Instantaneous Active and Reactive Current Component Method for Active Filters under Balanced & Unbalanced mains Voltage Conditions for 3-ph 3-wire System

A dissertation submitted in partial fulfillment of the requirements for

The degree Of **BACHELOR OF TECHNOLOGY** *in*

ELECTRICAL ENGINEERING

By

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CERTIFICATE

This is to certify that the thesis entitled, " An Instantaneous Active and Reactive Current Component Method for Active Filters under Balanced & Unbalanced mains Voltage Conditions " submitted by Manjeet Vashistha Kanojiya, Dannana Santosh and Banoth Madhu in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electrical Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him/her under my/our supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

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ACKNOWLEDGEMENT

We would like to thanks Prof. A. K. Panda, Department of Electrical Engineering, our Project Guide, for his guidance, support, motivation and encouragement to work on this project. His readiness for consultation at all times, his educative comments, his concern and assistance have been invaluable.

Our sincere thanks also to Prof. B. D. Subudhi, Prof. K.B. Mohanty for their valuable suggestions and comments.

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CONTENTS

Abstract

Power quality problem is the most sensitive problem in a power system. Most of the pollution issues created in power system is because of the nonlinear nature of loads. Due to large amount of non-linear equipment, impact and fluctuating loads (such as locomotive, arc-furnace, heavy merchant mill, welding equipment etc.), problems of power quality is becoming more and more serious problem with time. To overcome this problem APF (Active power filter) has gained more attention because of its excellent performance of harmonic mitigation and reactive power compensation. But still performance of the active filter depends upon different control strategies. This paper presents detailed analysis to compare and elevate the performance of two control strategies for extracting reference currents of shunt active power filter under balanced and un-balanced voltage condition by using PI controller .The instantaneous active and reactive current component (*id*-*iq*) method and instantaneous active and reactive power (*p*-*q*) method are two control strategies which are extensively used in active filters. A shunt active filter based on the instantaneous active and reactive current component (*id*-*iq*) method is proposed. This method aims to compensate harmonic and first harmonic unbalance. Both methods are completely frequency independent. Simulations are carried out with PI controller for the (I_d-I_q) control strategies for different voltage condition. Under un-balanced voltage condition it is found that the instantaneous active and reactive current component (*id*-*iq*) has a better harmonic compensation performance.

Index Terms—Shunt Active power filter, *id*-*iq* control method, p-q control method, PI controller

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Chapter-1

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1.1 Introduction

Due to extreme use of power converters and other non-linear loads in industry it is observed that it deteriorates the power systems voltage and current waveforms. Static power converters such as single phase and three phase rectifiers, thyristor converters and large number of power electronic equipment are nonlinear loads which generate considerable disturbances in the ac mains. Mainly voltage harmonics and power distribution problems arise due to current harmonics [1] produced by nonlinear loads. As nonlinear currents flow through electrical system and the distribution-transmission lines, additional voltage distortion produce due to the impedance associated with the electrical network. The presence of harmonics in the power system cause greater power loss in distribution, interference problem in communication system and, sometimes result in operation failure of electronic equipments which are more and more sensitive because it contains microelectronic controller systems, which work with very low energy levels. It is noted that non-sinusoidal current results in many problems for the utility power supply company, such as low power factor, low energy efficiency, electromagnetic interference (EMI), distortion of line voltage etc. Passive filters have been used as a solution to solve harmonic current problems, but because of the several disadvantage of passive filter like it can mitigate only few harmonics and gives rise to resonance problem. Additionally, passive filters have drawback of bulk size [2].To cope with these advantages, recent efforts have been concentrated in the development of active filters, which are able to compensate not only harmonics but also asymmetric currents which is caused by nonlinear and unbalanced loads. Because of the remarkable progress in the last two decades in the field of power electronics devices with forced commutation ,active filters have been extensively studied and a large number of the works have been published[3]-[4].

There are basically two types of active filters: the shunt type and series type. The shunt-connected active power filter, with a self-controlled dc bus used for reactive power compensation in power transmission systems. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. Series active power filters were introduced by the end of the 1980s and 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. The series active filter injects a voltage component in series with the supply voltage and therefore can be regarded as a controlled voltage source, compensating voltage sags and swells on the load side. Till now many control strategies have been developed but instantaneous active and reactive current (*id*-*iq*) component method [5] and instantaneous active and reactive power (*p*-*q*) method [6] are more popular methods. This paper mainly concentrates on these two control strategies (*id*-*iq* and *p*-*q*) with PI controller. Both methods are compared under distorted main voltage condition and it is found that *id*-*iq* control method achieve superior harmonic compensation performance. The *id*-*iq* control is based on a synchronous rotating frame derived from the mains voltages without the use of a phase-locked loop(PLL).By the id-iq control method many synchronization problems are avoided and a truly frequency-independent filter is achieved.

Using MATLAB Software Simulation is done in Simulink power system to analyze the performance of the (*id*-*iq*) control method.

1.2 Literature survey

1.2.1 Evolution of electric power theory

At the end of 19th century the development of alternating current (ac) transmission system was based on sinusoidal voltage at constant frequency generation. Sinusoidal voltage with constant frequency has made easier the design of transformer, machines and transmission lines. If the voltage will be non-sinusoidal then it will create many complications in the design of transformer, machine and transmission system. Conventional power theory was based on active, reactive and apparent-power definitions were sufficient for design and analysis of power systems. Nevertheless, some papers were published in the 1920s, showing the conventional concept of reactive and apparent power losses its usefulness in non-sinusoidal cases. Then, two important methods to power definitions under non sinusoidal condition were introduced by Budeanu in 1927 and Fryze in 1932.Fryze defined power in time domain whereas Budeanu did it in frequency domain.

Subsequently power electronics was introduced in 1960s, non-linear loads that consume non sinusoidal current have increased significantly. Today everywhere power electronics based equipment are used from domestic purpose to residential purpose. In 1976, Harshima, Inaba and Tsuboi presented, probably for the first time, the term "instantaneous reactive power" for a single phase circuit. That same year, Gyugyi and Strycula used the term "active ac filters" for the first time. A few years later, in 1981, Takahashi, Fujiwara, and Nabae published two papers giving the hint of the appearance of the instantaneous power theory or "p-q theory" [7].

1.2.2 Power quality

The PQ issue is defined as “any occurrence manifested in voltage, current, or frequency deviations that results in failure, damage, upset, or misoperation of end-use equipment.” Today, most of the power quality issues are related to the power electronics equipment which is used in commercial, domestic and industrial application. The applications of power electronics equipment for residential purposes-TVs, PCs, Refrigerator etc. For business purposes-copiers, printers etc. For industrial purposes-PLCs (Programmable logic controller), ASDs (Adjustable speed drive), rectifiers, inverters etc. Today almost all electrical equipment is based on power electronics which causes harmonics, inter-harmonics, notches and neutral currents. Transformers, motors, cables, interrupters, and capacitors (resonance) are some of the equipment which is affected by harmonics. Notches are produced mainly because of the converters, and they basically affect the electronic control devices. Neutral currents are produced in that equipment which uses switched-mode power supplies, such as printers, photocopiers, PCs, and any triplets' generator. Neutral current affects the neutral conductor temperature and transformer capability. Inter-harmonics are generated because of cyclo-converters, static frequency converters, arching devices and induction motors.

The presence of harmonics in the power lines results in greater power losses in distribution, and cause problem by interfering in communication systems and, sometime cause operation failures of electronic equipment, which are more and more critical because it consists of microelectronic control systems, which work under very low energy levels. Because of these problems, the power quality issues delivered to the end consumers are of great concern. International standards concerning electrical power quality (IEEE-519, IEC 61000, EN 50160, etc.) impose that electrical equipments should have limitation on the injection of harmonics in the system within a specified limit which has been satisfied by the international standards. Meanwhile, it is very important to solve the problems of harmonics caused by that equipment which is already installed.

The major causes of power quality problems are due to the wide spread application of nonlinear loads such as fluorescent lamps, saturable devices, static power electronic converters and arch furnaces. These equipments draw harmonic and reactive power components of current from the ac mains. In three phase system, they can cause unbalance and draw excessive neutral currents. The injected harmonic, reactive power burden, and excessive neutral currents cause low system efficiency and poor power factor, they also cause disturbance to other consumers. So far to come out of this problems shunt passive filters (consist of tuned LC filters and/or high pass filters) have been used to improve power factor and to reduce harmonics in power systems. But, shunt passive filters was not giving desired performance which leads to the development of "Active Power Filters (APF's)".

