current is unpredictable, which leads to increase in switching frequency.

Dell Aquila et al (2003) have proposed a hysteresis current controller with fixed switching frequency which results in low current tracking error[5–8]. But, this method is found to result in high value of total harmonic distortion with increased amount of neutral current. Kale et al (2005) have proposed an adaptive hysteresis band controller for active power filter applications. The adaptive hysteresis band controller changes the hysteresis bandwidth as a function of reference compensator current variation to optimize switching frequency and THD of the supply current. But, in this method, the source current is found to posses large number of spikes which increases the THD value. PI controller is used to remove steady sate error. Here we want it to maintain Vdc by comparing it with a constant value of Vref. If Vdc is lesser than Vref then it would create a positive ploss signal and if Vdc is greater than Vref it would create negative plosssignal[8–10].

Power Filter Topologies

Depending on the particular application or electrical problem to be solved, active power filters can be implemented as shunt type, series type, or a combination of shunt and series active filters (shunt-series type). These filters can also be combined with passive filters to create hybrid power filters.

Shunt Active Power Filters

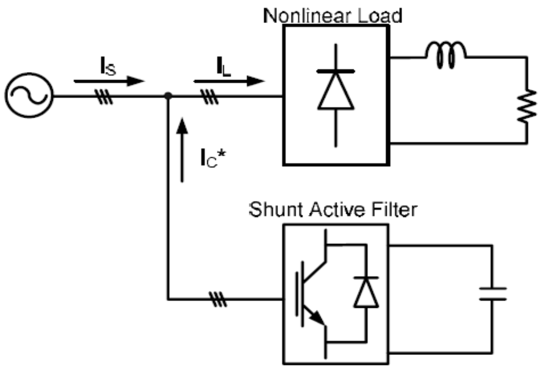

Fig. 1: *Shunt Active Power Filters.*

The shunt-connected active power filter, with a self-controlled DC bus, has a topology similar to that of a static compensator (STATCOM) used for reactive power compensation in power transmission systems (Figure 1). Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase-shifted by 180°.

Series Active Power Filters

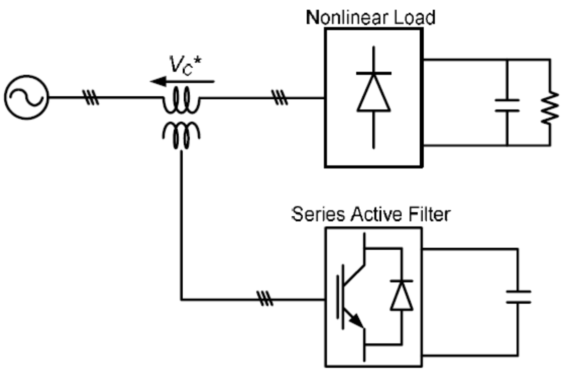

Fig. 2: *Series Active Power Filters.*

Series active power filters operate mainly as a voltage regulator and as a harmonic isolator between the nonlinear load and the utility system. The series-connected filter protects the consumer from an inadequate supply-voltage quality.

This type of approach is especially recommended for compensation of voltage unbalances and voltage sags from the AC supply and for low-power applications and represents an economically attractive alternative to UPS, since no energy storage (battery) is necessary and the overall rating of the components is smaller (Figure 2).

The series active filter injects a voltage component in series with the supply voltage and it acts as a controlled voltage source, compensating voltage sags and swells on the load side. In many cases, series active filters work as hybrid topologies with passive LC filters.

If passive LC filters are connected in parallel to the load, the series active power filter operates as a harmonic isolator, forcing the load current harmonics to circulate mainly through the passive filter rather than the power distribution system. The main advantage of this scheme is that the rated power of the series active filter is a small fraction of the load kVA rating.

Hybrid Active Power Filters

The series-shunt active filter is a combination of the series active filter and the shunt active filter. The shunt active filter is located at the load side and can be used to compensate for the load harmonics. On the other hand, the series portion is at the source side and can act as a harmonic blocking filter. This topology has been called the unified power quality conditioner. The series portion compensates for supply voltage harmonics and voltage unbalances, acts as a harmonic blocking filter, and damps power system oscillations.

The shunt portion compensates load current harmonics, reactive power, and load current unbalances. In addition, it regulates the DC link capacitor voltage. The power supplied or absorbed by the shunt portion is the power required by the series compensator and the power required to cover losses.

