A METHODOLOGY FOR POWER QUALITY IMPROVEMENT USING SYNCHRONOUS DETECTION AND DIGITAL CONTROL OF SHUNT ACTIVE POWER FILTER

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ABSTRACT

The growth of population is increasing day by day due to this the requirement of electricity is also increased. Due to this in the recent decades the world has seen an expansion in the used of nonlinear loads such as power electronics based loads, switch mode power supplies; nonlinear characteristics load etc. but used of these loads draw a non-sinusoidal current from the source and distribute them throughout the system. As a results gives the power quality is degrades. Therefore, the recent effort developed for solving such problems active power filter is used. Active power filter is used to solve the voltage and current harmonic problem and also for reactive power compensation. Basically there are two types of active power filter: series type and shunt type. This paper deal with the control of shunt active power filter (SAPF) from two different aspects Synchronous Detection Method (SDM) and digital control based on instantaneous power theory (p-q theory). Simulation result are demonstrated the application of these two method to the control of shunt active power filter using MATLAB SIMULINK. Moreover this paper also proves the digital control method improves the power quality better than the synchronous detection method because it provides individual harmonic detection and its mitigation along with separation of zero sequence components.

KEYWORDS: *Power Quality, Shunt Active Power filter, Synchronous Detection Method, digital control, p-q theory.*

I. INTRODUCTION

Power quality means to maintain the purely sinusoidal current waveforms forms equal to purely sinusoidal voltage waveforms. We know that the main aim of power generating company supplies good quality of electric supply to the end consumers [1]. The electrical energy is most important element in society and industry but wide spread application of the power electronic based load such as power converters ,adjustable speed drives, fast switching devices, rectifier equipment used in telecommunication networks etc. This static devices are used for the increasing the efficiency of overall power system and controllability over the devices used in power stations. But using such power electronics devices occurs the problems as voltage flicker, voltage variation, voltage sag, voltage swell, voltage unbalancing, single phasing, reactive power, voltage interruption etc results the voltage and current harmonic present in the end users and overall power system[1].
The percent of voltage and current harmonic results the problems in power lines such as power losses in distribution system, failure of protection devices, electromagnetic interference in communication system, over heating of generator and transformer etc. and also quality of power supply to the end consumers is not suitable format. For reducing the harmonic distortion problem we uses a passive filter but passive filter have been many disadvantages as it only filters the frequency has previously tuned for, for the certain load operation cannot be limited, resonance occurs at interaction between passive filter and their load and gives unpredictable result[1]. Because of such disadvantage occurs using passive filter recently developed the active power filter. Active power filter is special equipment

uses a power electronic converter for compensating the voltage and current harmonics. Basically there are two types of active power filter: namely shunt type and secondly series type [2].

In this paper detail discussion about the working principle of shunt active power filter and control of shunt active power filter for compensation of harmonic distortion with two different aspects are shown. Firstly the controls of shunt active power filter (SAPF) using Synchronous detection method (SDM) and secondly the control using digital control based on instantaneous power theory (p-q theory) method was discussed and simulation model prepared for both controlling methods [2]. In this paper we get the simulation results and by comparing the results of two method it proves that power quality improvement using p-q theory gives better result than synchronous detection method.

II. PRINCIPLE OF OPERATION SAPF

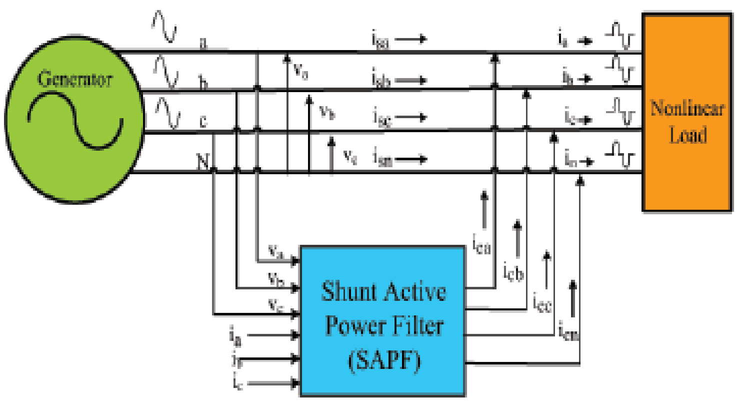

Figure 1. Operation of Three Phase Shunt Active Power Filter

The main principle of shunt active power filter is to inject a compensating current in the line based on nonlinear load current. Figure 1 above shows a electrical scheme of compensating principle of three phase shunt active power filter [2]. The source is a three phase star connected voltage source where the phase voltages are v_a, v_b and v_c as seen in figure. While the i_a, i_b and i_c are the non linear load current produces by the nonlinear loads which is connected to the each phases of the source. When shunt active filter block is not operating the current flowing through the lines it self's as a nonlinear load current as i_{sa}, i_{sb} and i_{sc}. But when shunt active power filter is operating it inject a compensating current in the line as i_{ca}, i_{cb} and i_{cc} which is in phase with the line current but phase opposition to the harmonic current [3]. By using this compensating current harmonic present in the line is reduce and power factor is improve.

