HARMONIC ELIMINATION IN THREE PHASE SYSTEM BY MEANS OF A SHUNT ACTIVE FILTER

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Abstract - *This paper presents Three-phase shunt active power filter for harmonic and power factor compensation of multiple non-linear loads. The most popular technique and widely used for reduction of harmonics in power system by shunt Active Power Filter (SAPF); Shunt Active Power Filter can easily eliminate unwanted harmonics, With the increase of non-linear loads in the power system, more and more filters are required. Active filter are designed and analyzed to improve the power quality at ac mains. This system is simulated using MATLAB/Simulink and the results are presented. As a result of the simulation, shunt active power filter is the better way to reduce the total harmonic distortion (THD).*

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

1. INTRODUCTION

The growing use of non-linear and time-varying loads has led to distortion of voltage and current waveforms and increased reactive power demand in ac mains. Then several problems are occurs such as a voltage unbalance, neutral currents problem, increased power losses, power factor reduction, decrease in efficiency, include overheating, capacitor failure, vibration, resonance problem, overloading, communication interference and power fluctuation. Various current detection methods, such as instantaneous reactive power theory, synchronous reference frame method. One of the method used for elimination is the use of shunt active power filter (SAPF) in which a reference current is generated to remove distortion from the harmonic currents. Among the various options available to improve power quality, the use of active power filters is widely accepted and implemented as a more flexible and dynamic means of power conditioning. They are easy to design, have simple structure, low cost and high efficiency. Thus to improve the performance it is required to eliminate harmonics from power utility system [1].

The SAPF is connected in parallel with the line through a coupling inductor. Its main power circuit consists of a three phase current source inverter with a DC link capacitor. An active power filter operates by generating a compensating current with 180 degree phase opposition and injects it back to the line so as to cancel out the current harmonics introduced by the nonlinear load. This will thus suppress the harmonic content present in the line and make the current waveform sinusoidal. So the process comprises of detecting the harmonic component present in the line current, generating the reference current, producing the switching pulses for the power circuit, generating a compensating current and injecting it back to the line. SAPF can be used with different current control strategy such as d-q method, fuzzy logic controller, p-q method, neural networks etc. which is helpful in removing effective Harmonic from power system.

1.1 OBJECTIVE OF PROJECT WORK

1. To design shunt active power filter to reduce total harmonic distortion.

2. To study the Power Quality issues in the industry.

3. To study the Harmonic limitation standards for voltage and current waveforms.

4. To model and simulate three phase shunt active power filter with different current control strategy in MATLAB/SIMULINK environment.

5. To compare different control strategies based on FFT analysis (an important tool for harmonic behavioral analysis) for harmonic elimination in power system network..To compare different control strategies based on FFT analysis (an important tool for harmonic behavioral analysis) for harmonic elimination in power system network.

2. HARMONIC AND HARMONIC COMPENSATION SCHEMES

2.1. SOURCE OF HARMONICS AND EFFECTS

Harmonics are caused by non-linear load, That is loads that draw a non-sinusoidal current from a sinusoidal voltage source. Some examples of harmonic producing loads are electric arc furnaces, static VAR compensators, inverters, DC converters, switch-mode power supplies, and AC or DC motor drives.

Power system problems related to harmonics are rare but it is possible for a number of undesirable effects to occur. High levels of harmonic distortion can cause such effects as increased transformer, capacitor, motor or generator heating, miss-operation of electronic equipment (which relies on voltage zero crossing detection or is sensitive to wave shape), incorrect readings on meters, miss-operation of protective relays, interference with telephone circuits, etc. The likelihood of such ill effects occurring is greatly increased if a resonant condition occurs. Resonance occurs when a harmonic frequency produced by a non-linear load closely coincides with a power system natural frequency.

2.2 HARMONIC MITIGATION TECHNIQUE

Improve the performance of power system and maintain particular THD limits in current harmonic distribution by Harmonic elimination techniques are used. Some of widely used equipments are:

1) Line reactors (Inductive reactor)

2) Isolation transformers (provide isolation of high power circuit from low power circuit)

3) K-Factor or harmonic mitigating transformers

4) Phase shifting transformer

5) Harmonic filters

But Harmonic filters are mostly used to reduce current harmonics in power system. Generally two types of harmonic filters are present: (1) passive filter and (2) active filters.