Hybrid power filters are a combination of active and passive filters. With this topology the passive filters have dynamic low impedance for current harmonics at the load side, increasing their bandwidth operation and improving their performance. This behavior is reached with only a small power rating PWM inverter, which acts as an active filter in series with the passive filter.

Voltage Source Converters

Most of the active power filter topologies use voltage source converters, which have a voltage source at the DC bus, usually a capacitor, as an energy storage device. This topology, shown in Figure 3, converts a DC voltage into an ac voltage by appropriately gating the power semiconductor switches. For most applications pulse width modulation (PWM) is the most commonly used PWM technique.

PWM techniques applied to a voltage source inverter consist of chopping the DC bus voltage to produce an ac voltage of an arbitrary waveform.

There are a large number of PWM techniques available to synthesize sinusoidal patterns or any arbitrary pattern. With PWM techniques, the ac output of the filter can be controlled as a current or voltage source device.

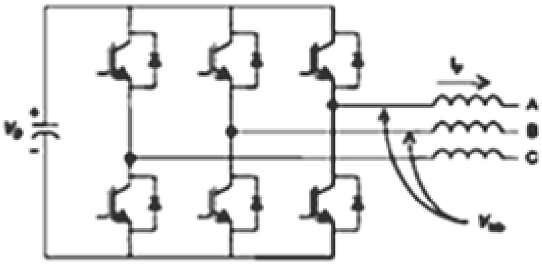

Fig. 3: *Voltage Source Converter Topology for Active Filters.*

Figure 3 shows the way PWM works by means of one of the simplest and most common techniques: the triangular carrier technique. It forces the output voltage va over a switching cycle, defined by the carrier period of Vcar, to be equal to the average amplitude of the modulating wave Va ref. The resulting voltages for a sinusoidal modulation wave contain a sinusoidal fundamental component Va(1) and harmonics of unwanted components. These unwanted components can be minimized using a frequency carrier as high as possible, but this depends on the maximum switching frequency of the semiconductors (IGBTs, GTOs, or IGCTs).

Control Strategies

Most of the active filters developed are based on sensing harmonics and reactive volt-ampere requirements of the non-linear load and require complex control. In some active filters, both phase voltages and load currents are transformed into the α-β orthogonal quantities, from which the instantaneous real and reactive power are calculated. The compensating currents are calculated from load currents and instantaneous powers. The harmonic components of power are calculated using high pass filters. The control circuit of the DC capacitor voltage regulates the average value of the voltage to the reference value. Reactive power compensation is achieved without sensing and computing the reactive current component of the load, thus simplifying the control circuit. Current control is achieved with constant switching frequency producing a better switching pattern. An active filter based on the instantaneous active and reactive current component in which current harmonics of positive and negative sequence including the fundamental current of negative sequence can be compensated. The system therefore acts as a harmonic and unbalanced current compensator.

A comparison between the instantaneous active and reactive current component method and the instantaneous active and reactive power method is realized. A scheme has been proposed in which the required compensating current is generated using simple synthetic sinusoid generation technique by sensing the load current. This scheme is further modified by sensing line currents only.

An instantaneous reactive volt-ampere compensator and harmonic suppressor system is proposed without the use of voltage sensors but require complex hardware for current reference generator. The generated reference current is not a pure sine wave but stepped sine wave. Also, without the use of voltage sensors, the scheme generates balanced sine wave reference currents but do not compensate reactive power completely (if source voltage is unbalanced/distorted) due to waveform difference between voltage and current).

Conventional solutions for controller requirements were based on classical control theory or modern control theory. Widely used classical control theory based design of PID family controllers requires precise linear mathematical models. The PID family of controllers failed to perform satisfactorily under parameter variation, non linearity, load disturbance, etc.[8–10]

PROPOSED SHUNT ACTIVE FILTER

Figure 4 shows the schematic representation of a shunt active filter connected in a three phase system feeding a non-linear load.