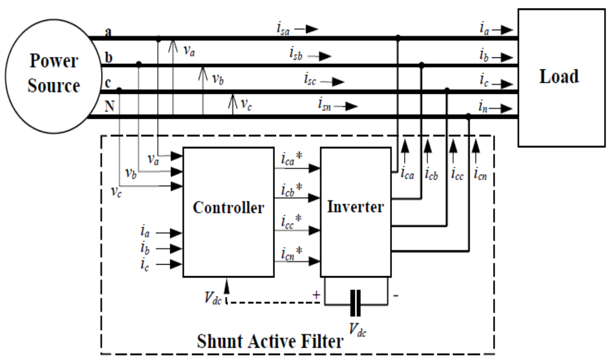

Figure 2. Shunt active filter in a three-phase power system

Basically the shunt active filter divided into two blocks which is shown in figure 2 above. First block is a control block i.e. controller it generates a reference current as i_{ca}*, i_{cb}* , i_{cc}*, i_{cn}* from the measured value of phase voltages v_a, v_b and v_c and nonlinear load currents i_a, i_b and i_c. Second block is a IGBT based voltage source inverter with only a single capacitor on DC side i.e. Active power filter does not requirement of any internal power supply. A dc capacitor is usually work as a source of power in voltage source inverter. This second block means voltage source inverter calculates the compensating currents as i_{ca}, i_{cb} , i_{cc},i_{cn} from reference current i_{ca}*, i_{cb}* , i_{cc}*, i_{cn}* which is calculated from controller block. In this paper discuss the two methods of controlling the shunt active power filter as synchronous detection method and p-q theory [3].

III. CONTROL METHODS FOR ACTIVE FILTERS

There are varies method available for controlling the active power filter for calculating the compensating current for harmonic reduction, in determination of filter rate and steady state response of the filter performance [4]. In this paper out of many methods two methods are used for controlling of shunt active power filter as SDM and P-Q theory.

3.1. Control using Synchronous Detection Method

Synchronous detection method or theory works under both balanced and unbalanced condition because in this method the compensating current is calculating using per phase voltage magnitude. In this method it is assumed that after compensation the three phase main current is balanced and also it tries to determine the required amplitude of main current [4]. Synchronous detection method also called as an equal current distribution method because in this method three phase compensating current is calculated using per phase magnitude. In this method firstly calculating the instantaneous real power using instantaneous value of supply voltage as $v_a(t)$, $v_b(t)$ and $v_c(t)$ and corresponding instantaneous value of non linear load current as $i_a(t)$, $i_b(t)$ and $i_c(t)$ measured from line [4]. After calculating this real average power it is divided equally among the three phases. The real power p(t) is calculated from equation below,

$$P(t) = [v_a(t)\ v_b(t)\ v_c(t)]\ [\ i_a(t)\ i_b(t)\ i_c(t)\ ]' \qquad (1)$$

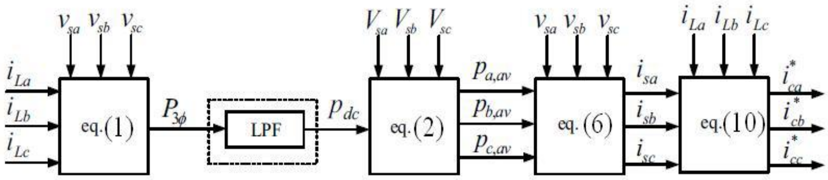

Figure 3. The block diagram of the synchronous detection calculation

After calculating the real power p(t) then calculate the average power p_{dc} . This average power p_{dc} is calculating by applying the real power p(t) to the low pass filter as seen in figure 3 above. The main function of low pass filter is to limit the greater frequency than specified cut-off frequency [4]. After calculating power this real power is split into three phases,

$$P_a = (P_{dc}\ v_{am})/(v_{am} + v_{bm} + v_{cm}) \qquad (2)$$

$$P_b = (P_{dc}\ v_{bm})/(v_{am} + v_{bm} + v_{cm}) \qquad (3)$$

$$P_c = (P_{dc}\ v_{cm})/(v_{am} + v_{bm} + v_{cm}) \qquad (4)$$

Where, v_{am}, v_{bm} and v_{cm} are the amplitude of the instantaneous value of supply voltages $v_a(t)$, $v_b(t)$ and $v_c(t)$ respectively. By using this power the balanced per phase line current is determined as follows,

$$i_{sa} = (2v_aP_a)/v^2_{am} \qquad (5)$$

$$i_{sb} = (2v_bP_b)/v^2_{bm} \qquad (6)$$

$$i_{sc} = (2v_cP_c)/v^2_{cm} \qquad (7)$$

After calculating the balanced per phase line current the compensation reference current is determine. This is calculate by subtracting the non linear load current i_a, i_b and i_c from positive sequence current i_{sa},i_{sb} and i_{sc} as follows,

$$I^*_{ca} = i_{sa} - i_a \quad (8)$$

$$I^*_{cb} = i_{sb} - i_b \quad (9)$$

$$I^*_{cc} = i_{sb} - i_c \quad (10)$$

The compensation per phase reference currents i^*_{ca}, i^*_{cb} and i^*_{cc} is given to the voltage source inverter it gives exact replica of these current i.e. i_{ca}, i_{cb} and i_{cc}. The voltage source inverter gives the compensating current which is of equal in magnitude of line current and phase opposition of harmonic current [4]. Since the PWM based voltage source inverter is model as a current amplifier with unity gain.