1.3 Motivation

Passive filters have been used as a solution to solve harmonic current problems, but passive filters having many disadvantages, namely: they can filter only the frequencies they were previously tuned for; their operation cannot be limited to a certain load; resonances can occur because of the interaction between the passive filters and other loads, with unpredictable results. To come out of these disadvantages, recent efforts are concentrated in the development of active filters. Control strategy (Bhim 1999 and Joao 2001) is the heart of Active Power Filters which are classified into shunt, series, and combination of both. Mainly active power filters can be classified into following configuration: 1) Shunt configuration in which the filter is connected in parallel with harmonic loads and 2) Series configuration in which the filter is connected in series with the loads. Taking the basic idea of harmonic cancellation, shunt active filter injects current to directly cancel polluting current while, series active filter compensate the voltage distortion caused by non-linear loads. In this paper we will focus on the control of shunt active power filters which has been widely used to improve power quality. The performance of active filter is dependent on two parts: current control system and harmonic reference generation.

The development of compensating signals in terms of voltages or currents is the important part of APF's control strategy which affects its ratings and transient as well as steady state performance. The control strategy which generates compensating signals is based on time-domain or frequency-domain. The frequency domain approach takes the use of the Fourier transform and its analysis, which leads to a large amount of calculations, making the control method much more complicated. In the time domain approach, traditional concepts of circuit analysis and algebraic transformations associated with changes of reference frames are used, simplifying the control task. One of the time domain control strategies is the instantaneous reactive power theory based *(p-q theory)* control strategy which proposed by Akagi et al. (Hirfumi 1983 and Hirfumi1984) and instantaneous active and reactive current component (*id-iq*) method. And since (Joao 2003) the p-q theory is based on the time domain, this theory is valid both for steady-state and transient operation, as well as for generic voltage and current waveforms, allowing the control of APF in the real-time; another advantage of this theory is the simplicity of its calculations, since only algebraic operations are required.

Voltage source converters use as the active power filter topologies, which have a DC capacitor voltage control as an energy storage device. This topology is shown in Figure-1, converts a dc voltage into an ac voltage by getting appropriate gating signal the power semiconductor switches. Although a single pulse for each half cycle can be applied to synthesize an ac voltage, for most of the application which shows dynamic performance, pulse width modulation (PWM) is the most commonly used today.

PWM techniques applied to a voltage source inverter consist of chopping the dc bus voltage to produce an ac voltage of an arbitrary waveform. With PWM techniques, the ac output of the filter can be controlled as a current or voltage source device.

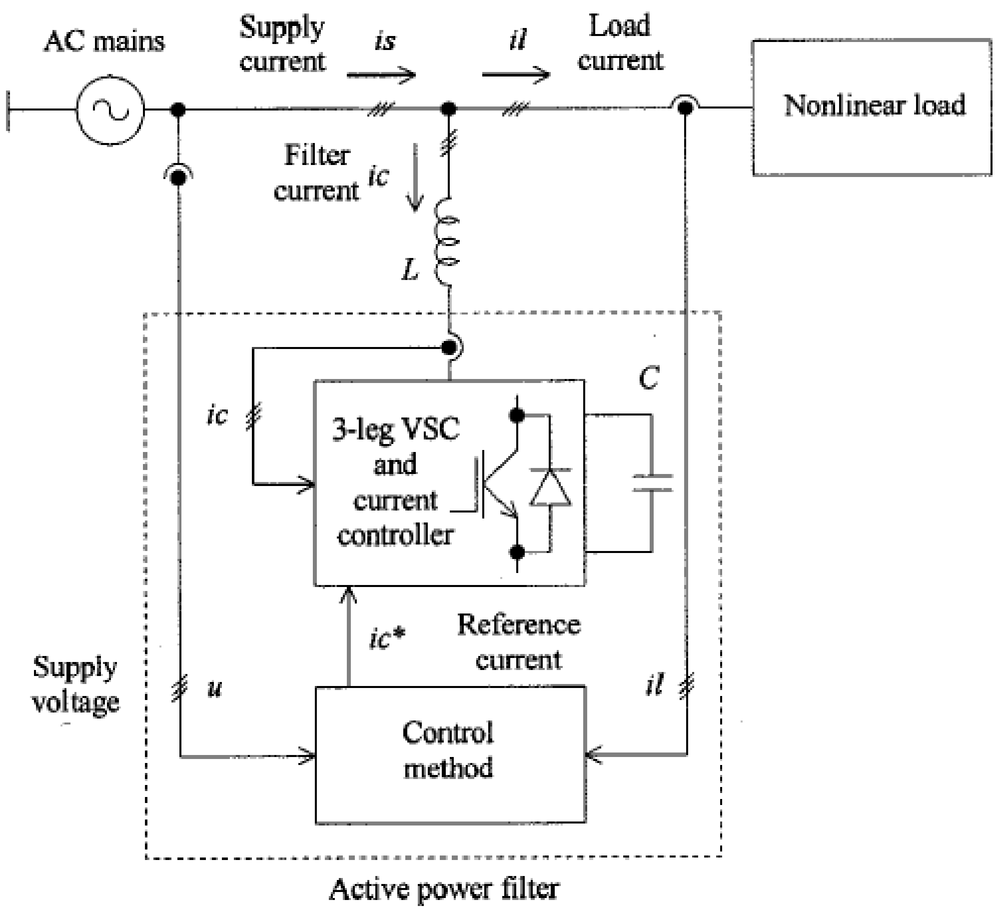

Fig. 1. Basic structure of a shunt AF with a three-leg VSC.

Voltage source converters are preferred over current source converter because it is higher in efficiency and lower initial cost than the current source converters [8, 9, and 10]. They can be readily expanded in parallel to increase their combined rating and their switching rate can be increased if they are carefully controlled so that their individual switching times do not coincide. Therefore, higher-order harmonics can be eliminated by using converters without increasing individual converter switching rates.

1.4 Objective

- In modern electric power systems there has been a sudden increase of single phase and three-phase non-linear loads. These non-linear loads employ solid state power conversion and draw non-sinusoidal currents from AC mains and cause harmonics and reactive power burden, and excessive neutral currents that result in pollution of power systems. Active power filters have been developed to overcome these problems.
- Shunt active filters based on current controlled PWM converters are seen as viable solution. The techniques that are used to generate desired compensating current are based on: Instantaneous active and reactive power *(p-q)* method and Instantaneous active and reactive current component (*id-iq*) method.
- In this paper PI controlled based shunt active power filter with DC capacitor voltage controlled is studied by using the two control methods *(p-q)* and (*id-iq*) method for the harmonics and reactive power compensation for a nonlinear load. It is found that under distorted voltage condition instantaneous active and reactive current component (*id-iq*) method is superior to instantaneous active and reactive power (p-q) method.

1.5 Thesis Outline

The body of this thesis consists of the following chapters including first chapter:

- In Chapter-2, Instantaneous active and reactive power *(p-q)* method is described.
- In chapter-3, Instantaneous active and reactive current component *(id-iq)* method is described.
- In Chapter-4, Comparison between two methods is done; conclusion and future work is presented.

Chapter-2

Introduction

Instantaneous Active and Reactive Power (p-q) method

2.1 Introduction

The p-q theory is based on the set of instantaneous power defined in time domain. No restrictions are imposed on the current or voltage waveform and it can be applied on the three phase system with or without neutral wire. The p-q theory first transformed three phase voltage and current waveforms from the a-b-c coordinates to α-β-0 coordinates and then defines instantaneous power on these coordinates. The p-q theory uses α-β-0 transformation or Clarke transformation which consists of a real matrix that transforms three phase components into α-β-0 stationary reference frames. In this method reference current is generated from the instantaneous active and reactive power of the non-linear load.

2.2 Instantaneous Active and Reactive Power (p-q) method

Akagi et al [11] proposed a theory based on instantaneous values in three phase power system with or without neutral wire, and is valid for steady-state or transient operations, as well as for generic voltage and current waveforms called as Instantaneous Power Theory or Active-Reactive (*p-q*) theory which consists of an algebraic transformation (Clarke transformation) of the three-phase voltages in the *a-b-c* coordinates to the *α-β-0* coordinates, followed by the calculation of the p-q theory instantaneous power components. The theory is based on a transformation from the phase reference system 1-2-3 to the 0-α-β system.