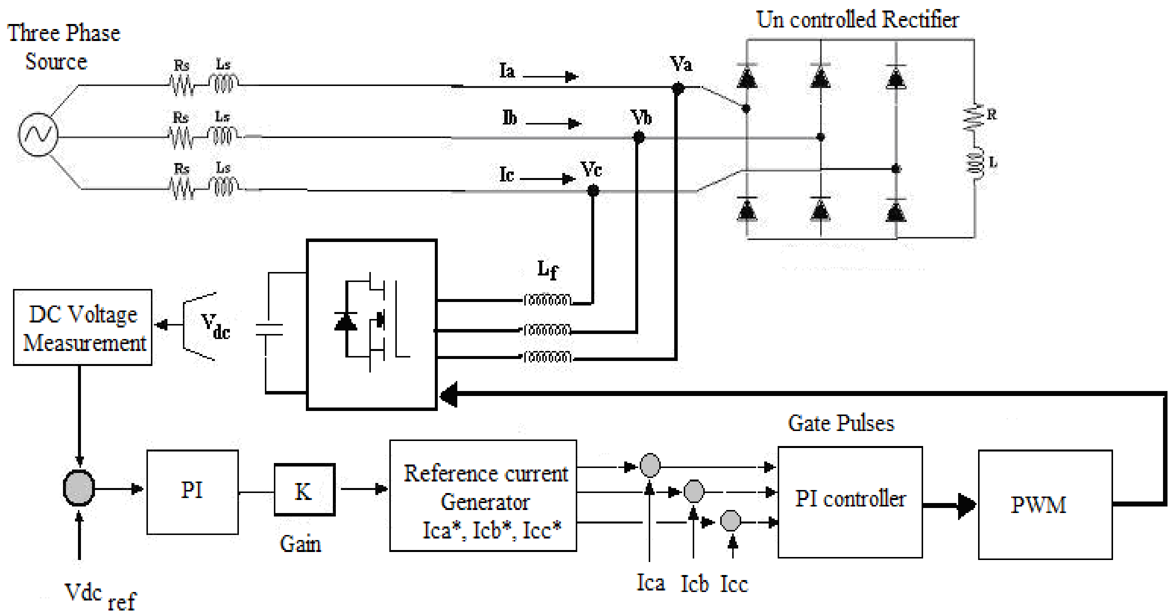

Fig. 4: *Schematic Representation of Active Power Filter with theProposed Control Technique.*

Voltages Va, Vb, Vc and current Ia, Ib, Ic indicate the phase voltages and currents at the load side respectively. The active filter is connected in parallel with the load to suppress the harmonics. The shunt active filter generates the compensating currents Ica, Icb, Icc to compensate the load currents Ica, Icb, Icc so as to make the current drawn from the source as sinusoidal and balanced.

The performance of the active filter mainly depends on the technique used to compute the reference current and the control strategy followed to inject the desired compensation current into the line. In this work, the instantaneous p-q theory is used to determine the current references (Ica*, Icb*, Icc*).

Another important task in the development of active filter is the maintenance of constant DC voltage across the capacitor connected to the inverter. This is necessary because there is energy loss due to conduction and switching power losses associated with the diodes and IGBTs of the inverter in active power filter, which tend to reduce the value of voltage across the DC capacitor.

Harmonics Extraction Technique

Derivation of compensation current is the important part of active filter control. The time domain methods are mainly used due to its speed with less calculation compared to the frequency domain methods. Instantaneous p-d theory, one of the time domain methods is followed in this work. The details of instantaneous p-q theory are presented here:

The p-q theory is based on α-β the transformation, and is known as the Clarke

Transformation. It transforms the three phase voltage and current into α-β stationary reference frame using the following equations:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (2)$$

Since in a balanced three-phase three wire system, neutral current is zero, the zero sequence current does not exist. The power components p and q are related to theα-β voltages and currents, and can be written as,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (3)$$

where p is the instantaneous real power and q is the instantaneous imaginary power. The instantaneous real power includes AC and DC values and can be expressed as follows:

$$p = \bar{p} + \tilde{p} \quad (4)$$

Where; $\tilde{P}$ is the alternating value of the instantaneous real power which is exchanged between the source and load and$\bar{P}$ is the average real power.

The alternating (AC) value of instantaneous real power is calculated back to a-b-c frame which represents the harmonic distortion, given as reference for the current controller.

