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HARMONIC ELIMINATION IN A THREE PHASE SYSTEMBY USING D-Q METHOD

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Abstract:

An active power filter for harmonic and power factor adjustment of numerous non-linear loads is presented in this study. Shunt Active Power Filter (SAPF) is the most popular and extensively used method for reducing harmonics in the power system; SAPF can readily eliminate undesired harmonics, and as non-linear loads in the power system increase, more and more filters are needed. Toincrease ac mains power quality, active filters are built and analyzed. Simulated using MATLAB/Simulink, the results are shown.

Key Words*: Shunt Active Filter, Total harmonic Distortion, Power Quality*1.INTRODUCTION:**

In the recent years, Power quality (PQ) is emerging as an issue of major concern, (globally as well as nationwide) requiring accurate monitoring, in-depth analysis and adoption of planned PQ improvement initiatives. The present scenario has changed in our country, with a large proportion of the industrial, commercial, and domestic load now turning out to be non-linear due to growing use of power electronics, automation, computers, and information technology. Widespread use of non-linear loads degenerates the quality of power in both transmission and distribution systems. All non-linear loads draw non-sinusoidal currents which cause distortion in the voltage waveform not only withinthe individual plant but also in the power supply network [3]. Harmonics propagate from one consumer to another, causing many undesirable effects on the power system. The harmonic current components do not represent useful active power due to the frequency mismatch with the source voltage [4]. A simple and effective technique for harmonic analysis is current injection model which is most commonly applied for harmonic simulation studies. This approach treats harmonic producing load as an injection current source to the system assuming steady-state condition. Consequently, all non-linearities in the system are represented as current injections of corresponding harmonic frequencies and therefore, the superposition principle can be applied. The consumption of reactive power in industrial and domestic loads also presents an important issue in the discussion of power quality problems. The reactive power consumed by non-resistive loads causes higher RMS current values in addition to extra heating of power transmission and distribution systems. The use ofbatteries of capacitors or synchronous machines for local reactive power production has been proposed for a long time. The accelerated development of power electronics and semiconductor production has encouraged the use of STATIC VAR compensators for reactive power compensation. However, these solutions look inefficient and can cause extra problems in power systems in the case of high current and voltage harmonic emissions. The fact that these systems are especially designed to compensate the fundamental based reactive power, in addition to high possibilities of interaction between these compensation elements and system harmonics make it unstable solutions in modern technologies. To face the problem of harmonics, many solutions have been proposed. These solutions included modifications on the load itself for less harmonic emissions like the case of special structure single phase and three phase rectifier, and PWM rectifiers. Or the connection on the polluted power grids of other traditional or modern compensation systems.

1.1 Motivation of the Work:

Harmonic pollution is mostly common in low voltage side due to wide use of nonlinear loads(UPS, SMPS, Rectifier etc.), which is undesirable as it causes serious voltage fluctuation and voltage dip in power system. So it required to eliminate undesirable current and voltage harmonics and to compensate the reactive power to improve the performance and operation of the power system. The use of traditional passive filter in removing harmonics is not that much effective because their static action and no real time action or dynamic action is taken for the removal of harmonics. But the shunt active power filter on the other hand gives promising results when compared with conventional active and passive filters. This project gives detail performance analysis of SAPF under two current control strategy namely, instantaneous active and reactive power theory (p-q) and synchronous frame reference theory (d-q) and their comparative analysis to justify one of the method better over other. In both method a reference current is generated for the filter which compensate either reactive power or harmonic current component in power system.

2. LITERATURE SURVEY:

Morán, Luis A., et al.: aims at improving the power quality with controlling method shunt active power filter in Microgrid System. A hybrid compensation system consisting of an active filter and passive filters in the Micro-grid is discussed. Passive filter is connected to a distortion source and designed to eliminate main harmonics and supply reactive power for the distortion source, while the active filter is applied to the correction of the unbalance condition a system and cancellation of the remaining harmonics.

Jou, H-L.: This study deals with the design, analysis and simulation of shunt active power filter SAPF which compensate harmonic currents and reactive power under balanced supply network.An **optimal control** theory for currents compensation based on **particle swarm optimization** is developed in this study. The SAPF is connected in parallel with a nonlinear load which has caused current harmonics in industrial power plants and utility power distribution systems. The proposed optimal PI current controller using particle swarm algorithm determines the switching signals of the SAPF and the algorithm based on instantaneous power (p-q) theory has been used to determine the suitable current reference signals