3.2. Control using Digital Control Method

In this section discus the main principle of p-q theory i.e. digital control method and application of p-q theory on shunt active power filter [5]. This method gives compensation current for harmonic reduction and power factor improvement.

3.2.1. Principle of p-q theory

This theory is based on time domain and uses an algebraic transformation for calculating the compensating current. In 1983, *Akagi et al.* have proposed the generalize theory based on instantaneous reactive power theory also known as p-q theory [5]. In this method we have to calculate instantaneous valves of power by using transforms the some quantity of instantaneous values of voltage and current. This method based on very simplified calculation exception done in this method is that there is need to separate the mean and alternating quantity of power components. The p-q theory consists of an algebraic transformation i.e. Clarke transformation in which the three phase voltages and currents in a-b-c coordinate transform into α-β-0 coordinate. This transformation is done for calculation of p-q theory instantaneous value of active and reactive power. The real and reactive power is calculate as follows,

$$[v_\alpha\ v_\beta\ v_0] = A^*[v_a\ v_b\ v_c]' \quad (11)$$

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$[\ i_0\ i_\alpha\ i_\beta\ ] = A^*[\ i_a\ i_b\ i_c\ ]' \quad (12)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Where,

$$A = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}$$

is a Clarke transformation matrix and

$p_0 = v_0\, i_0$ instantaneous zero sequence power (13)

$p = v_\alpha\, i_\alpha + v_\beta\, i_\beta$ instantaneous real power (14)

$q = v_\alpha\, i_\beta - v_\beta\, i_\alpha$ instantaneous reactive power (15)

The power component p and q are related to the α-β of the voltage and current. This component are written in matrix forms as,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (16)$$

In p-q theory considering the all power component i.e. the mean and alternating value of power component. Figure 6 below shows the power component of the p-q theory [5]. The physical meaning of the power component for an electrical system represented in a-b-c coordinates as follows,

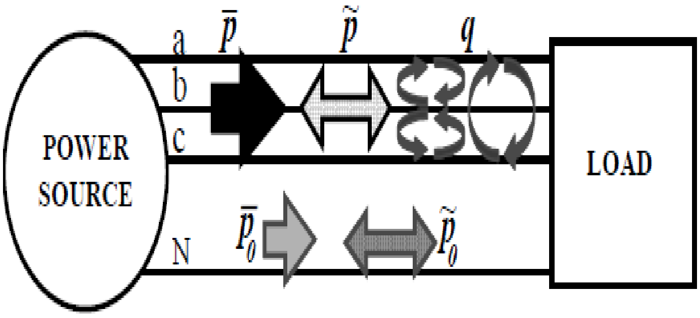

Figure 4. Power components of the p-q theory

$\overline{P_0}$ = It is the mean value of instantaneous zero sequence power. It transferred the power from power supply to load through the zero sequence components of voltage and current.

$\widetilde{P_0}$ = It is the alternating value of instantaneous zero sequence power. It exchanged the power between power supply and load through zero sequence components of voltage and current.

$\overline{P}$ = it is the mean value of instantaneous real power. It corresponds to the energy per time unity which is transferred from the power supply to the load in balanced way.

$\tilde{p}$ = It is the alternating value of instantaneous real power. It corresponds to the energy per time unity which exchanged between power supply and the load.

q = It is the instantaneous reactive power. It corresponds to the power exchange between the phases of load. This quantity does not any transferred and exchanges the power between power supply and load but it responsible for undesirable current which is circulates between the phases.

3.2.2.p-q theory applied to SAPF

The figure below shows the p-q theory applied to the shunt active power filter and also shows the desirable power components in p-q theory.