The mean (DC) value of the instantaneous real power is usually the only desirable power component. The other quantities have to be compensated using the shunt active filter. To calculate the reference compensation currents in the α-β coordinates, the Eq. (3) is inverted as given below,

$$\begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} = \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\beta \end{bmatrix} \begin{bmatrix} \tilde{p} \\ q \end{bmatrix} \quad (5)$$

Where; $\tilde{P}$ is the alternating value of the instantaneous real power which is exchanged between the source and load and q is the instantaneous imaginary power corresponding to the power that is exchanged between the phases of the load.In order to obtain the reference compensation currents in the a-b-c coordinates the inverse of the transformation is applied to Eq. (2) and isgiven as:

The Eq. (6) gives the reference compensation current to be injected to the system.

$$\begin{bmatrix} i_{ca}^{*} \\ i_{cb}^{*} \\ i_{cc}^{*} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{\sqrt{2}} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} \quad (6)$$

Current Controller for Filter

In shunt active power filter, the output voltage of the inverter is controlled by changing the switching pulses. This causes a flow of instantaneous power into the inverter which charges/discharges the inverter DC bus capacitor. Despite the resultant DC bus voltage fluctuations, its average value remains constant in a lossless active filter.

However, the converter losses and active power filter exchange causes the capacitor voltage to vary. Hence the DC bus capacitor must be designed to achieve two goals, i.e., to comply with the minimum ripple requirement of the DC bus voltage and to limit the DC bus voltage variation during load transients. In this work, a PI controller is developed to control the DC bus voltage[10–12].

Voltage Controller for DC Voltage Maintenance

Another important task in the development of active filter is the maintenance of constant DC voltage across the capacitor connected to the inverter. This is necessary because there is energy loss due to conduction and switching power losses associated with the diodes and IGBTs of the inverter in active power filter, which tend to reduce the value of voltage across the DC capacitor. Generally, PI controller is used to control the DC bus voltage. The PI controller based approach requires precise mathematical model which is difficult to obtain. Also, it fails to perform satisfactorily under parameter variations, non-linearity, and load disturbances.

The controller adjusts the real power (Preg) requirement for voltage regulation to keep the constant voltage across the capacitor.

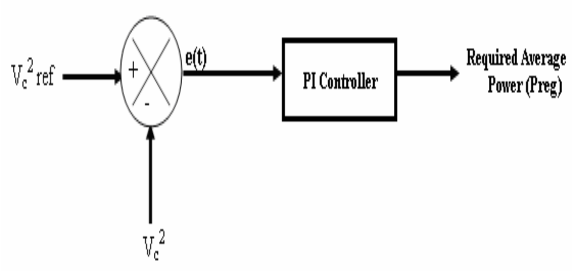

Fig. 5:*Block Diagram of the Current Controller using a PI Controller.*

SIMULATION DIAGRAM

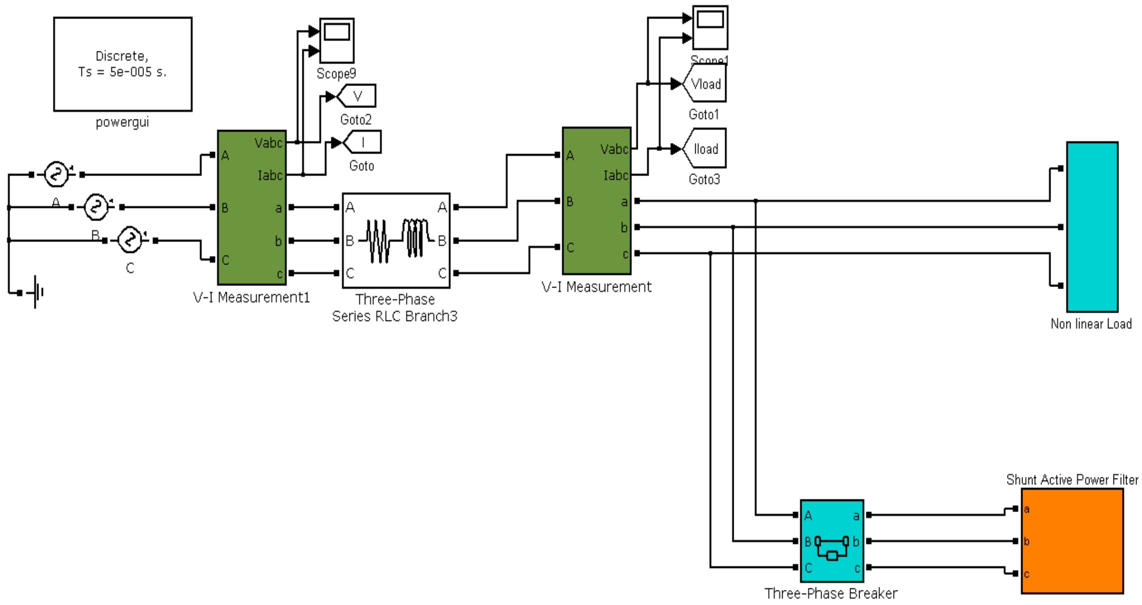

Fig. 6: *Simulation in Shunt Active For Harmonic Reduction.*

The shunt active power filter simulation diagram is shown in the Figure 6.In this simulation the non-linear load is connected in the AC source.The non-linear load generate the harmonics current.