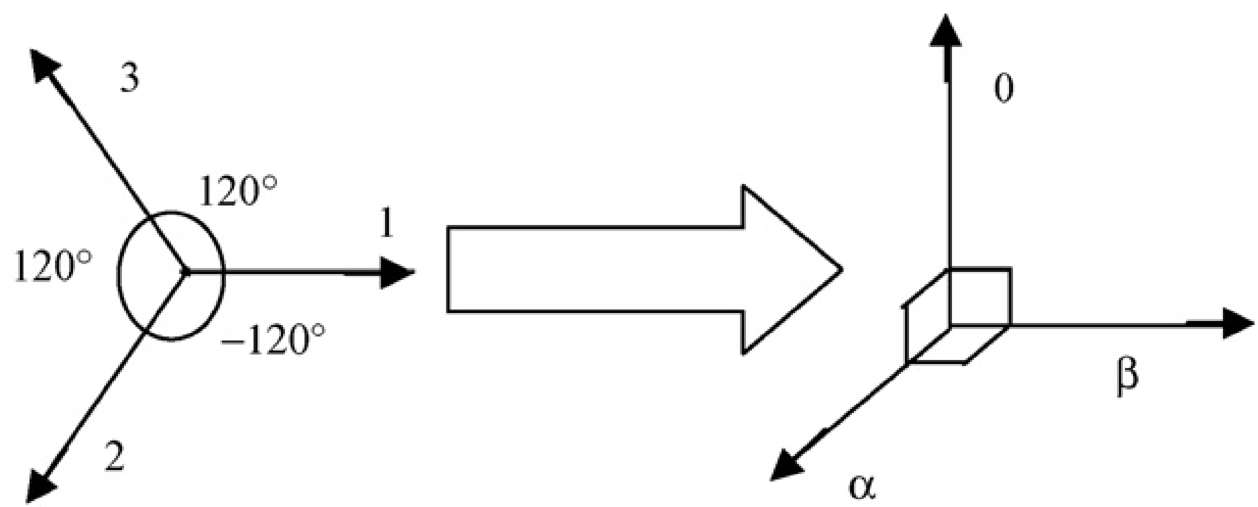

Fig. 2. $0\alpha\beta$ reference system.

The transformation matrix associated is as follows:

$$\begin{pmatrix} uo \\ u\alpha \\ u\beta \end{pmatrix} = \sqrt{2}/\sqrt{3} \begin{pmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{pmatrix} \begin{pmatrix} u1 \\ u2 \\ u3 \end{pmatrix} \quad (1)$$

$$\begin{pmatrix} io \\ i\alpha \\ i\beta \end{pmatrix} = \sqrt{2}/\sqrt{3} \begin{pmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{pmatrix} \begin{pmatrix} i1 \\ i2 \\ i3 \end{pmatrix} \quad (2)$$

$$\begin{pmatrix} i1 \\ i2 \\ i3 \end{pmatrix} = \sqrt{2}/\sqrt{3} \begin{pmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{pmatrix} \begin{pmatrix} io \\ i\alpha \\ i\beta \end{pmatrix} \quad (3)$$

Where v_1 v_2 v_3 and i_1 i_2 i_3 are phase voltage and currents.

From equation (1) and (2) it can be deduced that

$$i_N = i_1+i_2+i_3 = i_0\sqrt{3} \quad (4)$$

The different power terms are defined as follows:

$$\begin{pmatrix} po \\ p\alpha\beta \\ q\alpha\beta \end{pmatrix} = \begin{pmatrix} uo & 0 & 0 \\ 0 & u\alpha & u\beta \\ 0 & -u\beta & u\alpha \end{pmatrix} \begin{pmatrix} io \\ i\alpha \\ i\beta \end{pmatrix} \quad (5)$$

Where $po -$ is the zero sequence real instantaneous power

$p\alpha\beta$- is the $\alpha - \beta$ instantaneous real power

$q\alpha\beta$- is the $\alpha - \beta$instantaneous imaginary power

$$\begin{pmatrix} io \\ i\alpha \\ i\beta \end{pmatrix} = 1/uo\,u\alpha\beta^2 \begin{pmatrix} u\alpha\beta & 0 & 0 \\ 0 & uou\alpha & -uou\beta \\ 0 & uou\beta & uou\alpha \end{pmatrix} \begin{pmatrix} po \\ p\alpha\beta \\ q\alpha\beta \end{pmatrix} \quad (6)$$

Where $u\alpha\beta^2 = u\alpha^2+u\beta^2$

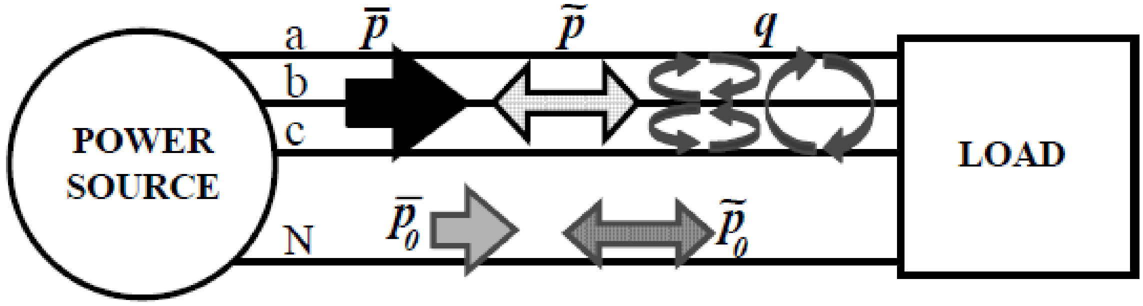

Fig.3. Power components of the p-q theory in *a*-*b*-*c* coordinate.

The active filter currents i_{ci} are obtained from the instantaneous active and reactive powers *pl* and ql of the nonlinear load. This is achieved by calculation of the main voltages u_i and the nonlinear load currents il_i in a stationary reference frame, that is in α-β component by (1) and (2).A null value is assumed for the zero component voltage . Due to the absence of neutral wire a null value is considered for the zero current components. So as a result equation will be:

$$\begin{pmatrix} u\alpha \\ u\beta \end{pmatrix} = \sqrt{2}/\sqrt{3} \begin{pmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{pmatrix} \begin{pmatrix} u1 \\ u2 \\ u3 \end{pmatrix} \tag{7}$$

$$\begin{pmatrix} il\alpha \\ il\beta \end{pmatrix} = \sqrt{2}/\sqrt{3} \begin{pmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{pmatrix} \begin{pmatrix} il1 \\ il2 \\ il3 \end{pmatrix} \tag{8}$$

Power compensated by active filter is given in fig.2.

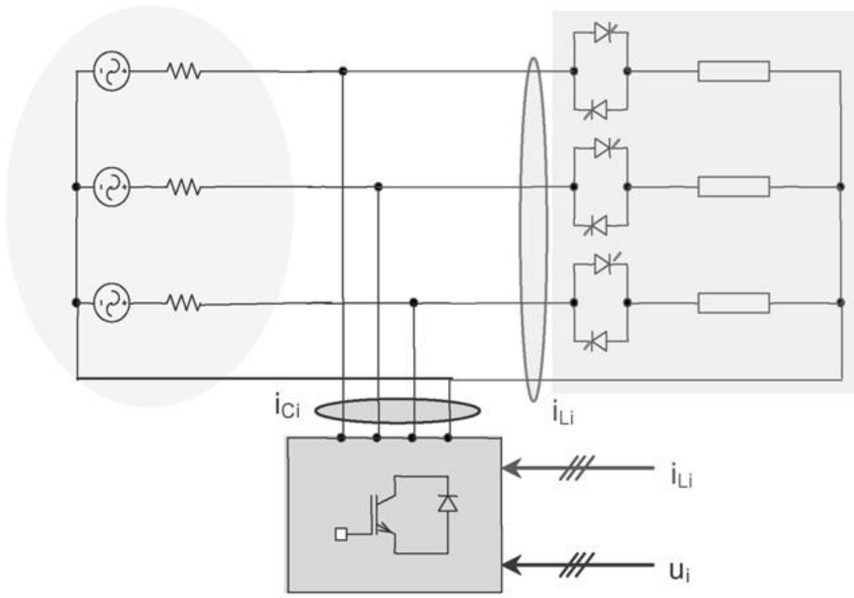

Fig.4. Power system compensated by an active power filter

The instantaneous active and reactive load powers *pl* and *ql* are given by eq. (5)

$$\begin{pmatrix} pl \\ ql \end{pmatrix} = \begin{pmatrix} u\alpha & u\beta \\ u\beta & -u\alpha \end{pmatrix} \begin{pmatrix} il\alpha \\ il\beta \end{pmatrix} \tag{9}$$

This equation can be decomposed into oscillatory and average terms:

$pl = \widetilde{pl} + Pl$ and $ql = \widetilde{ql} + Ql$

$\widetilde{pl}$ *and* $\widetilde{ql}$ are oscillatory terms and *Pl and Ql* are average terms

- Under balanced and sinusoidal condition the average power component can be related to the first harmonic current of the positive sequence il_{1h}^{+}.
- The oscillatory components represent all higher order harmonics including negative sequence of the first harmonic current, $il_{nh}^{+-} + il_{1h}^{-}$.