Suresh, M., et al :Due to a large amount of non-linear power electronic equipments , impact and fluctuating loads (such as that of arc furnace, heavy merchant mill and electric locomotive, etc), problems of power quality have become more and more serious with each passing day, as a result Active power filter (APF) gains much more attention due to excellent harmonic compensation. But still the performance of the active filter seems to be in contradictions with different control strategies. The well known methods, instantaneous real active and reactive power method (p-q) and active and reactive current method (id-iq) are two control methods which are extensively used in active filters.On owing id - iq method gives away an outstanding performance under any voltage conditions (balanced, un-balanced, balanced non- sinusoidal and balanced sinusoidal with different main frequencies)

Singh, Bhim, Kamal Al-Haddad, and Ambrish Chandra :Active filtering of electric power has now become a mature technology for harmonic and reactive power compensation in two-wire (single phase), three-wire (three phase without neutral), and four-wire (three phase with neutral) AC power networks with nonlinear loads. This paper presents a comprehensive review of active filter (AF) configurations, control strategies, selection of components, other related economic and technical considerations, and their selection for specific applications.

Mendalek, Nassar, and Kamal Al-Haddad: describes about mitigation of power quality issues usingShunt active filter in a Grid connected hybrid energy system consisting of PV-Battery-Fuel Cell. The Shunt active filter control is based on Sinusoidal Current Control Strategy. Shunt Active Power Filters(SAPF) is implemented in the hybrid systems to mitigate the harmonic current component as well asto recompense the imaginary or reactive power owing to their exact and reckless operation. Sinusoidalcurrent based controller used in a SAPF has been focused over here. Sinusoidal current control strategy is utilized to extricate sinusoidal current commencing from the source. The sinusoidal Currents in addition with a stout synchronizing circuit (Phase Locked Loop or PLL circuit), custom a brief controller meant for SAPF which is precise by a sinusoidal current control-based controller in order to perform like a harmonic isolator amid supply and load.

Charles, S., and G. Bhuvaneswari: The ability of reactive power and harmonics reductions are generally met by using passive and active power filters. A modified active power filter with a modified harmonics pulse width modulation algorithm is used to minimize the source harmonics and force the AC supply current to be in the same phase with AC voltage source at both sending and receiving sides of a line commutated converter high voltage DC link. Therefore, it is considered as power factor corrector and harmonics eliminator with random variations in the load current. The modified harmonics pulse width modulation algorithm is applicable for active power filter based on a three-phase five-level and seven-level cascaded H-bridge voltage source inverter.

3. Shunt Active Power Filter:

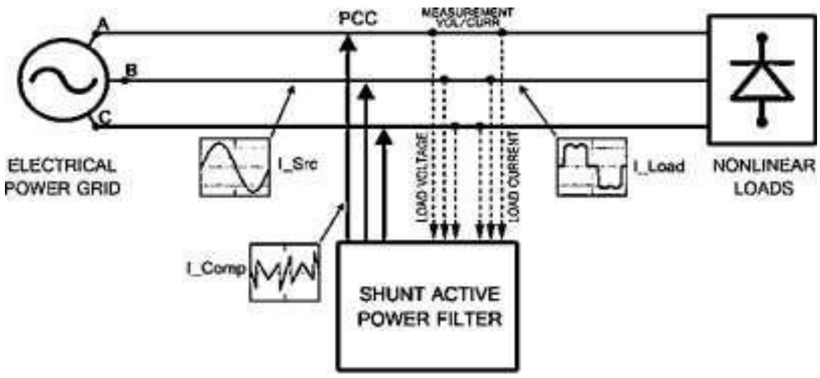

Figure. 3.1 Shunt Active Power Filter

As the name depicts the shunt active power filter (SAPF) are connected in parallel to the powersystem 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 180o 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 figure 1 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 presentin the load current.

3.1 Instantaneous Active and Reactive Power (p-q) Method:

The control algorithm block diagram for p-q method is depicted in Figure 3. The three-phase source voltages (vsa, vsb, vsc) and load currents (iLa, iLb, iLc) in the a-b-c coordinates are algebraically transformed to the α-β coordinates using Clarke‟s transformation as per (1) and (2), followed by the calculation of the instantaneous active power (p) and reactive power (q) by following (3).

$$\begin{bmatrix} Va \\ Vb \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (1)$$

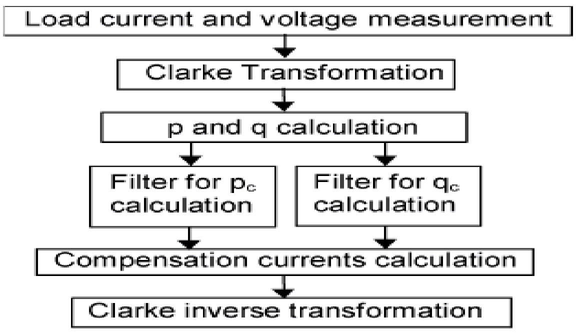

Figure 3.2: Basic control algorithm for shunt active power filter based on p-q theory

