Harmonic Mitigation for Power Quality Improvement using Active Power Filter with Current Control Strategy under Non-Linear Loads

CH. SHANMUKHA RAO[1], Dr. G.V. Siva Krishna Rao[2]

[1]PG Scholar, Dept. of Electrical Engineering, Andhra University College of Engineering, Visakhapatnam, A.P, India.
[2]Professor, Dept. of Electrical Engineering, Andhra University College of Engineering, Visakhapatnam, A.P, India

---

Abstract : Application of nonlinear loads are increasing day by day with advancement of technology. Non-linear electrical devices has led to a distortion in the output sine waveforms of source current and voltage. It may lead equipment (connected to it) to overheat and sometimes cause damage. This paper concentrates on better design and application of three-phase shunt active power filter (SAPF) by using two different methods p-q theory and d-q theory to mitigate the harmonics which are created by nonlinear loads. To obtain result for this paper, the MATLAB / Simulink was used as a simulation tool. The achieved results are within the recommended IEEE-519 standard i.e. less than 5% and also the power factor (PF) of the system to almost unity.

Index Terms: shunt active power filter, power quality, total harmonic distortion, power factor, UPS ,SMPS, Nonlinear Loads.

INTRODUCTION

In an electric power system, a harmonic is a voltage or current at a multiple of the fundamental frequency of the system, produced by the action of non-linear loads such as rectifiers, discharge lighting, or saturated magnetic devices. Harmonic frequencies in the power grid are a frequent cause of power quality problems. Harmonics in power systems result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsations in motors. Passive filters (combinations of capacitors and inductors) were used to mitigate the PQ problems. These approaches were extensively used in high voltage DC transmission (HVDC) for filtering the harmonics on the AC and DC sides. However, this approach is unsuitable at the distribution level as passive filters can only correct specific load conditions or a particular state of the PS. These filters are unable to follow the changing system conditions. Thus, the active power filter (APF) was introduced to compensate harmonics and reactive power. There are three types of APFs which are shunt APF, series APF, and hybrid APF (i.e. the combination of active and passive filters) (Badi, 2012), (Chaughule, Nehete, and Shinde, 2013).

The purpose of an APF as a power line conditioner is to repay the utility line current waveform with the goal that it approximates a sine wave in phase with the line voltage when a nonlinear load is connected with the system. Classically, shunt power line conditioner (shunt passive filter) consists of tuned LC filters.

OBJECTIVE

The main objectives of this project are To give a brief overview about the cause and effect of harmonics in power system To study different types proposed filter used to eliminate harmonics from the power system .To study and implement different control strategies already proposed for modeling of 3 phase shunt active power filter. To model and simulate three phase shunt active power filter with different current control strategy in MATLAB/ SIMULINK environment To compare different control strategies based on FFT analysis (an important tool for harmonic behavioral analysis) for harmonic elimination in power system network.

Passive Filter

It is a combination of series/parallel connection of passive elements such as capacitors, inductors and/or resistor. They provide a low resistance path for the harmonic current to flow owing to the formation of resonance at that particular harmonic frequency. Hence harmonic current is diverted through passive filter network and system current becomes distortion free. Likewise distortion in voltage waveform is also removed. For bypassing the current effective means of connection is connecting the passive filter in parallel with the load. In order to improve power factor passive filters are designed as capacitive filter so that it correct the current displacement factor and provide reactive power to the load.

Advantages of Passive Filters

Although passive filters doesn't eliminate harmonics to a greater extent yet it is used due to some prominent features which are described as under

1. They are simpler to configure and construct.

2. Low initial & maintenance cost (compared to APF)

3. Shunt passive filters of capacitive nature provide reactive power to the nonlinear load and on the other hand improve power factor by improving current displacement factor.

4. Lowering of THD in line current to a permissible limit can be possible by use of passive

Disadvantages of Passive Filters

Some major drawbacks with passive current filters are:

* Property and characteristics of filter depends on source impedance (i.e. impedance of the system and its topology) which are subjected to variations due to external condition.