- Thus, the oscillatory power should be compensated by active power filter so that the average power components remain in the mains and by this way rating of the active filter can be minimized.

The average power component will be eliminated by using high pass filter (HPF). The power to be compensated which is given as follows:

$pc = -\widetilde{pl}$ and $qc = \widetilde{ql}$

The compensation current can be found by the matrix equation (9) as follows:

$$\begin{pmatrix} ic\alpha \\ ic\beta \end{pmatrix} = 1/u\alpha\beta^2 \begin{pmatrix} u\alpha & u\beta \\ u\beta & -u\alpha \end{pmatrix} \begin{pmatrix} pc \\ qc \end{pmatrix} \tag{10}$$

Where $u\alpha\beta^2 = u\alpha^2 + u\beta^2$

By transforming α-β component into three phase component i_1 i_2 i_3 by Clarke transformation by equation (3) we get

$$\begin{pmatrix} ic1 \\ ic2 \\ ic3 \end{pmatrix} = \sqrt{2}/\sqrt{3} \begin{pmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{pmatrix} \begin{pmatrix} ic\alpha \\ ic\beta \end{pmatrix} \tag{11}$$

Chapter-3

Introduction

Instantaneous Active and Reactive Current Component (id-iq) method

DC Voltage Regulator

Construction of PI Controller

3.1 Introduction

In this method reference currents are generated through the instantaneous active and reactive current component of the nonlinear load. In the same way three phase current component a-b-c will be transformed into α-β-0 components in stationary frames then it will be rotated by angle θ in synchronous reference frame based on the Park transformation. Further, control scheme is described how to regulate DC voltage across the DC bus capacitor and the construction of PI controller which is very important for the generation of the error signal for switching purpose. During distorted voltage condition it is found that this method is superior to instantaneous active and reactive power method.

3.2 Instantaneous Active and Reactive Current Component (id-iq) method

In this method the active filter currents i_{ci} can be obtained from the instantaneous active and reactive current components il_d and il_q of the nonlinear load. By using Park transformation on two phase α-β (by Clarke transformation) we will get (*d*-*q*) components. In Park transformation two phase α-β are fed to vector rotation block where it will be rotated over an angle θ to follow the frame *d*-*q* .The calculation to obtain these components (il_d ,il_q) follows the same method to the instantaneous active and reactive power(*p-q)* theory. In a same manner the mains voltages u_i and the polluted currents il_i in α-β components will be calculated as same way calculated in (7) and (8). However, the *d*-*q* load currents components are derived from a synchronous frame based on the Park transformation.

$$\begin{pmatrix} ild \\ ilq \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} il\alpha \\ il\beta \end{pmatrix} \tag{12}$$

$$\text{Where } \theta = \tan^{-1} \ (u\beta |\ u\alpha) \tag{13}$$

Where θ is a transformation angle

Under balanced and sinusoidal mains voltage condition θ is a uniformly increasing function of a time. The transformation angle 'θ' is sensible to all voltage harmonics and unbalanced voltages therefore, dθ/dt may not be constant over a mains period. Fig.5. shows the voltage and current space vectors in the stationary *(α-β)* and rotating frames (d-q)

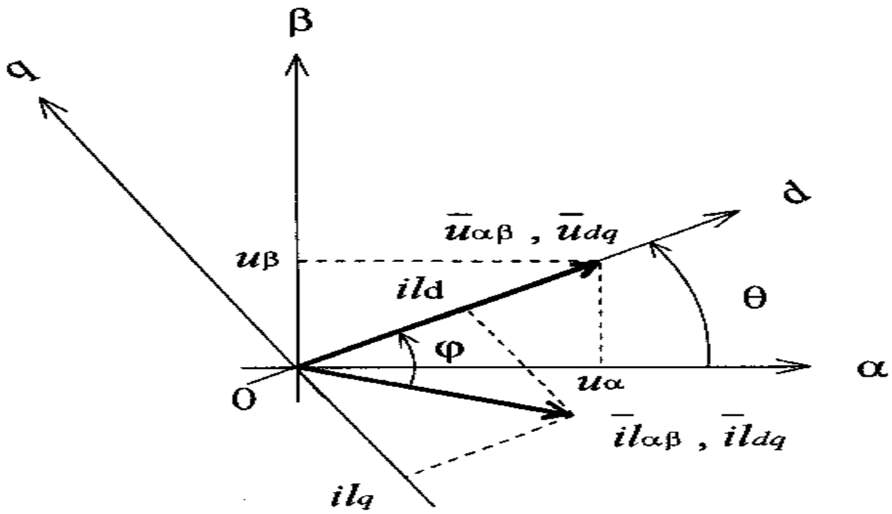

Fig. 5.Space vectors representation of voltage and current

By transformation (13) the direct voltage component is given as follows:

$u_d = |u_{\alpha\beta}| = |u_{dq}| = \sqrt{u\alpha^2 + u\beta^2}$ and the quadrature voltage component will be always null, $u_q=0$.So from the geometric relation equation (12) can be written as:

$$\begin{pmatrix} ild \\ ilq \end{pmatrix} = 1/\sqrt{u\alpha^2 + u\beta^2} \begin{pmatrix} u\alpha & u\beta \\ -u\beta & u\alpha \end{pmatrix} \begin{pmatrix} il\alpha \\ il\beta \end{pmatrix} \tag{14}$$

Instantaneous active and reactive load currents il_d and il_q can be decomposed into oscillatory and average terms as follows:

$il_d = \widetilde{ild} + Ild$ and $il_q = \widetilde{ilq} + Ilq$

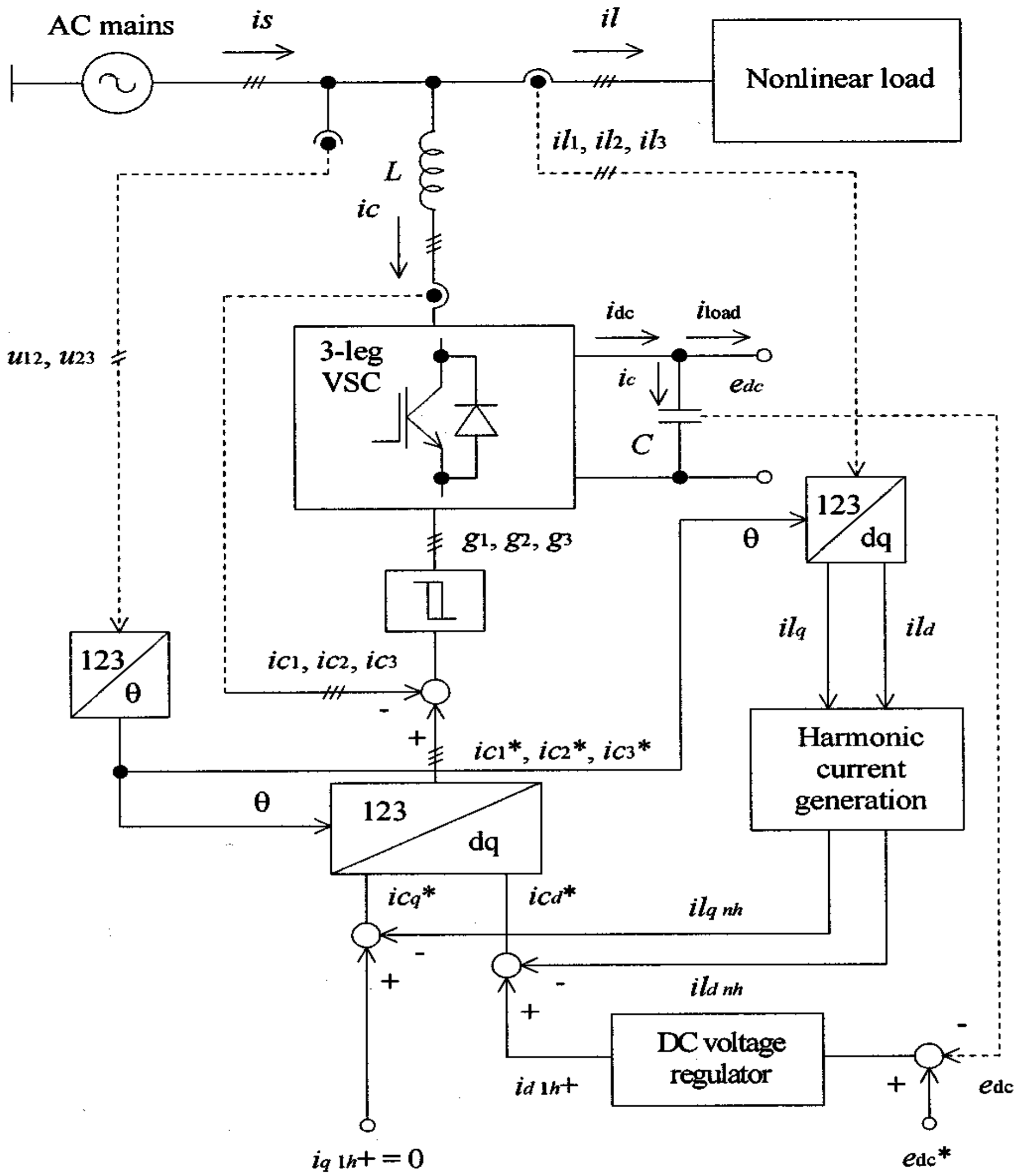

Fig.6. AF control system based on the i_d-i_q method

The first harmonic current of the positive sequence will be transformed to dc quantities, il_{d1h}^{+}, il_{q1h}^{+} .This components contain the average current components. And all the higher order harmonic current with the first harmonic of negative sequence of current are transformed to non dc quantities which will undergo frequency shift in the spectra which constitute the oscillatory components (il_{dnh}^{+-} + il_{d1h}^{-}), (il_{qnh}^{+-} + il_{q1h}^{-}). This assumption is valid for balanced and sinusoidal mains voltage conditions. The average current term will be eliminated by high pass filters (HPF).The currents which will be compensated can be obtained as $ic_d = -\widetilde{\imath l d}$ and $ic_q = -\widetilde{\imath l q}$.

Finally the compensation currents can be calculated as:

$$\begin{pmatrix} ic\alpha \\ ic\beta \end{pmatrix} = 1/\sqrt{u\alpha^2 + u\beta^2} \begin{pmatrix} u\alpha & -u\beta \\ u\beta & u\alpha \end{pmatrix} \begin{pmatrix} icd \\ icq \end{pmatrix} \quad (15)$$

The main advantage of this method is that angle 'θ' can be directly calculated from the mains voltages and thus make this frequency independent by avoiding the phase locked loop (PLL) in the control circuit. Furthermore, under unbalance and non-sinusoidal mains voltage conditions, a large number of synchronization problems can be avoided. Thus i_d-i_q achieves large frequency operating limit essentially by the cut-off frequency of voltage source inverter.

3.3 DC voltage regulator

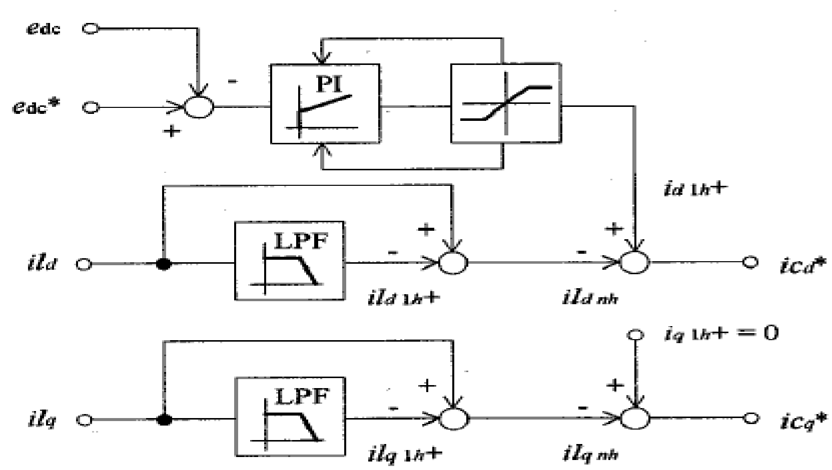

Fig.7. Harmonic current injection and DC voltage regulation circuit

The voltage regulation on the VSC dc side will be performed by a proportional-integral (PI) controller. The input to the PI controller is the capacitor voltage error C^{*}_{dc}-C_{dc}. On regulation of first harmonic active current of positive sequence i_{d1h}^{+} it is possible to control the active power flow in the VSI and thus the capacitor voltage C_{dc}. The reactive power flow may be controlled by the regulation of first harmonic quadrature current of positive sequence i_{q1h}^{+} .On the contrary the primary end of the active power filters is just the exclusion of the harmonics caused by non-linear loads hence the current i_{q1h}^{+} is always set to zero.

3.4 Construction Of PI Controller

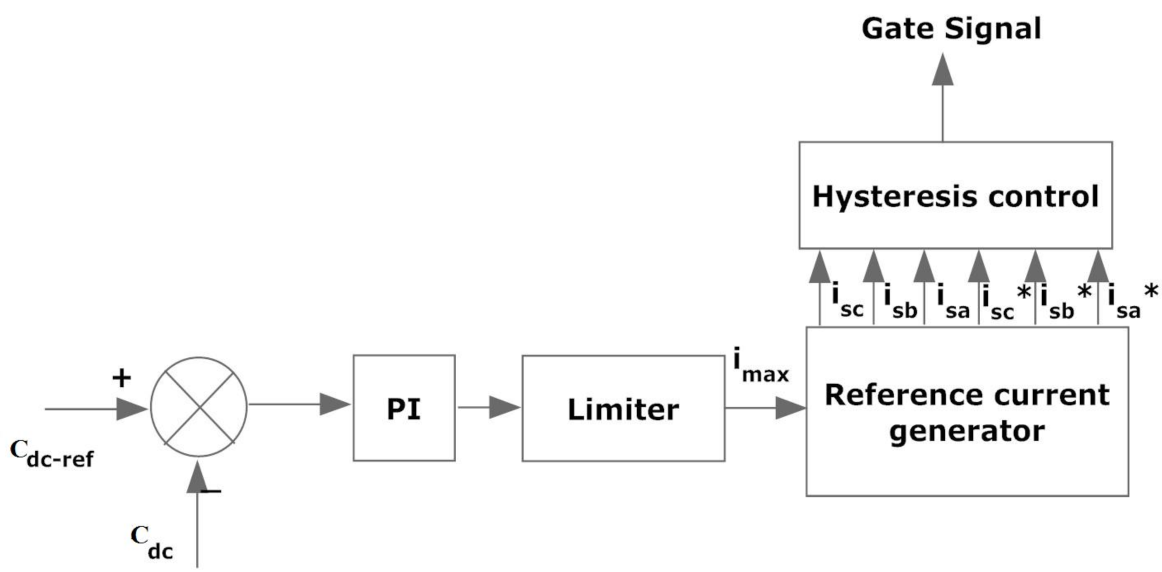

Fig.8. Block representation of PI controller

Fig.8 shows the schematic representation of the control circuit. The control scheme comprises of PI controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is studied by regulating the DC link voltage. The definite capacitor voltage will be compared with a set reference value. The error signal is then fed through a PI controller, which gives to zero steady error in tracking the reference current signal. The output of the PI controller is presumed as peak value of the supply current (I_{max}), which is composed of two components: (a) fundamental active power component of load current, and (b) loss component of APF; to preserve the average capacitor voltage to a constant value. Peak value of the current (I_{max}) so found, will be multiplied by the unit sine vectors in phase with the individual source voltages to obtain the reference compensating currents. These expected reference currents (I_{sa}*, I_{sb}*, I_{sc}*) and detected actual currents (I_{sa}, I_{sb}, I_{sc}) are equated at a hysteresis band, which delivers the error signal for the modulation technique. This error signal chooses the operation of the converter switches. In this current control circuit configuration the source/supply currents I_{sabc} are made to follow the sinusoidal reference current I_{abc}, within a fixed hysteretic band. The width of hysteresis window regulates the source current pattern, its harmonic spectrum and the switching frequency of the devices. The DC link capacitor voltage is always preserved constant during the operation of the converter. In this scheme, each phase of the converter is measured independently. To increase the current of a particular phase, the lower switch of the converter related with that particular phase is turned on while to decrease the current the upper switch of the corresponding converter phase is turned on. With this one can recognize, potential and viability of PI controller [12].