By using of shunt active power filter to reduce the harmonics current.In this shunt active power filter is based on PQ theory calculations,PI controller,PWM technics and Inverter circuits.

Design Parameters

The system parameters considered for the study of passive shunt filter with TCR and TSC combination is given below in Table 3.

Table 3: *Specification for Test System.*

Components	**Specifications**
Supply phase to phase voltage,frequency	415 V (rms), 50 Hz
Supply line Parameters	Rs=1 Ω, Ls=3 mH
Load Resistance	70 Ω
Load Inductance	37 mH
Filter coupling Inductance	Lf=3 mH, Rf =0.5 Ω
Inverter DC bus capacitor	1 mF
DC Voltage Control:ReferenceVoltageProportional gainIntegral gain	700 V0.050.4
Sampling Time	2e–6 sec

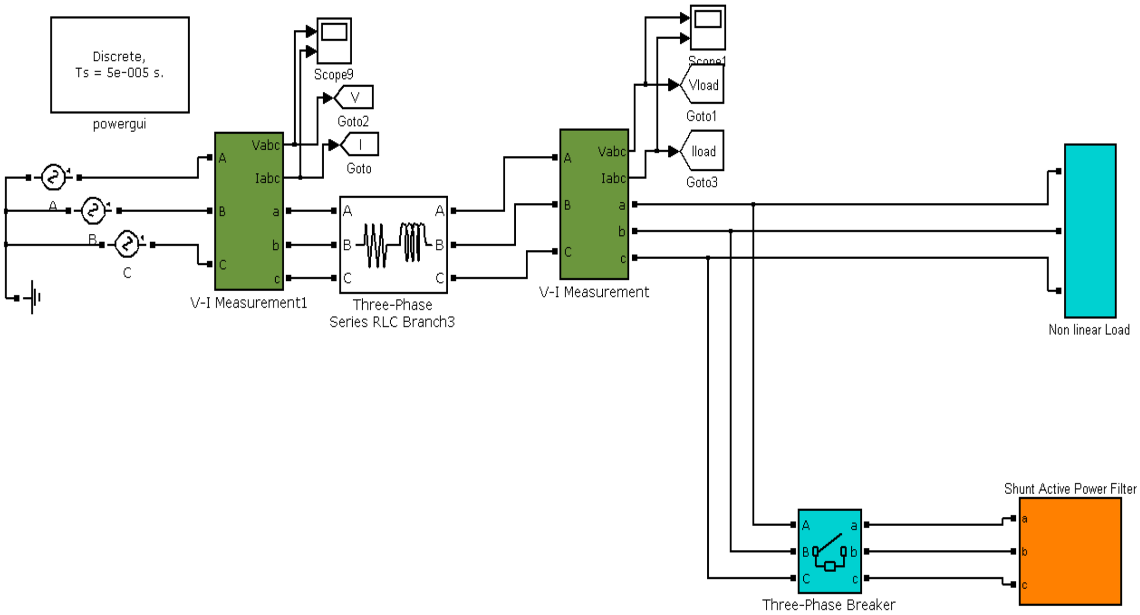

Fig. 7: *Three Phase Power system without Shunt Active Filter.*

Simulation Result without SAF

The harmonic current compensation is implemented in a three-phase power system using a shunt active power filter. The rms value of source voltage of the system is set as 415 V and a combination of three-phase universal bridge rectifier with an RLC load across it constitutes the nonlinear load which introduces the harmonics into the system.

Figure 7 presents simulation using Matlab/Simulink for a three-phase power system without a shunt active filter. And the Figures 8 and 9 present simulation resultsfor a three-phase power system without a shunt active filter. In this simulation model the circuit breaker is placed in the shunt active power filter.The circuit breaker is open condition the load current is without connected the filter current.Theharmonics current is present on the load side. The waveform of harmonics in the load side is shown in the Figure 8.