* Resonating condition in the filter may create problem with loads and network leading to voltage fluctuation.

* It basically able to remove some particular harmonic components through tuning whenever the magnitude of those harmonic component is constant and pf of the system is low.

* Filter response is static i.e. if load variation introduce some new harmonic components then the filter have to redesigned which increases the maintenance and operation cost of the filter.

* Load unbalancing or neutral shifting problems can't be solved.

Active Filter

An active filter consists of serial/parallel array of arrangement of both active and passive components and it is a type of analog electronic filter. Basic building block of active filter are Amplifiers. Thus filter performance and response is improved by the use of amplifiers instead of inductors that are used in passive filter for the same purpose. Active filter have dynamic response and thus can remove current distortion, current harmonics etc. faster than passive filter. It can also be used for reactive power compensation and also for voltage based distortions such as flickering, voltage dip, unbalancing. It uses PWM techniques to remove load unbalancing and neutral shifting problems. There is no possibility of resonating condition as tuning of frequency isn't taking place in active filtering, so the power system network remain more stable during operation. Unlike passive filter, there performance doesn't depends on system parameters and its topology

Operation of Active Filters

Active Filter generate compensating current signal by continuously monitoring the load current with the help of some algorithm such as p-q theory, d-q transform, sliding mode control, DSP based algorithm etc. Now the generated compensating current is used to generate the switching pulse and switching sequence of IGBT inverter with the help of hysteresis controller or any other type of current controller. The inverter then generate the required harmonic current for the load through charging and discharging of DC link capacitor and injected into the system through coupling transformer with a phase difference to compensate the reactive power coming from the AC mains. Major types of Active filters are: i) Series AF, ii) Shunt AF and iii) Hybrid AF.

Advantages of Active Filter

1. Widely compensated the THD in source current waveform.
2. Only a single filter can be able to eliminate all the unwanted harmonics.
3. Resonance condition is absent which increase the stability of power system.
4. Filter characteristics changes with load variation due to dynamic response of the filter.

Shunt Active Power Filter

As the name depicts the shunt active power filter (SAPF) are connected in parallel to the power system network wherever a source of harmonic is present. Its main function is to cancel out the harmonic or non-sinusoidal current produce as a result of presence of nonlinear load in the power system by generating a current equal to the harmonic current but off opposite phase i.e. with 180^{o} phase shift w.r.t to the harmonic current. Generally SAPF uses a current controlled voltage source inverter (IGBT inverter) which generates compensating current (ic) to compensate the harmonic component of the load line current and to keep source current waveform sinusoidal.

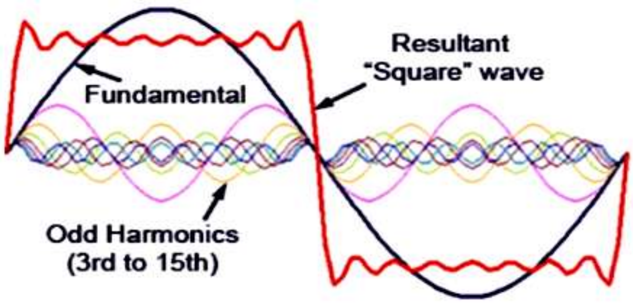
Basic arrangement of SAPF is shown in through block model.

Compensating harmonic current in SAPF can be generated by using different current control strategy to increase the performance of the system by mitigating current harmonics present in the load current. Various current control method [2]-[4] for SAPF are discussed below.

SHUNT ACTIVE POWER FILTER DESIGN

Effect of harmonics

Harmonics in PS can turn into the wellspring of a mixture of unwelcome impacts. For example, harmonics can cause signal interference, overvoltage, data loss, and circuit breaker failure, as well as equipment heating, breakdown, and harm. Any dissemination circuit serving modern electronic gadgets will contain some degree of harmonic frequencies. The greater the power drawn by nonlinear loads, cause higher the level of voltage and current distortion as shown in Figure.