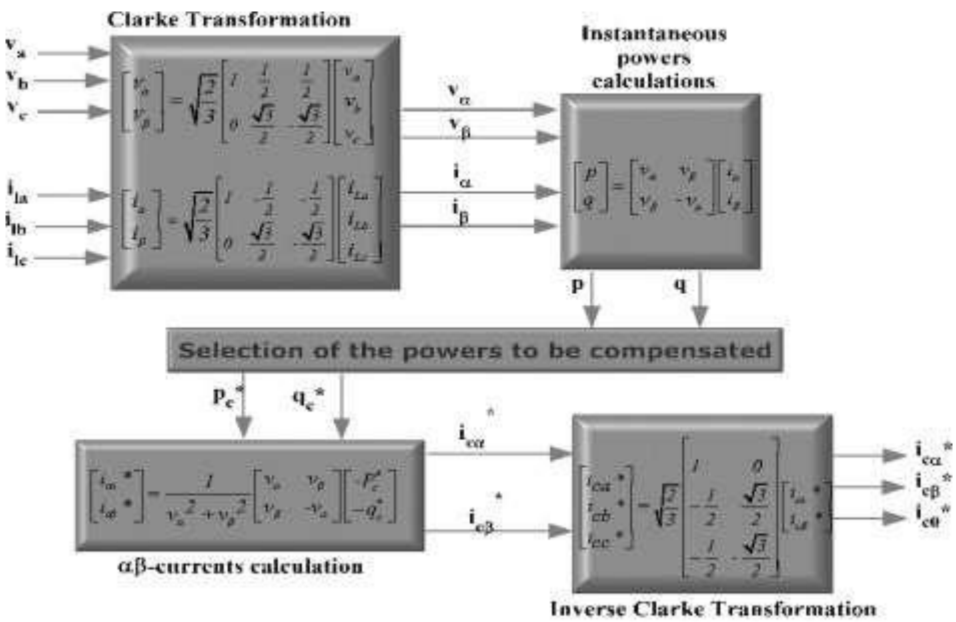

Figure 3.3 control strategy of p-q theory

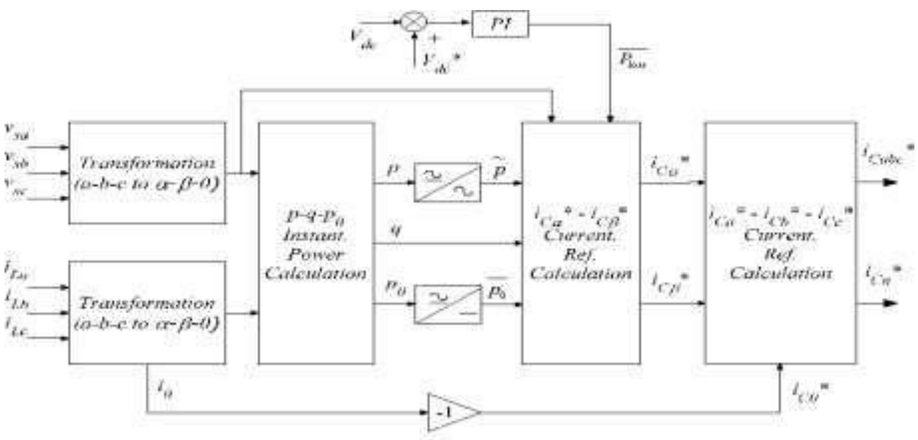

Figure 3.4: Reference current extraction with conventional *p-q* method.

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \text{---------} (2)$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \text{--------} (3)$$

Each of these powers has dc component (1st component) and ac component (2nd component) asshown in

$p = \bar{p} - \tilde{p}$ ——————————————————————(4)

$q = \bar{q} - \tilde{q}$ ---(5)

For reactive and harmonic compensation, the entire reactive power and ac component of active powerare utilized as the reference power. The reference currents in *α-β* coordinates are calculated by using

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} -Pc^* \\ -q_c^* \end{bmatrix} ----(6)$$

$$\begin{bmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} \text{------------} (7)$$

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 this hysteresis current controlled method is widely used due to itsrobustness, better accuracy and performance which give stability to power system.

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3.2: 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 currentand hence independent on sourcecurrent 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 5 illustrate the d-q method with simple block diagram.