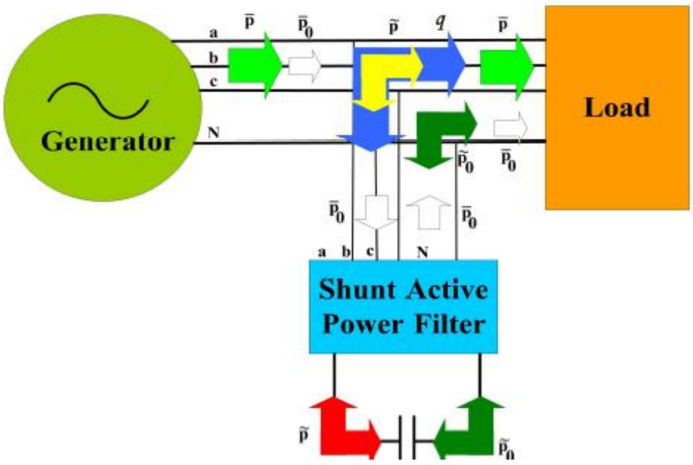

Figure 5. System power components in a-b-c coordinate

The p-q theory obtains the power component out of this only p is a desirable quantity because it corresponds to energy transferred from power supply to the load. All other powers components obtain from the p-q theory are less desirable and it is compensated by shunt active power filter. The Watanabe et al. proposed a convenient way to compensate the p_0 without the any need of power supply to the shunt active power filter. Using this watanabe et al [5] theory all the power components are compensated and deliver from source to the load through the active power filter. Hence the active power filter compensate the all power component obtain form p-q theory through zero coordinates in balanced way. This means that the energy which is previously transferred from the source to the load through zero sequence component of current and voltage but now is delivering to the load in balanced way from the source phases [5].

The figure shows that the dc capacitor is connected to the active power filter to compensated $\tilde{P}_0$ and $\tilde{P}$ power component of p-q theory. This alternating quantity of power components are stored in one movement and later movement it delivered to load. The remaining power component is instantaneous reactive power i.e. the conventional reactive power is compensated without the participation of dc capacitor. This means that the size of dc capacitor is not depends up on the reactive power to be compensated. Because of this the size of capacitor is reduce and also cost is less. So in three phase system the three phase supply voltage and current are sinusoidal and current is in phase with the supply voltage.

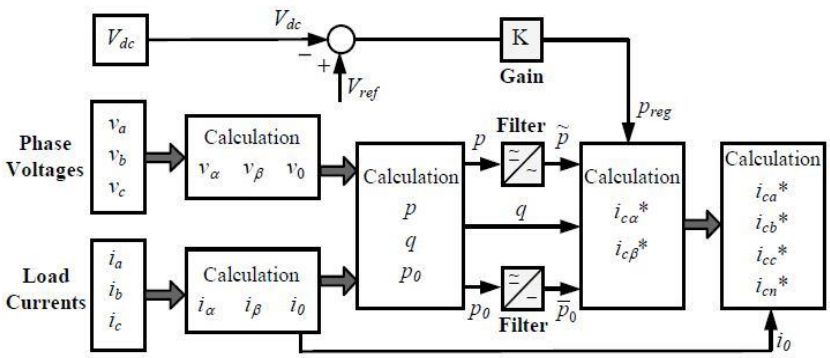

Figure 6. Control diagram for SHAF using p-q control theory

The figure above shows the control diagram for shunt active power filter using p-q theory. After calculating the power component using p-q theory the next important component is high pass filter for calculating the reference compensating current. The high pass filter used with cut off frequency 50Hz which takes the input as instantaneous real power from equation 13, 14, 15 and filters all the frequency of power greater than the fundamental power. The output waveforms of the high pass filter containing harmonic which is of in current form which is of alpha and beta [6]. To calculating compensation reference current $i_{c\alpha}$* and $i_{c\beta}$* using power component as follows,

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{v_\alpha^2+v_\beta^2}\begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix}\begin{bmatrix} p_z \\ q_z \end{bmatrix} \qquad (17)$$

Where, P_z and q_z are the power component which is compensated. Since the zero sequence component power must be compensated [6]. The compensation reference current in zero sequence is equal to the zero sequence current i_0 itself i.e. $i^*_{c0} = i_0$

$$P_z = \tilde{P} - \Delta\bar{P} \qquad (18)$$

$$\Delta\bar{P} = \bar{P}_0 \qquad (19)$$

$$q_z = q = \bar{q} + \tilde{q} \qquad (20)$$

After calculating the compensation reference current, the compensation current is calculated by using the inverse Clarke transformation is applied as follows,

$$\begin{bmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i^*_0 \\ i^*_\alpha \\ i^*_\beta \end{bmatrix} \qquad (21)$$

$$i_{cn} = -(i^*_{ca} + i^*_{cb} + i^*_{cc}) \qquad (22)$$

After calculating the compensating reference current, it gives to the voltage source inverter. The voltage source inverter determine exact replica of this current which is of equal magnitude of line current and opposite magnitude of harmonic current [6]. The output of PWM voltage source inverter injected into the line it gives the source current in phase with the voltage and harmonic current is reduces i.e. power quality is improve [7].

IV. SIMULATION MODEL

In this paper implement the model for shunt active power filter for two methods first is synchronous detection method and digital control method.