Effect of harmonics on voltage or current waveform

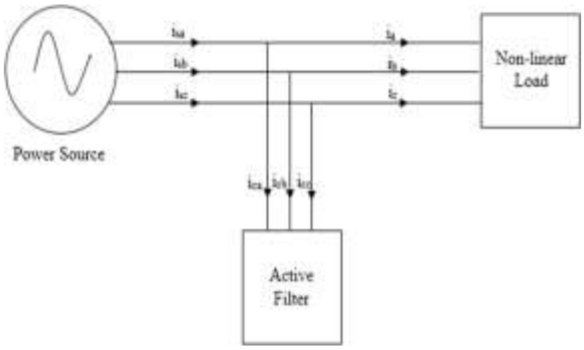
HD in power distribution system can be measured by using equation (1)

Where n = 2, 3,4,5, ...

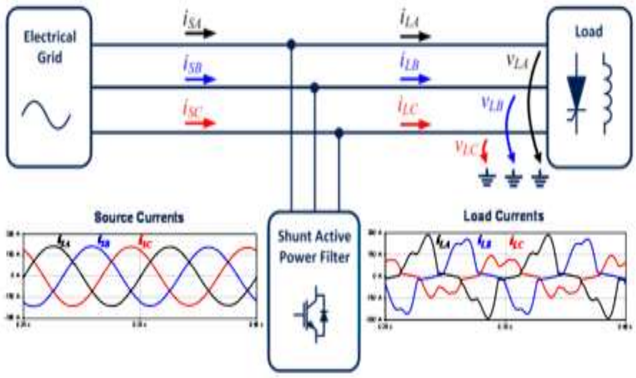
APFs are becoming a viable alternative to passive filters and are gaining market share speedily as their cost becomes competitive with the passive variety, one of the most common type of APF to reduce the harmonic current distortion is SAPF.

Principle of SAPF

The shunt-connected APF, 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. SAPF compensates load current harmonics by injecting equal but opposite harmonic compensating current. In this case, the SAPF operates as a current source injecting the harmonic components generated by the load but phase shifted by



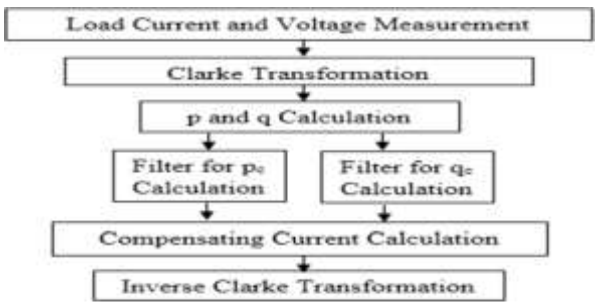
180°. Figure shows the connection of a SAPF compensating the harmonic load currents.



Connection of a SAPF.

Instantaneous Real and Reactive Power Theory (p-q method)

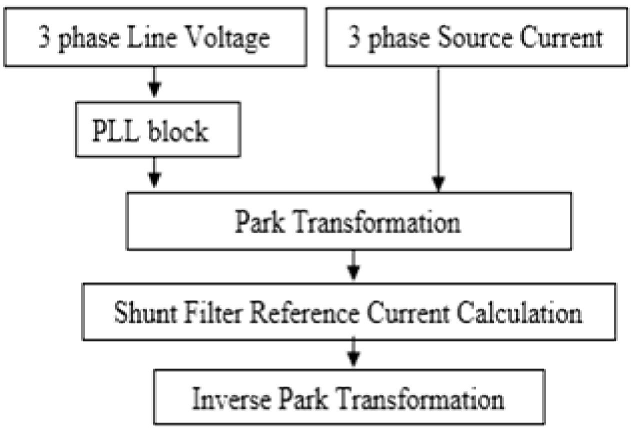
This theory takes into account the instantaneous reactive power arises from the oscillation of power between source and load and it is applicable for sinusoidal balanced/unbalanced voltage but fails for non-sinusoidal voltage waveform. It basically 3 phase system as a single unit and performs Clarke's transformation (a-b-c coordinates to the α-β-0 coordinates) over load current and voltage to obtain a compensating current in the system by evaluating instantaneous active and reactive power of the network system.The p-q method control strategy in block diagram form is shown in figure .This theory works on dynamic principal as its instantaneously calculated power from the instantaneous voltage and current in 3