Chapter-4

Introduction

Comparison between the (p-q) and (id-iq) Control Methods

Simulation and Results

Conclusion

Future Work

4.1 Introduction

In this Chapter comparison is done between both the methods mathematically. And it is found that during balanced mains voltage condition both methods having same performance. During unbalanced mains voltage conditions instantaneous active and reactive current component method gives better performance than instantaneous active and reactive power method. Simulation is carried out in Simulink tool to analyze the performance of Instantaneous active and reactive current component method which is presented inn this Chapter. At the end of this chapter conclusion and how the analysis of this method can be verified in the future is presented.

4.2 Comparison Between the (p-q) and (id-iq) control Methods

The active and reactive power which is given by equation--- (9) in Chapter-2 is simply the inner and external product of the voltage and current space vectors. By the Park transformation we got the equation--- (12) in Chapter-3 which is a simple rotation of angle θ and is applied to both voltage and current space vectors, the power pl and ql will not be changed under park transformation. This realization is not applicable to all definitions of reactive power but it is applicable in this paper which is adopted [5].

As the Park transformation gives the confirmation of power will not be transformed during rotation because of that comparison because of that comparison between the two control methods is possible. This is observed by the active and reactive load powers. Therefore, the reference frame is chosen like that the u_q will be zero. The load power can be given as-

$$\begin{pmatrix} pl \\ ql \end{pmatrix} = u_d * \begin{pmatrix} ild \\ -ilq \end{pmatrix} \quad (16)$$

This equation can be decomposed into average and oscillatory components U_d and $\widetilde{ud}$ respectively. The average voltage component can be decomposed into the first harmonic voltage of positive sequence u_{1h}^{+} and all other higher order harmonic as well as unbalance (u_{nh}^{+-} +u_{1h}^{-}) are represented as a oscillatory components. So further equation--- (16) can be written as-

$$\begin{pmatrix} Pl \\ Ql \end{pmatrix} + \begin{pmatrix} \widetilde{pl} \\ \widetilde{ql} \end{pmatrix} = (U_d + \widetilde{ud}) * \left\{ \begin{pmatrix} Ild \\ -Ilq \end{pmatrix} + \begin{pmatrix} \widetilde{ild} \\ -\widetilde{ilq} \end{pmatrix} \right\} \quad (17)$$

The average value of the voltage and current will be resulted as average power components in the p-q method which will be eliminated by the HPF's. Filtering action will be performed on load current components in the id-iq method.

Here comparison is done by taking the supply mains voltage under balance and unbalanced condition. Under balanced mains voltage conditions the oscillatory voltage component $\widetilde{ud}$ will be null. So from the equation--- (17) the equivalent compensation power p_{c1} and q_{c1} for p-q method will be given by:

$$\begin{pmatrix} pc1 \\ qc1 \end{pmatrix} = -U_d * \begin{pmatrix} \widetilde{\imath l d} \\ -\widetilde{\imath l q} \end{pmatrix} \qquad (18)$$

And, for id-iq method equivalent compensation power will be given by:

$$\begin{pmatrix} pc2 \\ qc2 \end{pmatrix} = -U_d * \begin{pmatrix} \widetilde{\imath l d} \\ -\widetilde{\imath l q} \end{pmatrix} \qquad (19)$$

From equation--- (18) and (19) it is found that equivalent compensation power for both (p-q) and (id-iq) methods are equal under balanced voltage mains conditions.

Under unbalanced mains voltage conditions in which $\widetilde{ud}$ will be considered, equivalent compensation power in this condition will be given as:

$$\begin{pmatrix} pc1 \\ qc1 \end{pmatrix} + \begin{pmatrix} \widetilde{pl} \\ \widetilde{ql} \end{pmatrix} = -U_d * \begin{pmatrix} \widetilde{\imath l d} \\ -\widetilde{\imath l q} \end{pmatrix} - \widetilde{ud} * \left\{ \begin{pmatrix} Ild \\ -Ilq \end{pmatrix} + \begin{pmatrix} \widetilde{\imath l d} \\ -\widetilde{\imath l q} \end{pmatrix} \right\} \qquad (20)$$

$$\begin{pmatrix} pc2 \\ qc2 \end{pmatrix} = -(U_d + \widetilde{ud}) * \begin{pmatrix} \widetilde{\imath l d} \\ -\widetilde{\imath l q} \end{pmatrix} \qquad (21)$$

Therefore, the difference between the two control methods can be expressed as:

$$\begin{pmatrix} pc1 \\ qc1 \end{pmatrix} - \begin{pmatrix} pc2 \\ qc2 \end{pmatrix} = -\widetilde{ud} \begin{pmatrix} Ild \\ -Ilq \end{pmatrix} \quad (22)$$

This equation helps to understand the difference in the performance of the AF's under non ideal mains voltage conditions. It is to be found that under balanced mains voltage conditions both methods give the same performance. Under unbalanced mains voltage conditions the oscillatory and average power are disturbed by voltage harmonics and unbalanced voltage conditions, so total harmonic elimination cannot be achieved by any of methods. So, at the end it is found that under unbalanced voltage condition (id-iq) method gives the better performance than (p-q) method.

4.3 Simulation and Results

In this paper 3 phase 3 wire shunt active power filter responses are presented in steady state and transient state condition. During this simulation AHPF (alternative high pass filter) is used in Butterworth filter with cut-off frequency f_c = f/2. Simulation which is presented here are for different voltage condition namely balanced and unbalanced voltage condition.

Table-1

System Parameters

AC Voltage Source	V_s	220 v rms
Fundamental frequency	f	50 Hz
Source inductance	L_s	0.1 mH
Load	RL	15 Ohm / 60 mH
DC bus capacitor	C_{dc}	1000 uF
Filter inductor	L_f	1.0 mH

Simulation is carried out with PI controller for instantaneous active and reactive current component (id-iq) method. The application is developed in a Matlab / Simulink / Simpower tool to prove the result. The circuit parameters are given in table-1 [14]. Presented simulation is carried out with only AHPF of 2nd order with cut off frequency $f_c = f/2$, and it is assumed that currents are independent of mains voltages and there is no ripple on the rectifier dc current. Active Power filter has been analyze under several mains voltage conditions by using different kind of filters like HPF (high pass filter) with 2nd order, HPF with 4th order and AHPF with 4th order. In all those, AHPF shows good performance and it is very easy to obtain with LPF (low pass filter) of same order and cut-off frequency. The total THD is found for 3ph 3w Balanced mains voltage (id-iq) with PI controller is 3.13% and for 3ph 3w Unbalanced mains voltage (id-iq) with PI controller is 3.75%.

3-ph 3-w balanced mains voltage (id-iq) with PI controller

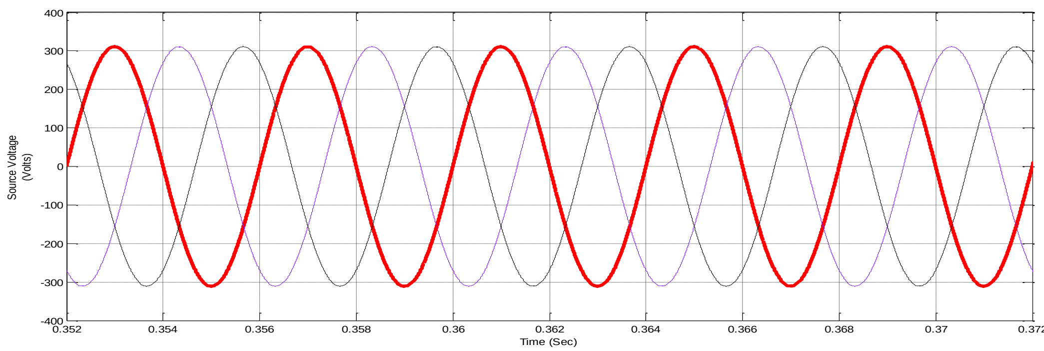

Fig.9.a. Source Voltage (Volts) Vs. Time (Sec)