2.3 PASSIVE FILTER AND ACTIVE FILTER

For mitigating the harmonic distortion passive filtering is the simplest conventional solution [8]. Passive elements like resistance, inductance and capacitance are used by the passive filters to control the harmonics. Common types of passive filters and their configurations are depicted in Fig. 1.

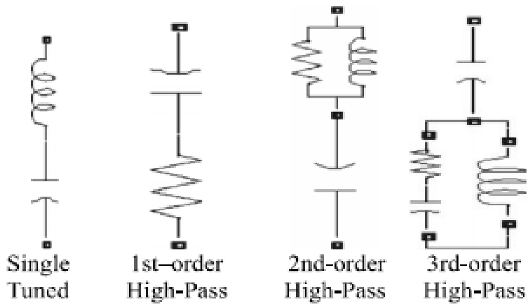

Figure: 1 Passive power filter configuration

The shunt connection of passive filters with the power system provides least impedance path to the harmonic current at tuning frequency. As compared to the shunt filter series filter is designed to carry full load current therefore they need over current protection devices. Whereas shunt passive filter carries a fraction of series filter current. The series filter is relatively more expensive hence shunt passive filter is commonly used as harmonic filter. Furthermore it also provides reactive power at system operating frequency.

Active power filters (APF) are filters, which can perform the elimination of harmonic in power system. Active power filters can be used to filter out harmonics in the power systems which are significantly below the switching frequency of the filter. The active power filters are used to filter out the higher and lower order harmonics in the power system.

The main difference between active power filters and passive power filters is that APFs mitigate harmonics by injecting Active power with the same frequency but with reverse phase to cancel that harmonic, where passive power filters use combination of Resistors, Inductors and Capacitors and does not require an external power source or active components. This difference, make it possible for Apfs to mitigate a wide range of harmonics.

2.3.2.1 OPERATION OF ACTIVE FILTER

Active power filters is the device which generate the same amount of harmonic as generated by the load. Use of some algorithm such as p-q theory, d-q transform, sliding mode control, DSP based algorithm etc. The compensating current generate by active filter 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. Harmonic current generate by inverter for the load through charging and discharging of DC link capacitor and injected into the transmission line through coupling transformer with a phase difference to compensate the reactive power coming from the AC mains.

Major types of Active filters are: (1) Series AF, (2) Shunt AF and (3) Hybrid AF.

3 LITERATURE REVIEW

3.1 SHUNT ACTIVE POWER FILTER

Figure 1 shows the basic compensation principle of the three phase shunt APF. It is designed to be connected in parallel with the nonlinear load to detect its harmonic and reactive current and to inject into the system. The compensation current references are generated based on the measurement of load currents. 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 degree. Phase shift with respect to the harmonic current. Generally SAPF uses a current controlled voltage source inverter (IGBT inverter) which generates compensating current (i_c) to compensate the harmonic component of the load line current and to keep source current waveform sinusoidal.

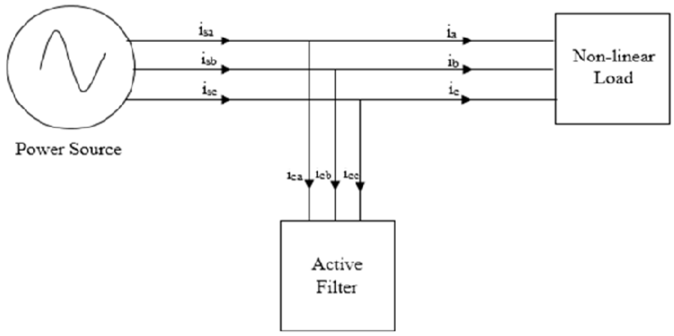

Figure: 2 Shunt Active Power Filter

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 methods for SAPF are discussed below.

3.2 INSTANTANEOUS REAL AND REACTIVE POWER THEORY (P-Q method)

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. The p-q method control strategy in block diagram form is shown in figure 2.

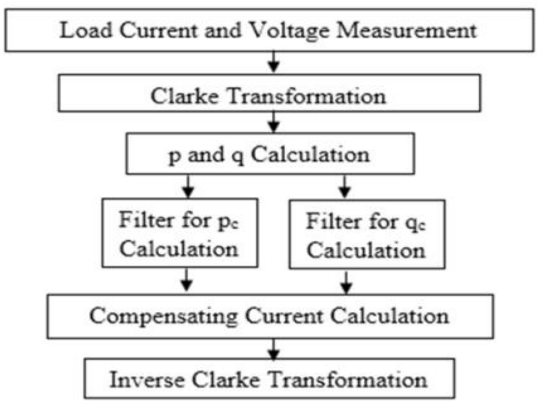

Figure: 3 P-Q method control strategy

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.