phase circuits. Since the power detection taking place instantaneously so the harmonic elimination from the network take place without any time delay as compared to other detection method. Although the method analysis the power instantaneously yet the harmonic suppression greatly depends on the gating sequence of three phase IGBT inverter which is controlled by different current controller such as hysteresis controller, PWM controller, triangular carrier current controller. But among these hysteresis current controlled method is widely used due to its robustness, better accuracy and performance which give stability to power system.

Synchronous Reference Frame theory (d-q method)

Another method to separate the harmonic components from the fundamental components is by generating reference frame current by using synchronous reference theory. In synchronous reference theory park transformation is carried out to transformed three load current into synchronous reference current to eliminate the harmonics in source current. The main advantage of this method is that it take only load current under consideration for generating reference current and hence independent on source current and voltage distortion. A separate PLL block it used for maintaining synchronism between reference and voltage for better performance of the system. Since instantaneous action is not taking place in this method so the method is little bit slow than p-q method for detection and elimination of harmonics. Figure illustrate the d-q method with simple block diagram.



P-Q mathematical modelling

The relation between load current & voltage of three phase power system and the orthogonal coordinates (α-β-0) system are expressed by Clarke's transformation which is shown by the following equation (1)&(2)

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

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

In orthogonal co-ordinate system instantaneous power can be found out by simply multiplying the instantaneous current with their corresponding instantaneous voltage. Here the 3 phase co- ordinate system (a-b-c) is mutually orthogonal is nature, so we can found out instantaneous power as in the form of equation 3.

$$p = v_a i_a + v_b i_b + v_c i_c \ldots\ldots\ldots\ (3)$$

From above equations, the instantaneous active and reactive power in matrix form can be rewritten as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \ldots\ldots\ldots\ldots\ldots(4)$$

The instantaneous reactive power produces an opposing vector with 180^o phase shift in order to cancel the harmonic component in the line current. From the above equations, yield equation 5.

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p_o + p_{loss} \\ 0 \end{bmatrix} \ldots\ldots\ldots(5)$$

After finding the α-β reference current, the compensating current for each phase can be derived by using the inverse Clarke transformations as shown in equation 6.

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

D-Q method Mathematical modelling

According to Park's transformation relation between three phase source current (a-b-c) and the d-q reference co-ordinate current is given by equation 7

$$\begin{bmatrix} i_{ld} \\ i_{lq} \\ i_{l0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} cos\mu & \cos(\mu - \frac{2\pi}{3}) & \cos(\mu + \frac{2\pi}{3}) \\ -sin\mu & -sin(\mu - \frac{2\pi}{3}) & -sin(\mu + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \ldots\ldots\ldots(7)$$

Where, 'μ' is the angular deviation of the synchronous reference frame from the 3 phase orthogonal system which is a linear function of fundamental frequency. The harmonic reference current can be obtained from the load currents using a simple LPF. The currents in the synchronous reference system can be decomposed into two components given by equation 8 & 9

$i_{ld} = i_{ld}^{-} + i_{ld}^{\sim}$ ……..(8)

$i_{lq} = i_{lq}^{-} + i_{lq}^{\sim}$ ……..(9)

After filtering DC terms (i⁻ , i⁻) are suppressed and alternating term are appearing in the output of extraction system which are responsible for harmonic pollution in power system.