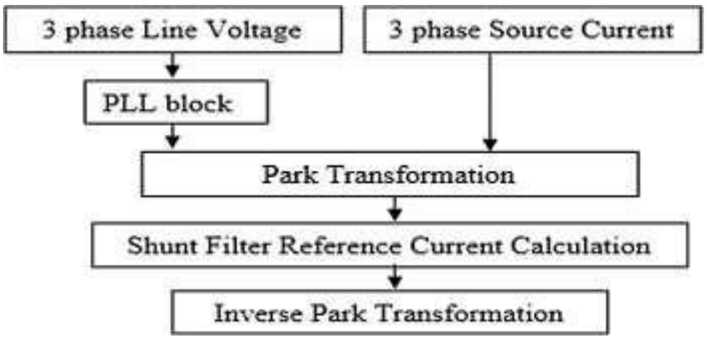

Figure 3.5: d-q method control strategy

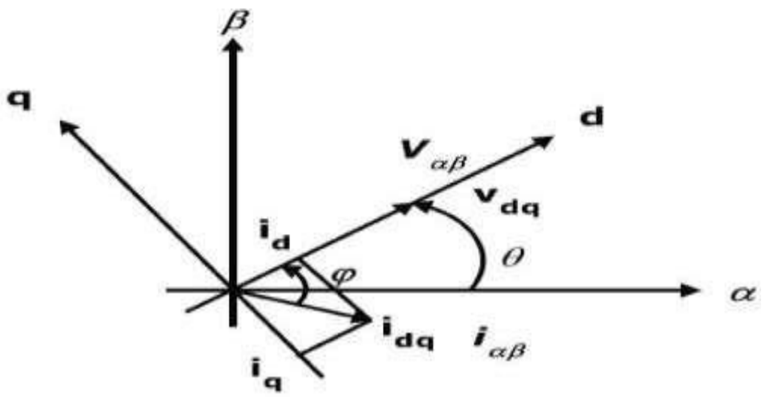

Figure 3.6: Instantaneous Voltage and Current Vectors

According to Park‟s transformation relation between three phase source current (a-b-c) and the d-q reference co-ordinate current,

$$\begin{bmatrix} i_{ld} \\ i_{lq} \\ i_{l0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\mu & \cos(\mu - \frac{2\pi}{3}) & \cos(\mu + \frac{2\pi}{3}) \\ -\sin\mu & -\sin(\mu - \frac{2\pi}{3}) & -\sin(\mu + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \text{--------(8)}$$

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.

$i_{ld} = \bar{i}_{ld} + \tilde{i}_{ld}$ --(9)

$i_{lq} = \bar{i}_{lq} + \tilde{i}_{lq}$ --(10)

After filtering DC terms (i-lq, i-ld) 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,

$$\begin{bmatrix} i_{fd}^* \\ i_{fq}^* \end{bmatrix} = \begin{bmatrix} \tilde{i}_{ld} \\ \tilde{i}_{lq} \end{bmatrix} ----(11)$$

In order to find the filter currents in three phase system which cancels the harmonic components inline side, the inverse Park transform can be used.

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\mu & -\sin\mu \\ \cos\left(\mu - \frac{2\pi}{3}\right) & -\sin\left(\mu - \frac{2\pi}{3}\right) \\ \cos\left(\mu + \frac{2\pi}{3}\right) & \sin\left(\mu + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} i_{fd}^* \\ i_{fq}^* \end{bmatrix} ----(12)$$

4. SIMULATION RESULT:

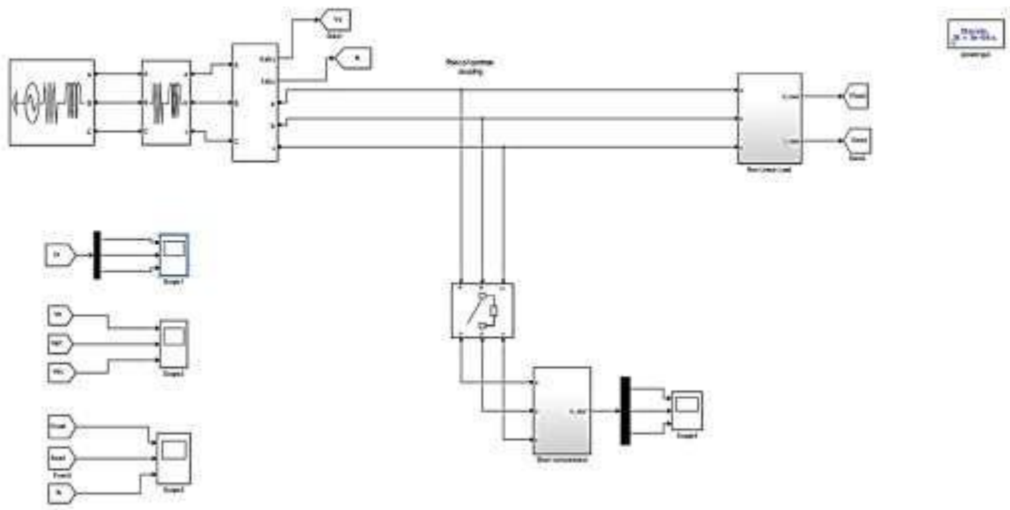

Figure 4.1: Simulink model of Shunt APF with p-q method:

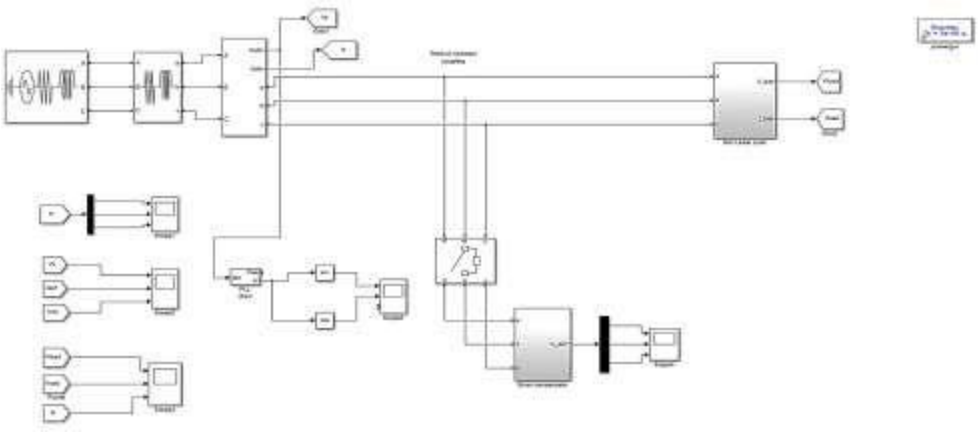

Figure 4.2: Simulink model of Shunt APF with d-q method

4.1 Design Parameters for MATLAB Simulation:

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

Table 1 System parameter specification

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

Table 2 SAPF parameter specification

Coupling Inductance	1mH
Coupling Resistance	0.01Ω
Dc link capacitance	1000μF
Source inductance	0.05mH
Source resistance	0.1Ω
Load resistance	0.001Ω
Load inductance	1μH