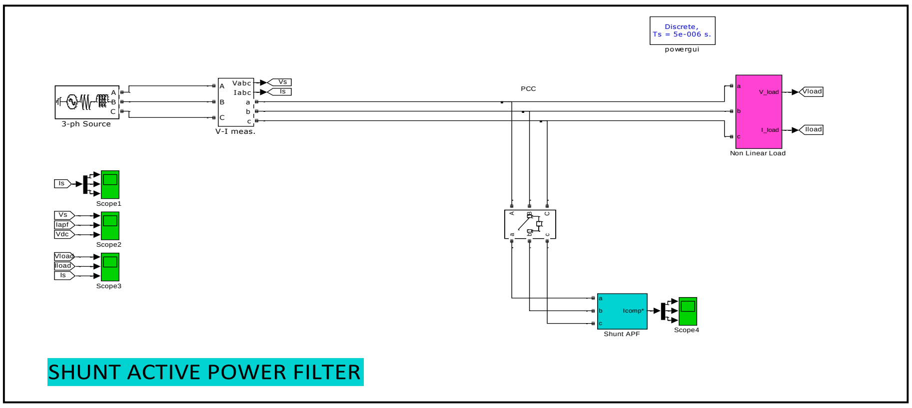

Figure 7. Simulation model developed for SAPF

The figure 7 shows simulation model developed for shunt active power filter. In this scheme taking the three phase source with star connected supplies the power to non linear load through shunt active filter [7]. The model developed for three phase non linear load generation is shown in figure 8 below.

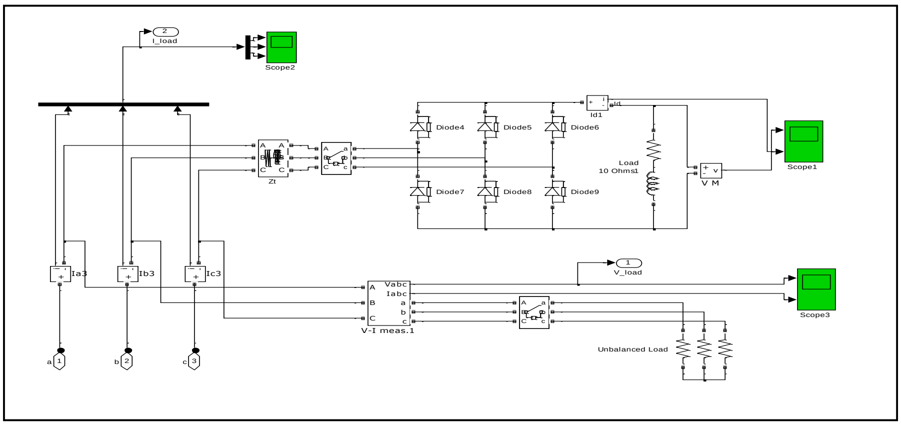

Figure 8. Simulation model developed for generation of nonlinear load for both methods

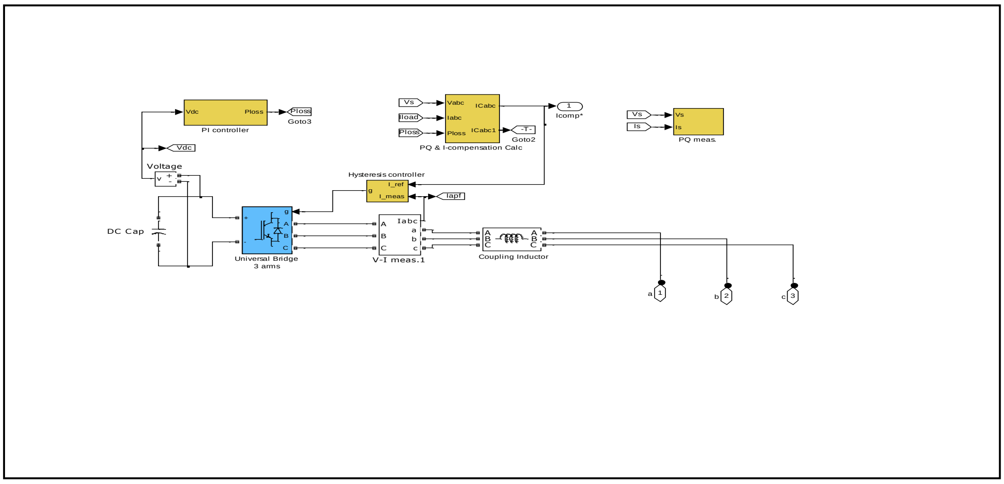

Figure 9. Simulation model developed for p-q method

The figure 8 and figure 9 and figure10 above shows the simulation model developed for the digital control means p-q theory [7]. By taking the value of currents and voltages of per phase gives the results for p-q method.