The APF reference currents is given by equation 10

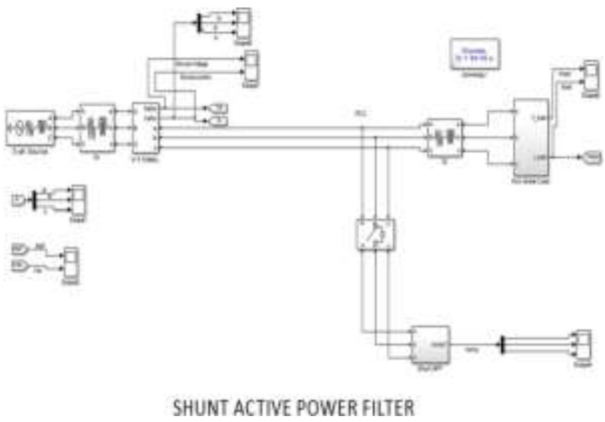
$$\begin{bmatrix} i_{fd}^{*} \\ i_{fq}^{*} \end{bmatrix} = \begin{bmatrix} i_{ld}^{\sim} \\ i_{lq}^{\sim} \end{bmatrix} \text{………(10)}$$

In order to find the filter currents in three phase system which cancels the harmonic components in line side, the inverse Park transform can be used as shown by equation 11

$$\begin{bmatrix} i_{fa}^{*} \\ i_{fb}^{*} \\ i_{fc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\mu & -\sin\mu \\ \cos(\mu - \frac{2\pi}{3}) & -\sin(\mu - \frac{2\pi}{3}) \\ \cos(\mu - \frac{2\pi}{3}) & \sin(\mu + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{fd}^{*} \\ i_{fq}^{*} \end{bmatrix} \text{……(11)}$$

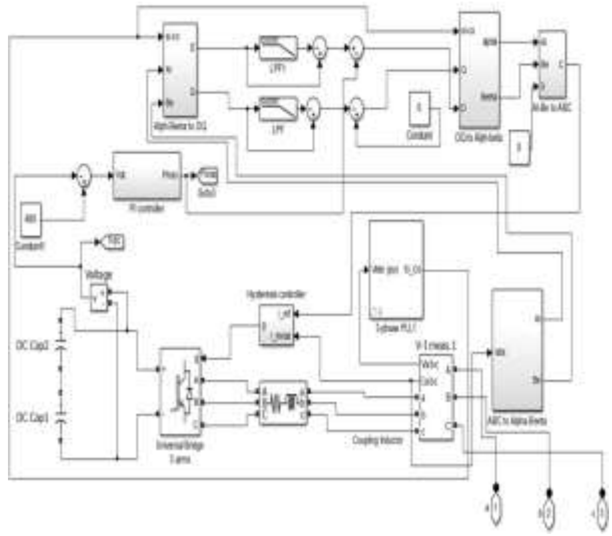
MATLAB/SIMULINK MODELLING:

Power system Simulink model with Shunt APF and Non-linear load



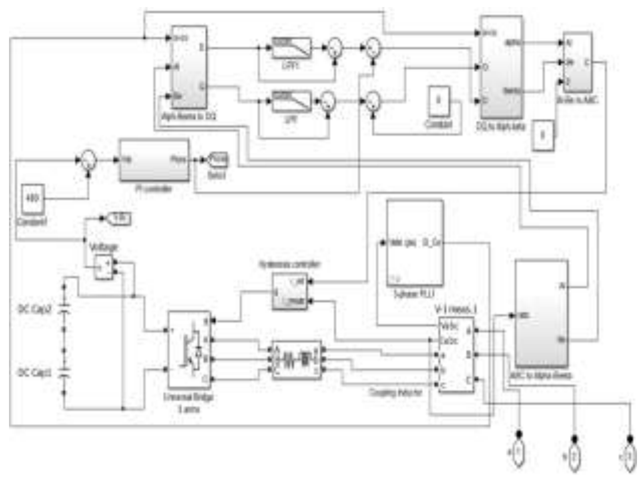
System model with filter

Simulink model of Shunt APF with p-q method



Model of Shunt APF with p-q method

Simulink model of Shunt APF with d-q method



Model of Shunt APF with d-q method

Design Parameters for MATLAB Simulation :

Simulation is performed on a balanced Non –Linear Load consisting of an R-L load and a bridge rectifier as shown below