4.2 Simulink Result using p-q method:

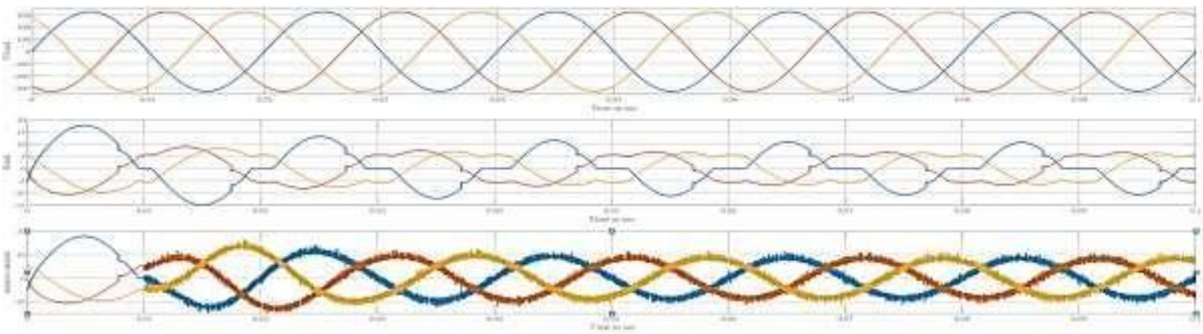

Figure 4.3: load voltage, load current and source current using P-Q method

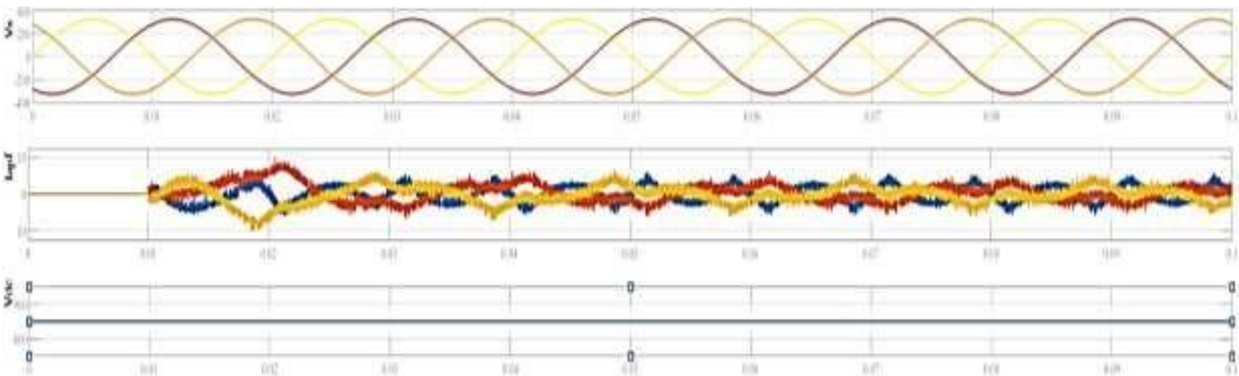

Figure 4.4: source voltage, APF Current Waveform and source current using P-Q method