This method analysis the power instantaneously yet the harmonic suppression greatly depend 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.

3.3 HYSTERESIS CURRENT CONTROLLER

Hysteresis current control method is used to provide the accurate gating pulse and sequence to the IGBT inverter by comparing the current error signal with the given hysteresis band. In the hysteresis algorithm, the current error is positioned in between two fixed hysteresis bands. When the error exceeds either the upper or lower hysteresis limit, an appropriate switching command will be sent to the power switches, to limit the error within the preset band so as to produce the desired reference current.

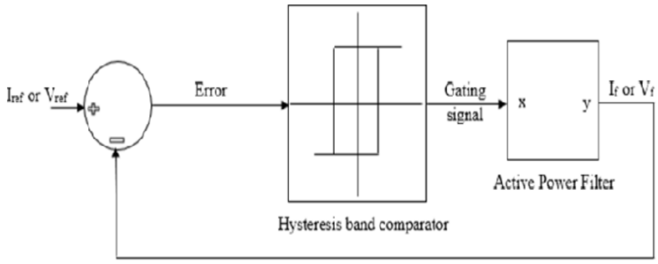

Figure: 4 Hysteresis Controller control logic

Asynchronous control of inverter switches causes the current of inductor to vary between the given hysteresis band, where it is continuously compare with the error signal, hence ramping action of the current takes place. This method is used because of its robustness, excellent dynamic action which is not possible while using other type of comparators.

There are two limits on the hysteresis band i.e. upper and lower band and current waveform is trapped between those two bands as seen from figure 4. When the current tends to exceed the upper band the upper switch of the inverter is turned off and lower switch is turned so that the current again tracks back to the hysteresis band. Similar mechanism is taking place when current tends to cross the lower band. This provides quick current control ability with high accuracy and does not require any information on system parameters Thus current lie within the hysteresis band and compensating current follow the reference current. Hence,

Upper limit hysteresis band = I_{ref} + max (I_e) and

Where, I_{ref} = Reference Current

Lower limit hysteresis band = I_{ref} - min (I_e) I_e = Error Current

As a result, the hysteresis bandwidth = 2*I_e.

Thus smaller the bandwidth betters the accuracy.

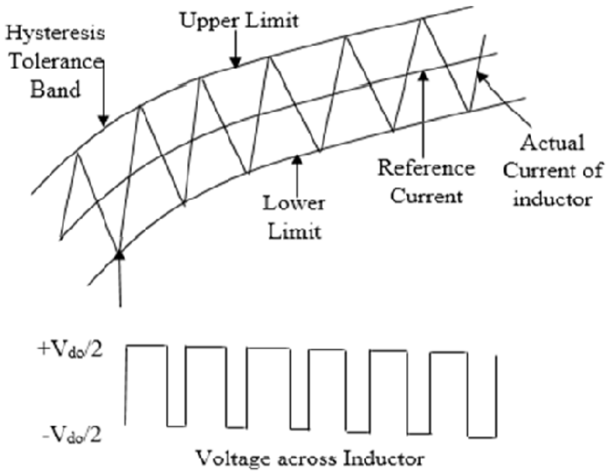

Figure: 5 Hysteresis Band

3.4 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. Synchronous d-q frame is derived from the space vector transformation of the input signals, which initially are achieved in the a-b-c coordinates from the sensors and then transformed into the d-q coordinates by means of the Park transformation. Here a-b-c coordinates are considered as stationary reference frame and d-q coordinates are considered as rotating reference frame with fundamental angular frequency. In d-q frame the fundamental currents are appeared as dc component and the harmonics as ac component. The d-q frame components are calculated using the Park transformation. 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.