- System Parameters

Source Voltage (r.m.s)	400Volt
System Frequency	50Hz

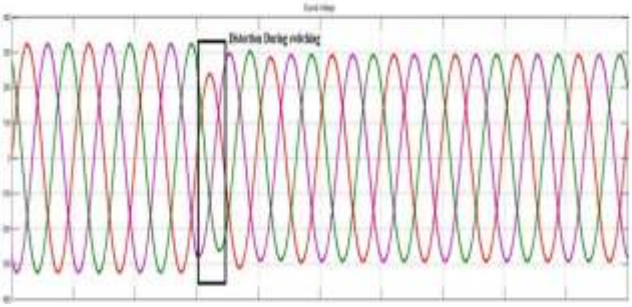
- Active Power Filter (APF) Parameters

Coupling Inductance	1mH
Coupling Resistance	0.01Ω
Dc link capacitance	1100μF
Source inductance	0.05mH
Source resistance	0.1Ω
Load resistance	0.001Ω
Load inductance	1μH

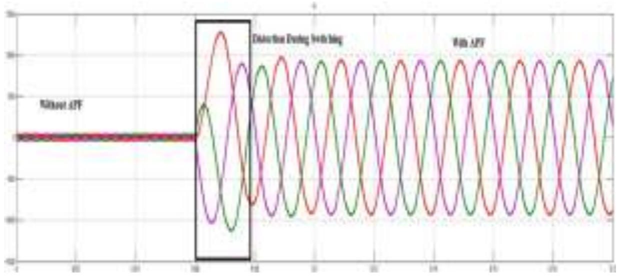
Simulink Result with P-Q control strategy

Breaker Transition Time: - 0.06 sec

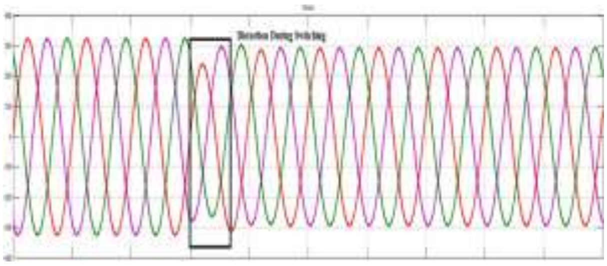
Simulation Run Time: - 0.2 sec



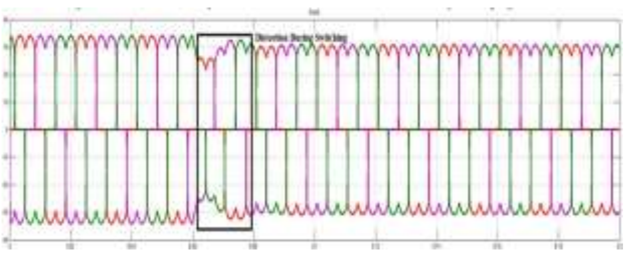
Source Voltage Waveform before and after filtering with p-q method



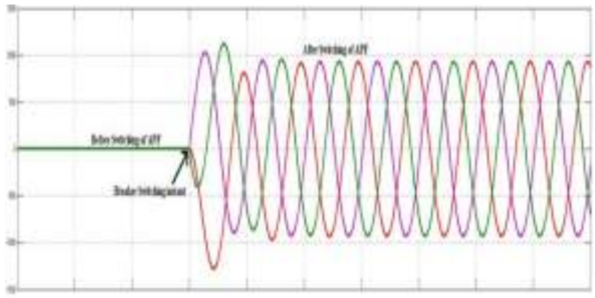
Source Current Waveform before and after filtering with p-q method



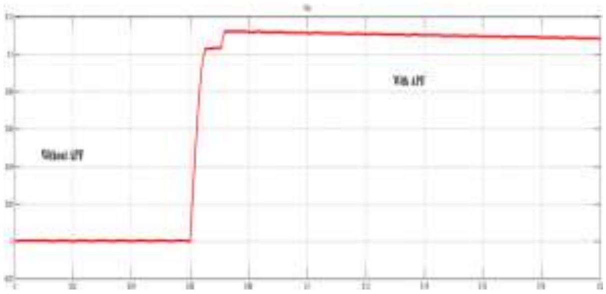
Load Voltage Waveform before and after filtering with p-q method