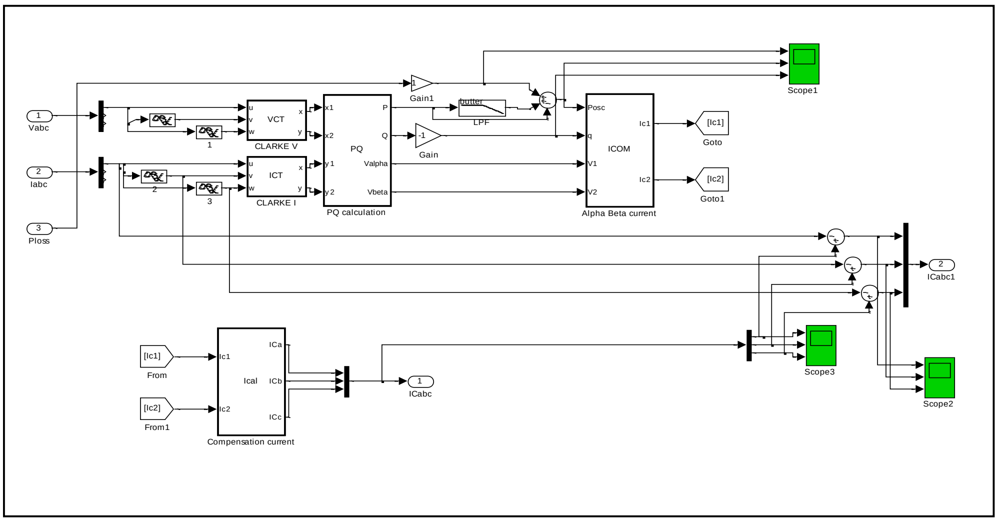

Figure 10. Simulation model developed for p-q calculation

The figure 11 below shows the simulation model developed for synchronous detection method.

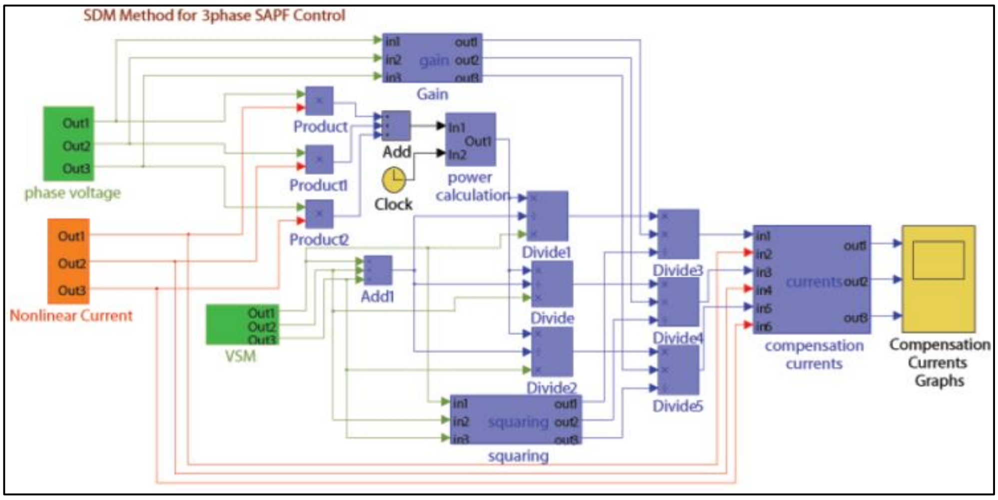

Figure 11. Simulation model developed for SDM calculation

V. SIMULATION RESULT

In this paper we used the matlab simulink tool developed for the calculation of synchronous detection method and p-q theory. For this calculation the balanced three phase system is consider having sinusoidal supply voltage presented as figure 12 which was used for simulation with different types of load [8]. There are various type of load are used for each phase which are for set A load as phase a: consider a typical single phase half wave rectifier with resistive load on dc side which gives the non sinusoidal current wave forms, for phase b: consider the linear RL load which gives the sinusoidal current wave forms but delayed by the phase voltage because inductance is present and for the phase c: consider the other non linear load as single phase full wave bridge rectifier with dc motor load is connected [8]. These per phase load current are shown in figure 13.