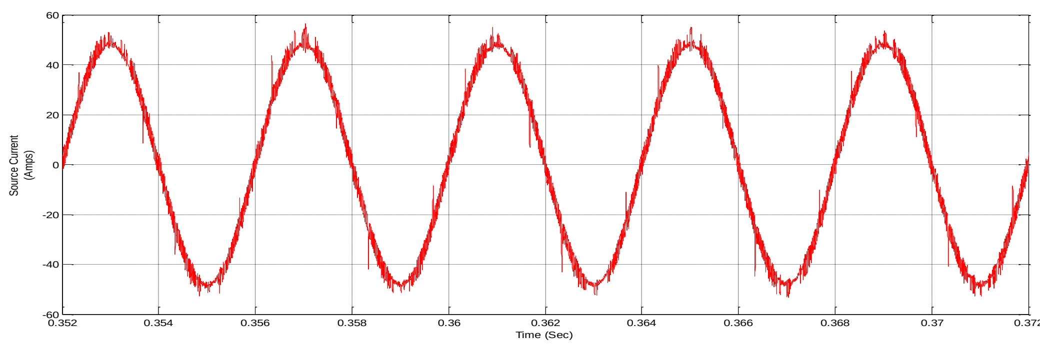

Fig.9.b. Source Current (Amps) Vs. Time (Sec)

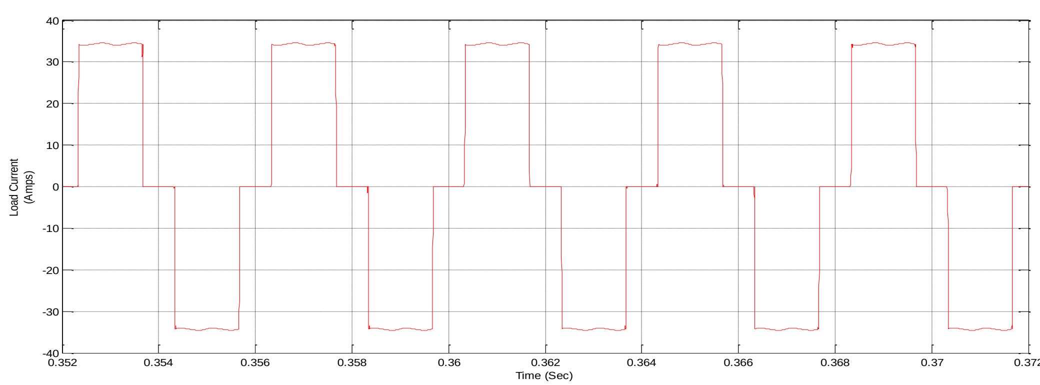

Fig.9.c. Load Current (Amps) Vs. Time (Sec)

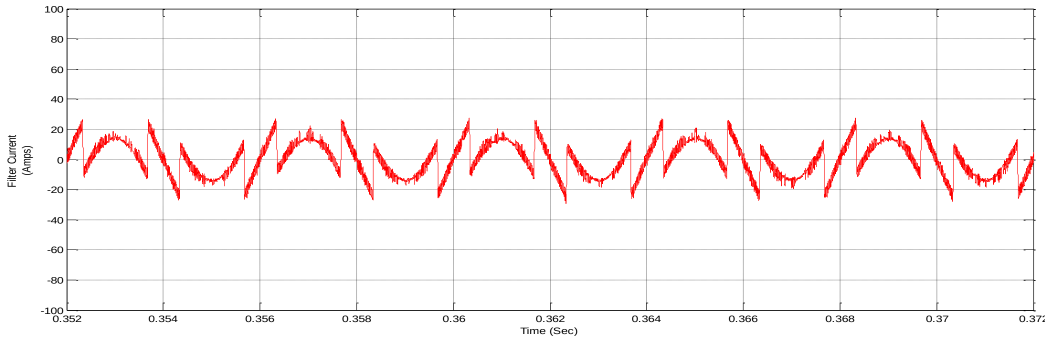

Fig.9.d. Filter Current (Amps) Vs. Time (Sec)

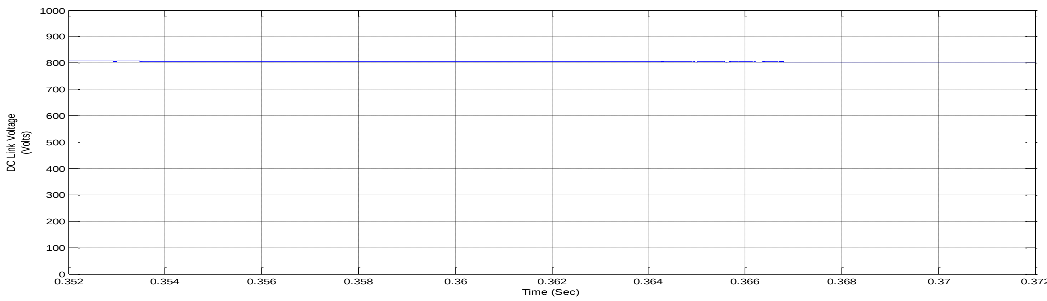

Fig.9.e. DC link Voltage (Volts) Vs. Time (Sec)

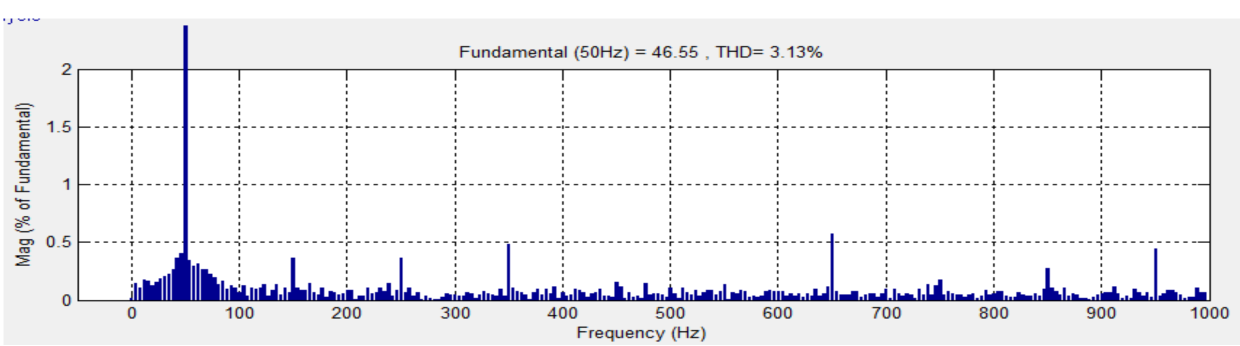

Fig.9.f. Magnitude Vs. Frequency (Hz)

Fig.9. 3-ph 3-w SAF using I_d-I_q method under balanced mains voltage condition

3-ph 3-w unbalanced mains voltage (id-iq) with PI controller

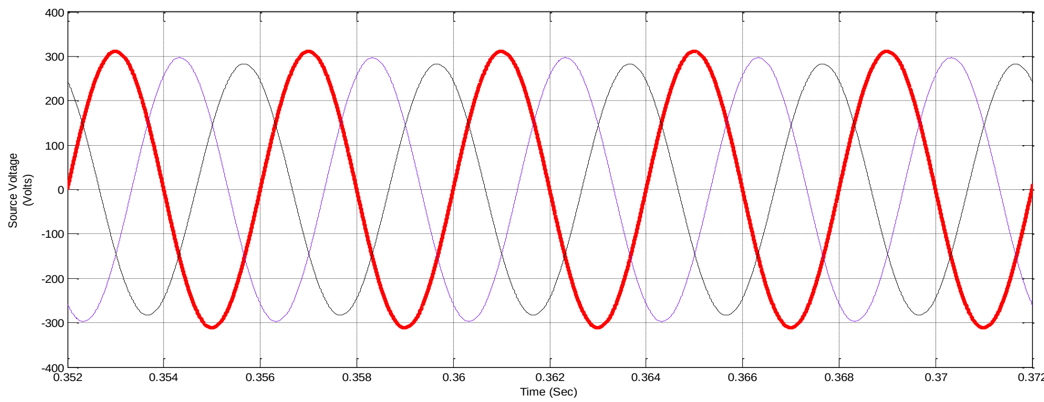

Fig.10.a. Source Voltage (Volts) Vs. Time (Sec)