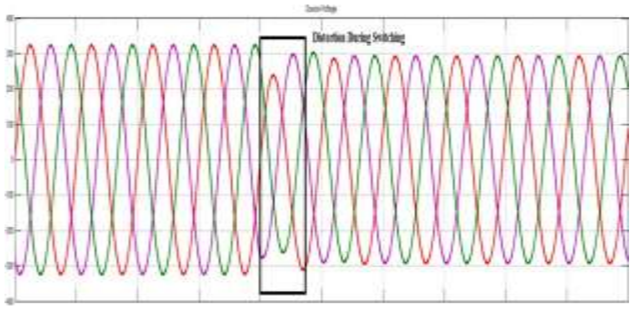
Load Current Waveform before and after filtering with p-q method



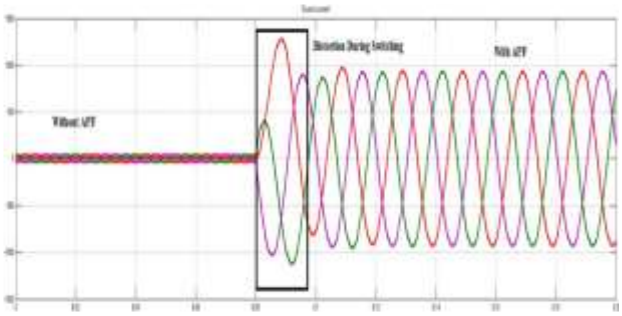
APF Current Waveform before and after filtering with p-q method



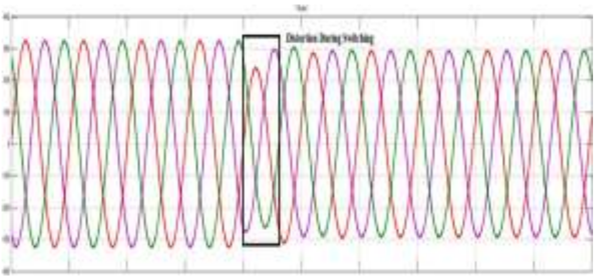
DC link Voltage Waveform before and after filtering with p-q method



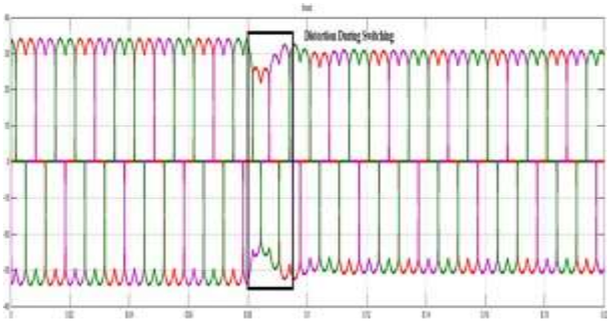
Source Voltage Waveform before and after filtering with d-q method



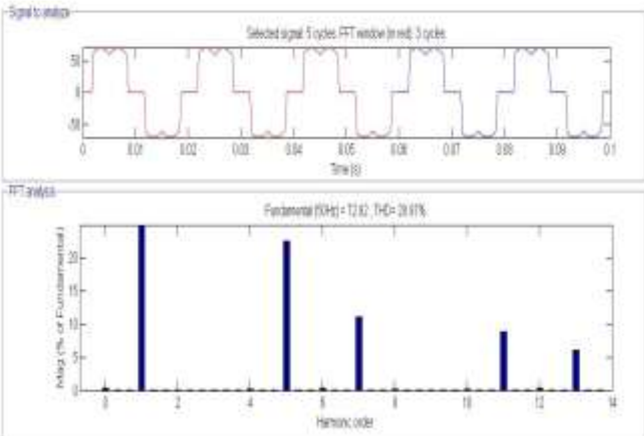
Source Current Waveform before and after filtering with d-q method