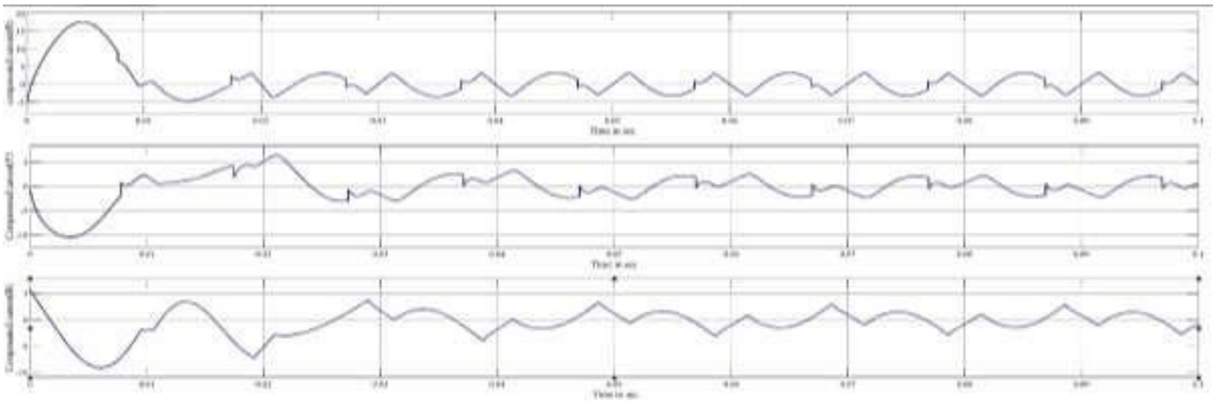

Figure 4.5: Compensating Current Waveform using P-Q method

4.3 FFT Analysis:

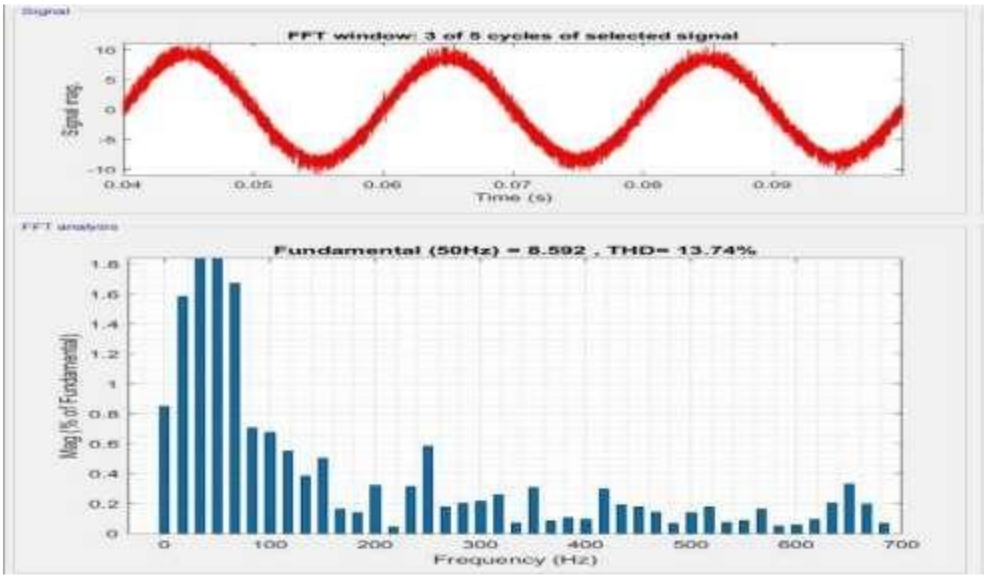

Figure 4.6 : FFT analysis of source current with SAPF using p-q method

4.4 Simulink Result using d-q method:

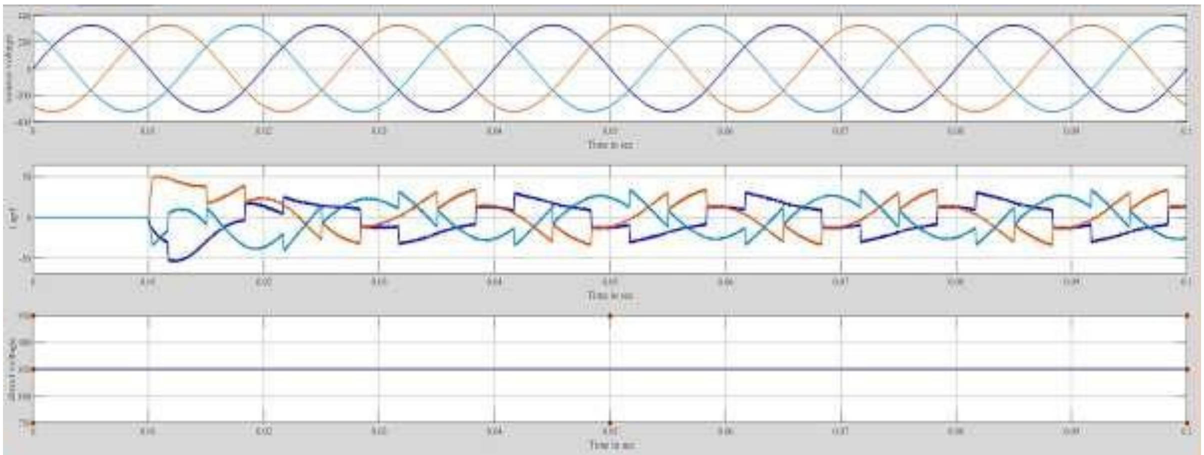

Figure 4.7: load voltage, load current and source current using d-q method

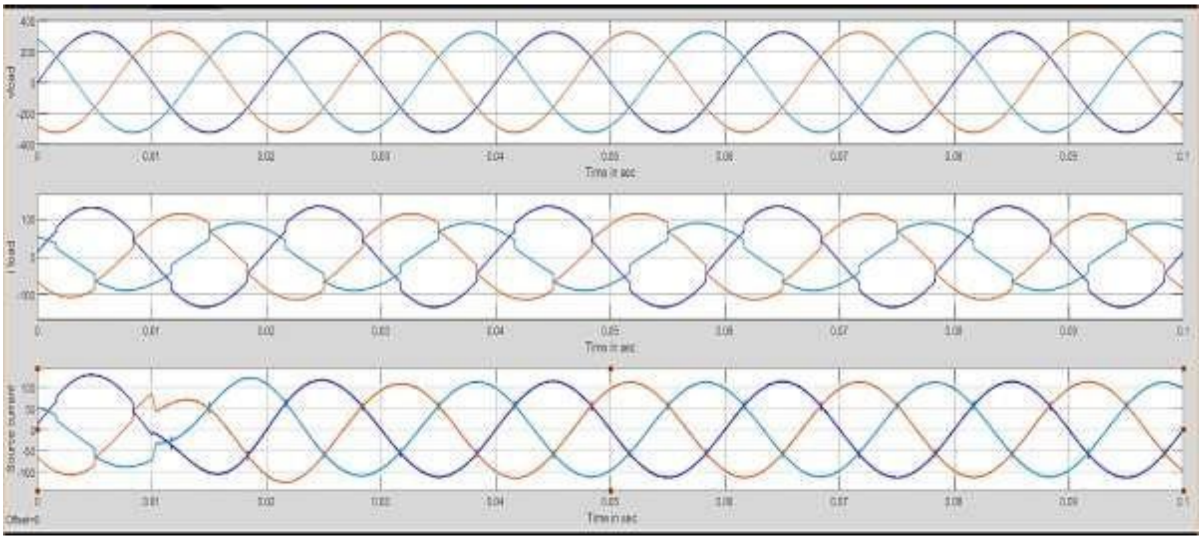

Figure 4.8: source voltage, APF Current Waveform and source current using d-q method