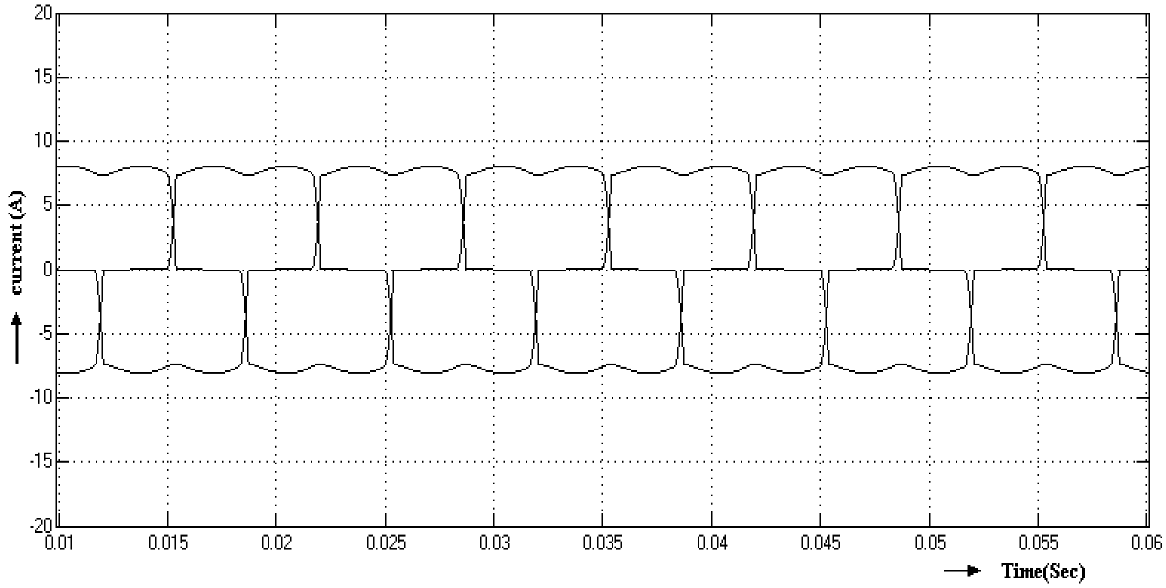

Fig. 8: *Load Current Wave Form without Shunt Active Filter*.

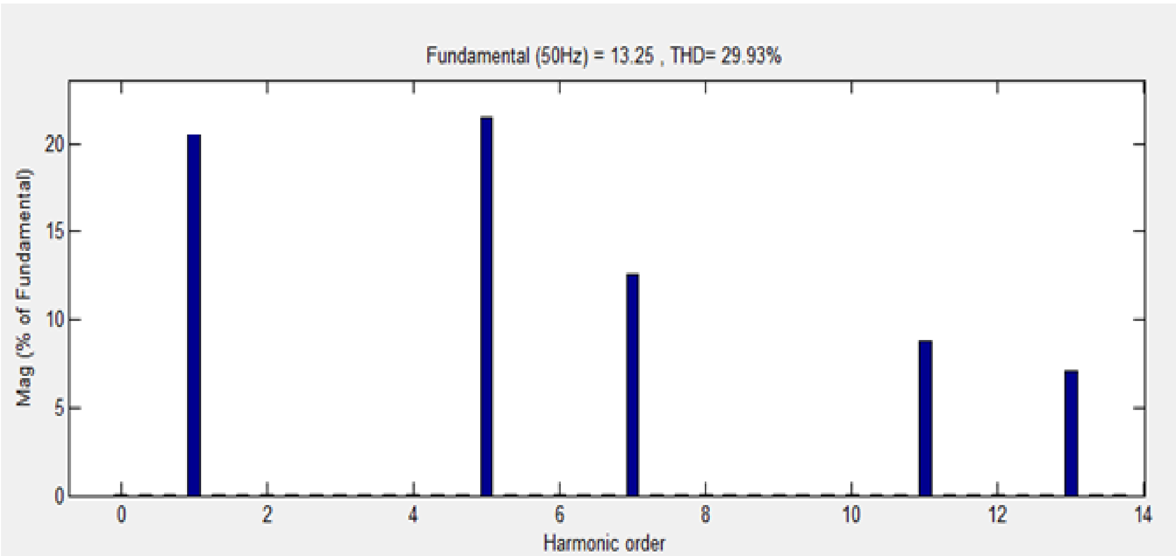

Fig. 9: *THD Spectrum without Active Power Filter*.