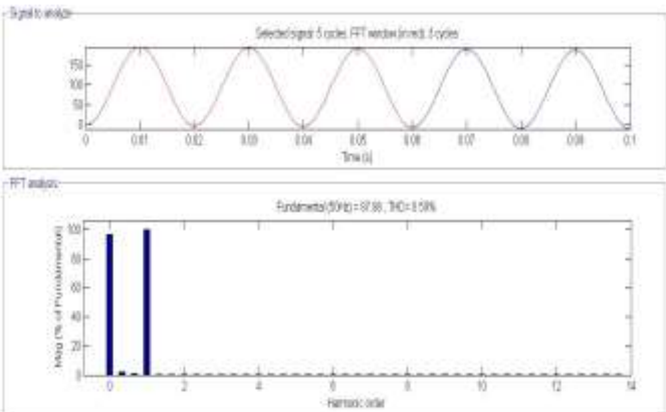
Load Voltage Waveform before and after filtering with d-q method



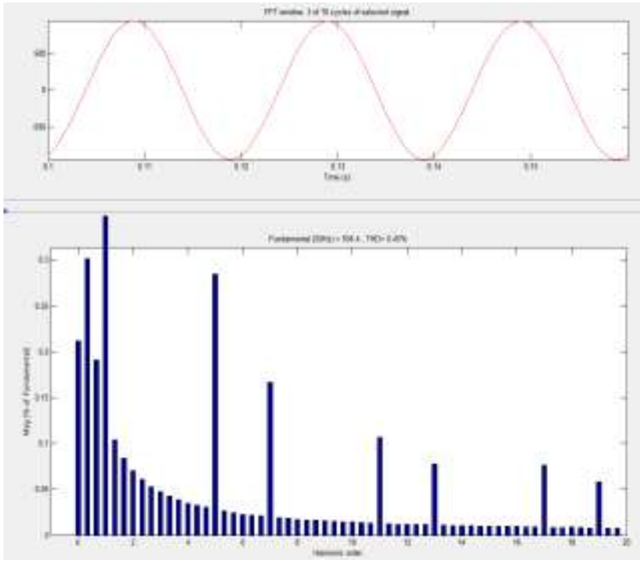
Load Current Waveform before and after filtering with d-q method



FFT analysis of source current without APF



FFT analysis of source current with SAPF using p-q method



FFT analysis of source current with APF using d-q method

System	**System without SAPF**	**System with SAPF using 'p-q' method**	**System with SAPF using 'd-q' method**
% THD	29.51%	0.69%	0.45%

Table1. Total Harmonic Distortion of System with and without filter

Conclusion:

The proposed three phase SAPF based on d-q and p-q current control strategy were simulated in matlab/simulink for nonlinear loads .The results successfully validated by observing that d-q showing better results than p-q current control strategy for harmonic mitigation.

Future Scope

As the Power Quality is major concerned issue in this increasing nonlinear load applications, effective controlling schemes are required for limiting of Power Quality issue like harmonics hence extension of this work with much more sophisticated controlling schemes like Model Adaptive Reference Scheme, and the modification of PI controllers can be effectively implemented using with ANN, Fuzzy logic and Algorithm like Genetic Algorithm.

References

1. Grady, W. Mack, and Surya Santoso. "Understanding power system harmonics." IEEE Power Engineering Review 21.11 (2001): 8-11

2. Morán, Luis A., et al. "Using active power filters to improve power quality." 5th Brazilian Power

Electronics Conference. 1999.

3. M. Suresh , S.S.Patnaik, Y. Suresh, Prof. A.K. Panda, "Comparison of Two Compensation Control Strategies for Shunt Active Power Filter in Three-Phase Four-Wire System", Innovative Smart Grid Technology, IEEE PES, 17-19 Jan. 2011, pp. 1 - 6

4. Adam G., Zbant A. and Livint G, 2013. New Simulink control block for single phase shunt activepower filters. In 8th International Symposium onAdvanced Topics in Electrical Engineering (ATEE),