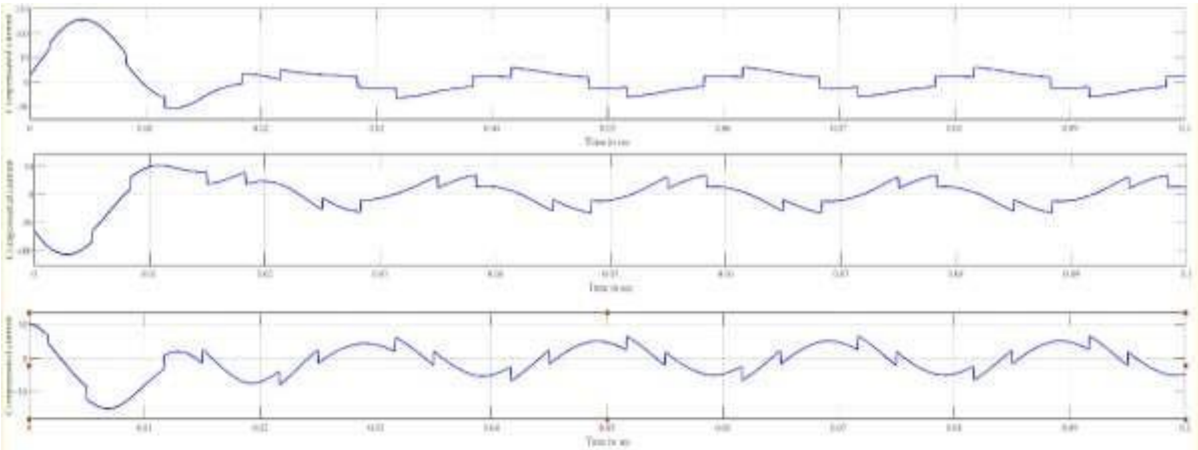

Figure 4.9: Compensating Current Waveform using d-q method

4.5 FFT Analysis:

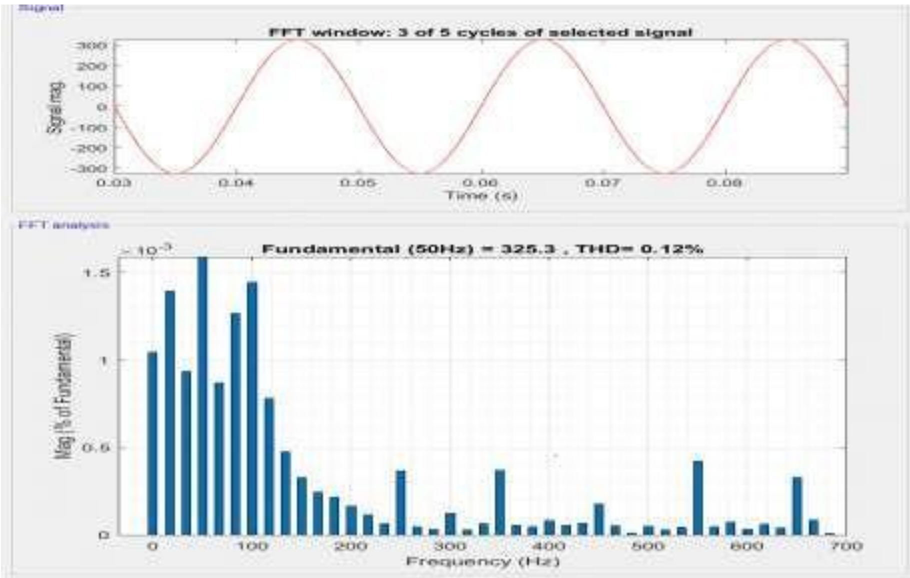

Figure 4.10: FFT analysis of source current with SAPF using d-q method

4.6 Comparative Analysis:

The comparative analysis between system with SAPF using p-q & d-q currentcontrol method based onFFT analysis is shown in table. Table shows the % of individualharmonics distortion w.r.t fundamentalpresent in the system er. As seen from the table the system with SAPF having d-q control strategy gives the better result as compared to the system with SAPF with p-q control strategy.

Table 3 comparative THD of P-Q and D-Q method

System	System with SAPF using 'p-q' method	System with SAPF using 'd-q' method
% THD	13.74%	0.12%

5. CONCLUSION:

An active filter based on the principle of instantaneous active and reactive current (id – iq method) compensation has been proposed in this project. A mathematical analysis of both instantaneous active and reactive power (p – q method) as well as id – iq method has been carried out to understand both the control scheme. Since the id – iq control method is based on a synchronous rotating frame derived from mains voltages without the phase locked loop (PLL) and has superior harmonic compensation performance, so simulation was carried out based on this control scheme. The harmonic component ofthe source is compensated for by the filter, as can be seen from the FFT analysis of the MATLAB/SIMULINK circuit model with filter. Employing the d-q method, the THD of the source current is reduced by nearly half, demonstrating that harmonic distortion is more effectively compensated when using a d-q control strategy than a p-q one. PWM-based current controllers may,in the future, provide an alternative solution to the d-q current control approach for eliminating harmonics in electrical utility systems while simultaneously maintaining system reliability and stability.

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