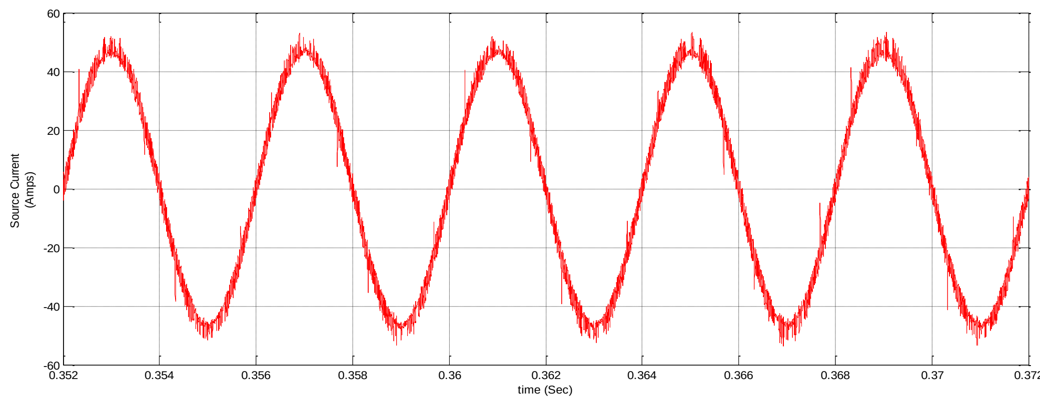

Fig.10.b. Source Current (Amps) Vs. Time (Sec)

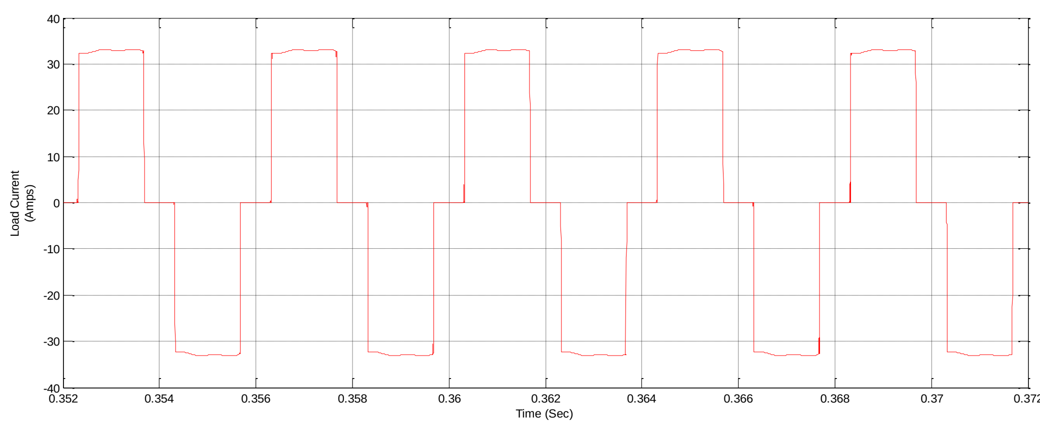

Fig.10.c. Load Current (Amps) Vs. Time (Sec)

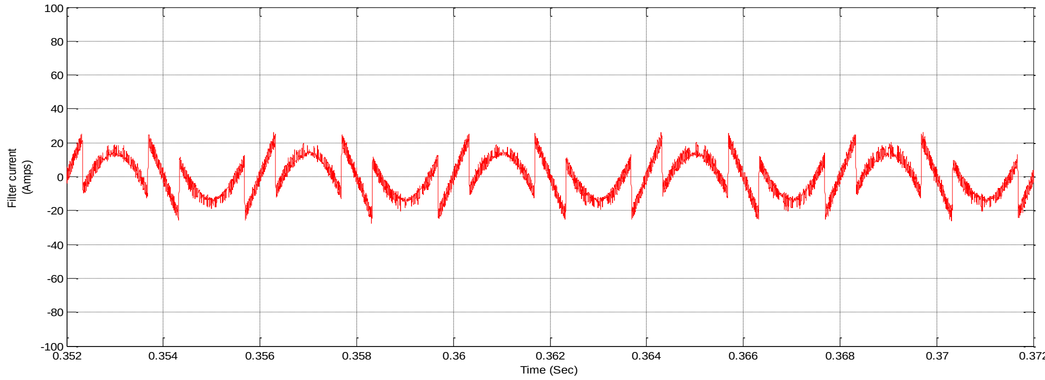

Fig.10.d. Filter Current (Amps) Vs. Time (Sec)

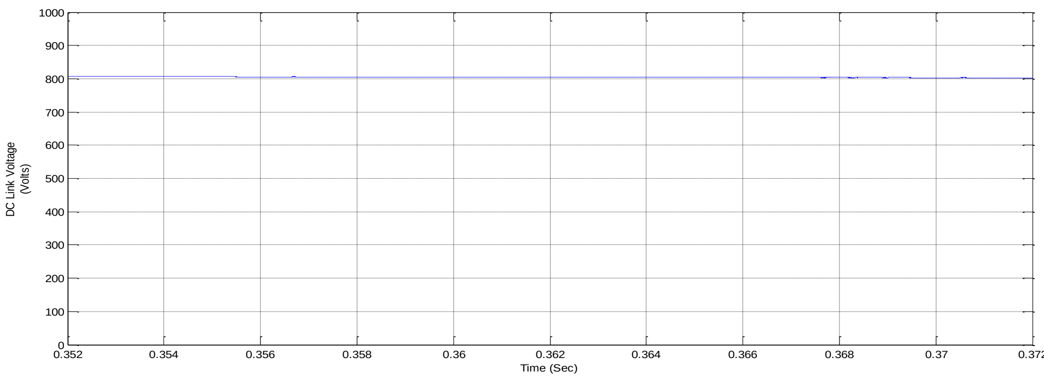

Fig.10.e. DC link Voltage (Volts) Vs. Time (Sec)

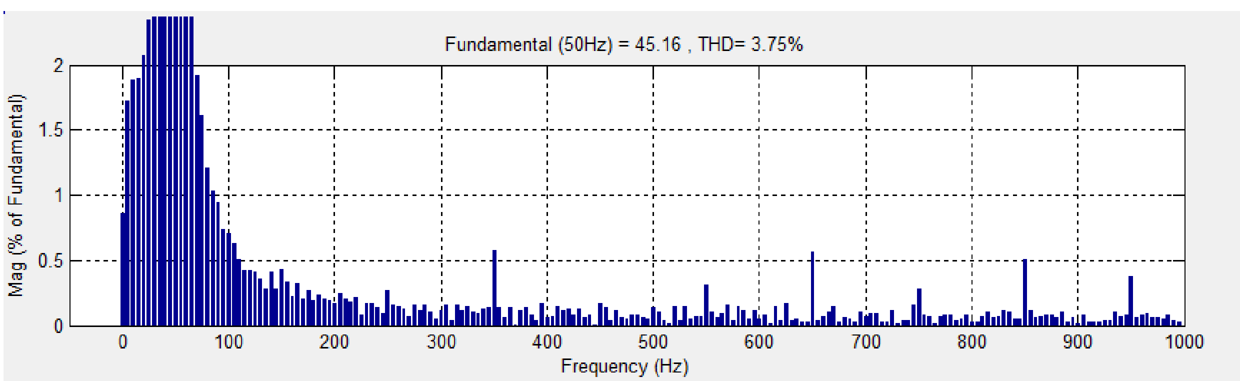

Fig.10.f. Magnitude Vs. Frequency (Hz)

Fig.10. 3-ph 3-w SAF using I_d-I_q method under unbalanced mains voltage condition

4.4 Conclusion

In this paper an Active filter based on the instantaneous active and reactive current component I_d-I_q method is studied. A comparison is done between two methods to realize the instantaneous active and reactive power method and instantaneous active and reactive current component method. Current harmonics consist of positive and negative sequence including the fundamental current of negative sequence can be compensated. Therefore, it acts as a harmonic and unbalance current compensator. Under balanced main voltage condition the equivalent power compensation by both the methods are equal. Under unbalanced main voltage condition neither of the two methods are able to compensate current harmonics accurately not even instantaneous active and reactive current component method. The active filter compensation currents are generated by a three-leg VSC with hysteresis current control. In I_d-I_q method angle θ can be directly calculated from the main voltages and thus enables the method to be frequency independent. Thus large numbers of synchronization problems with un-balanced voltages can be avoided. The I_d-I_q control method which is studied in this paper allows the operation of the AF in variable frequency conditions without adjustment.

4.5 Future Work

Experimental analysis can be done on Shunt Active Power Filter based on instantaneous active and reactive current component (I_d-I_q) method by developing prototype model in the laboratory to verify the simulation result based on (I_d-I_q) method with PI controller.

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