The source current waveform without filter in a-phase is shown in Figure 8. The total harmonic distortion (THD) spectrum in the system without filter is shown in Figure 9, which indicate a THD of 29.95%. The compensating current waveform in a phase is illustrated in figure . The source current after the injection of compensating current is also shown.

Simulation Results with Shunt Active Power Filter

Figure 10 present simulation using Matlab/Simulink for a three-phase power system with a shunt active filter. And the Figures 11 and 12 present simulation results for a three-phase power system with a shunt active filter.

In this simulation model the circuit breaker is placed in the shunt active power filter.The circuit breaker is in closed condition, the load current connected with the filter current to reduce the hormonics current on the load side. The with shunt active power filter wave form is shown in the Figure 11.

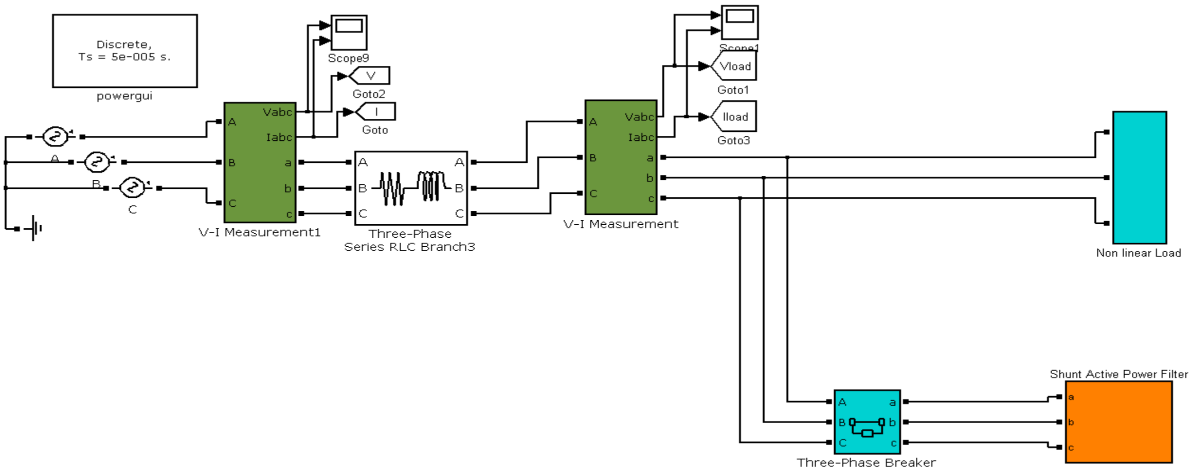

Fig. 10: *Three Phase Power System with Shunt Active Filter.*

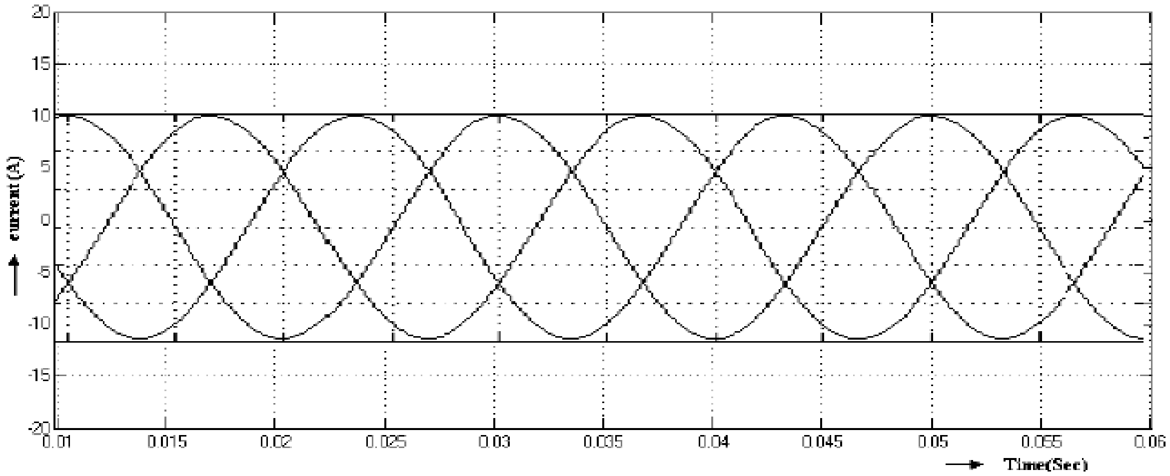

Fig. 11: *Load Current Wave Form with Shunt Active Filter.*

The THD with active power filter included is observed to be 4.60% which is within the allowable harmonic limit. Figure 12 shows the THD spectrum with active power filter in the circuit.