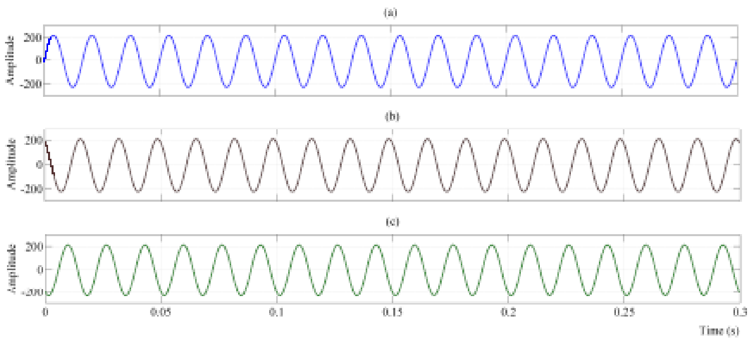

Figure 12. The three phase balanced line voltages (a)v_a,(b)v_b and (a)v_c

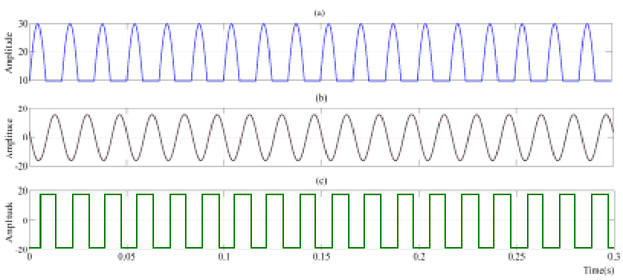

Figure 13. The three phase load currents for load set A (a)i_a,(b)i_b and (a)i_c

According to this non linear load current both synchronous detection method and p-q theory generates the compensation current for set A load which is shown in figure 14 and 15 respectively [8]. After generation of this compensation current, the resultant supply current for set A load of both methods is shown in figure 16 and 17. This means that after the application of shunt active power filter in the line the supply current is balanced, sinusoidal and in phase with the supply voltage and also gives zero current flows through the neutral wire [9].

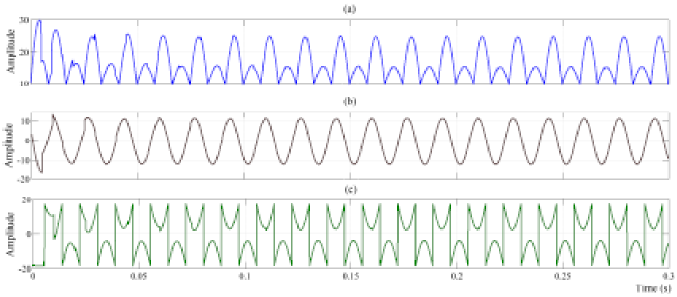

Figure 14. The three phase compensation currents for load set A (SDM-SAPF) (a)i_{ca}, (b)i_{cb} and (c)i_{cc}

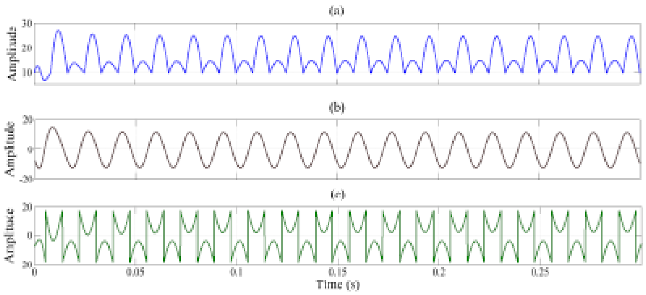

Figure 15. The three phase compensation currents for load set A (p-q SAPF) (a)i_{ca}, (b)i_{cb} and (c)i_{cc}

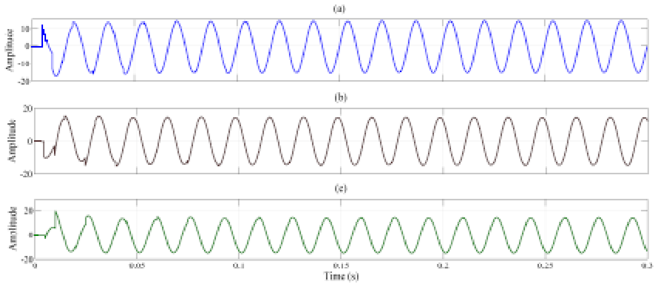

Figure 16. The three phase source currents after compensation for load A(SDM-SAPF) (a)i_{sa}, (b)i_{sb} and (c)i_{sc}

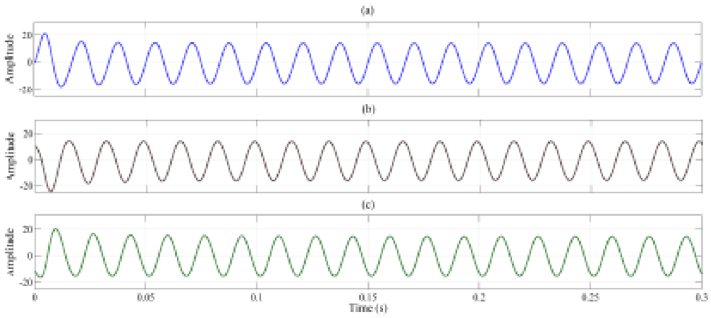

Figure 17. The three phase source currents after compensation for load A (p-q SAPF)(a)i_{sa},(b)i_{sb} and (c)i_{sc}

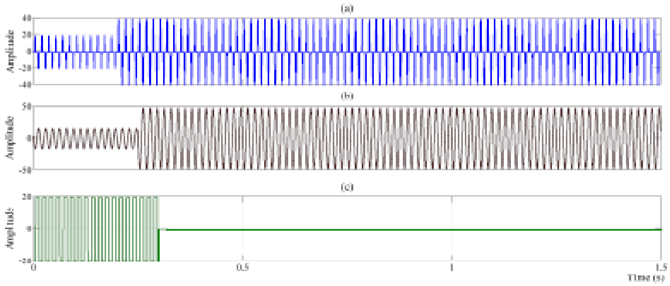

Figure 18. The three phase load currents for load set B (a)i_a,(b)i_b and (b)i_c

The shunt active filter also compensated the undesirable power component obtain from the theories by turning the instantaneous supply power into the constant values [9]. The instantaneous power for load A shown in figure 19 below.