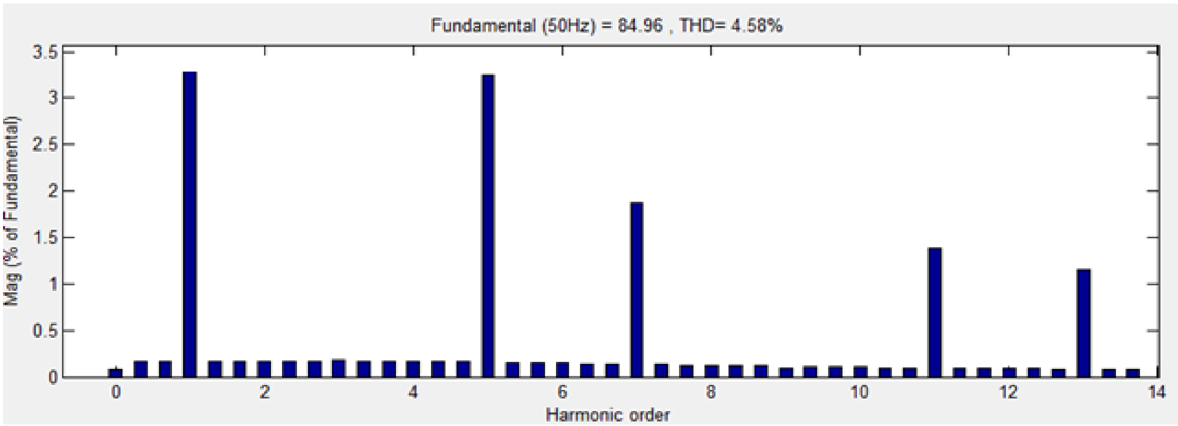

Fig. 12: *THD Spectrum with Active Power Filter.*

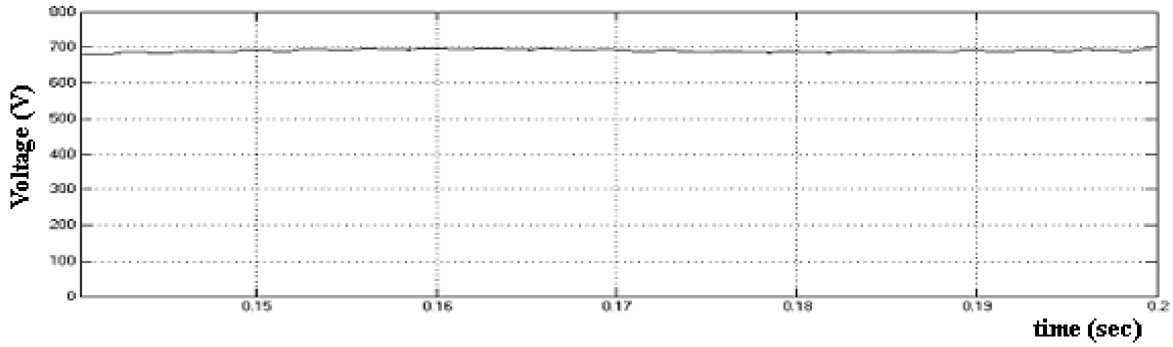

Fig. 13: *DC Bus Voltage Maintenance using PI Control.*

Another important task in the development of active filter is the maintenance of constant DC voltage across the capacitor connected to the inverter. This is necessary because there is energy loss due to conduction and switching power losses associated with the diodes and IGBTs of the inverter in active power filter, which tend to reduce the value of voltage across the DC capacitor. Generally, PI controller is used to control the DC bus voltage (Figure 13). The PI controller based approach requires precise mathematical model which is difficult to obtain. Also, it fails to perform satisfactorily under parameter variations, non-linearity, and load disturbances.

CONCLUSION

This proposed work has presented p-q theory based harmonics calculation, PI controller, PWM techniques and inverter based approach for developing the active filter for three-phase three-wire system. The p-q theory was employed for effectively computing the reference current under ideal source voltage conditions. The active filter has been simulated using MATLAB/SIMULINK and the performance has been analyzed in a sample power system with a source and set of non-linear loads. The simulation results show that the proposed technique is effective in current harmonic filtering. Further the proposed technique has quick response time and it keeps the good quality of filtering.

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