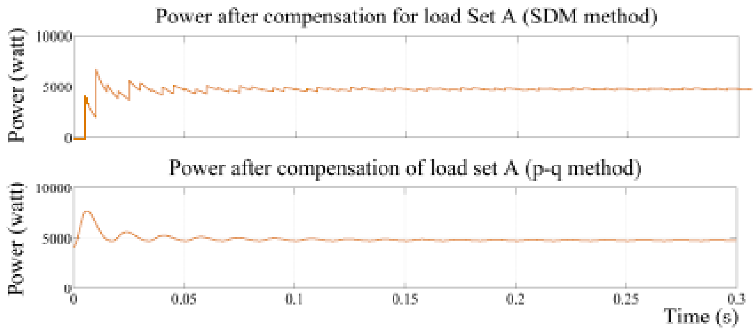

Figure 19. Overall source power after compensation for load set A

The table I shows the values of total harmonic distortion, power factor and displacement power factor before and applying the shunt active power filter [9]. By application of shunt active power filter the value of power factor is maintain to unity and percentage of total harmonic distortion reduce from some value to zero.

Table 1. THD, PF and DPF after and before compensation

Condition Phase	**Before Compensation**			**After Compensation**		
	a	***b***	***c***	***a***	***b***	***c***
THD%	43.52	0.00	48.34	0.00	0.00	0.00
PF	0.3925	0.7036	0.9004	1.00	1.00	1.00
DPF	1.00	0.7036	1.00	1.00	1.00	1.00

Now consider the other type of load name as set B having the per phase current waveforms is shown in figure 18 which have connected the different load to each phases. The specialty of this load is to change the current of phases a, b and c encounter as 0.2, 0.25 and 0.3 seconds respectively [10]. According to load of set A shunt active filter also gives the compensating current waveform for load of set B. the figure 20 shows the instantaneous value of supply power for second type of load means for set B.

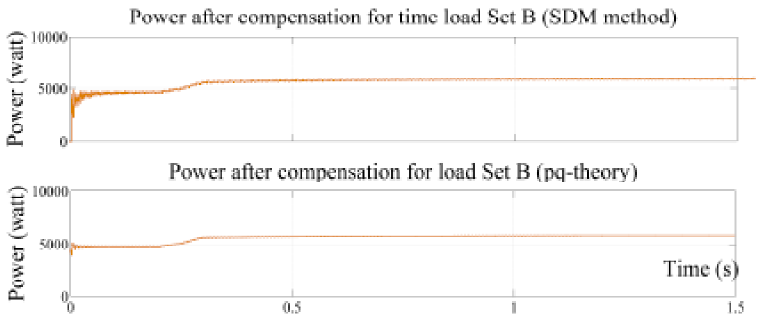

Figure 20. Overall source power after compensation for load set B

After the calculation of compensation current using both the methods comparing the results obtain from this. The comparing the performance of two methods it shows that the digital control method gives a faster result than synchronous detection method. it means that p-q theory shows that it compensate the undesirable current component from resultant supply current require 1 cycle whereas SDM compensated this current takes about 14 cycles i.e. approximately 0.23 sec is required for 50 Hz system [10]. This shows that p-q theory required less time than SDM to clear the harmonic current and for power quality improvement. So the digital control method is preferable than SDM.

VI. FUTURE WORK

The presented work has opened the following areas of further research work:

- Extension of the proposed work for high power applications as uses current controller technique for general n-level multilevel converter based SAPF and its implementation by different topologies of multi-level converters [10].
- Development of active power filters with fixed switching frequency operation using hysteresis controller with variable and on-line computed hysteresis bands for any n-level converter.
- Development of other soft computing techniques such as Artificial Neural Network (ANN) to remove the harmonic and improve the power quality.
- Development of rating of the required filter and its optimal allocation can be determined with the help of evolutionary algorithms such as Genetic Algorithm.
- The integration of wind energy into existing power system generates power quality issues such as voltage transients, instability, etc. for this power quality issues Adaptive shunt hybrid filters are suggested for improvement, when generation rapidly changes with wind speed.

VII. CONCLUSION

We know that the main requirement of industrial and end consumers are faster power quality improvement in this paper discuss the shunt active power filter which is the up to date solution of power quality. Shunt active power filter gives both the harmonic current reduction and power factor correction solution so there is no need of separate capacitor for power factor correction and passive filter for harmonic current reduction. In this paper results are calculated using matlab simulation and shows that faster power quality improvement using SAPF based on p-q theory than the SDM. So we preferred the digital control method than SDM for power quality improvement.

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