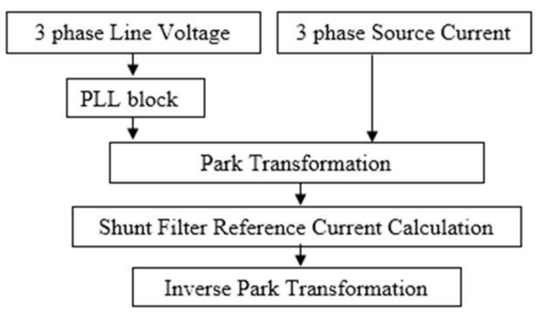

Figure: 6 D-Q method control strategy

4. MATHEMATICAL MODELLING

4.1 P-Q METHOD MATHEMATICAL MODELING

The relation between load current & voltage of three phase power system and the orthogonal coordinates (α-β- γ) system are expressed by Clarke's transformation,

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

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

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 coordinate system (a-b-c) is mutually orthogonal is nature, so we can found out instantaneous power,

$$p = v_a i_a + v_b i_b + v_c i_c \text{ .... (3)}$$

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

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \text{ .... (4)}$$

The instantaneous reactive power produces an opposing vector with 180 degree phase shift in order to cancel the harmonic component in the line current,

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} P_o + P_{loss} \\ 0 \end{bmatrix} \text{ ...... (5)}$$

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).

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

4.2 D-Q method Mathematical modeling

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

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

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.

$$i_{ld} = \bar{i_{ld}} + \tilde{i_{ld}} \text{ .... (8)}$$

$$i_{lq} = \bar{i_{lq}} + \tilde{i_{lq}} \text{ .... (9)}$$

After filtering DC terms ($\bar{i}_{lq}$, $\bar{i}_{ld}$) 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,

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

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.

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

5. SHUNT ACTIVE POWER FILTER SIMULATION MODEL AND RESULT

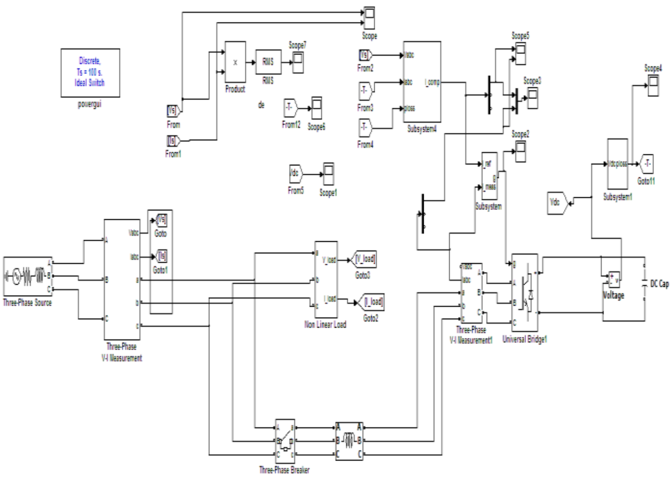

Figure: 7 System model with shunt active power filter

5.1 Simulation Result

The simulation result was obtained by in MATLAB/simulation environment using simulation power system Toolbox. Here a breaker is used to show the analysis during ON & OFF time of the Active power Filter. A slight distortion in current and voltage waveform is seen during switching of breaker which can be removed by using thyristor in series with DC link capacitor.

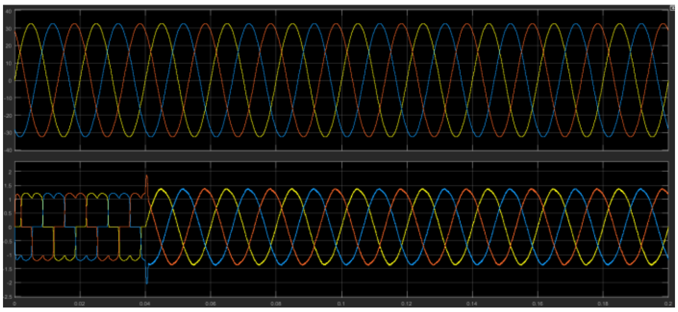

Figure: 8 Source Voltage Waveform before and after filtering with p-q method

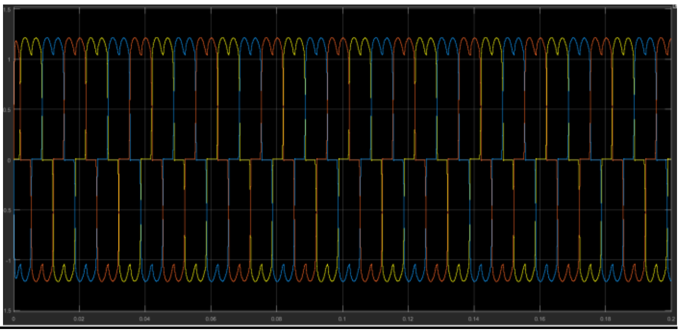

Figure: 9 Load Current Waveform before and after filtering with p-q method

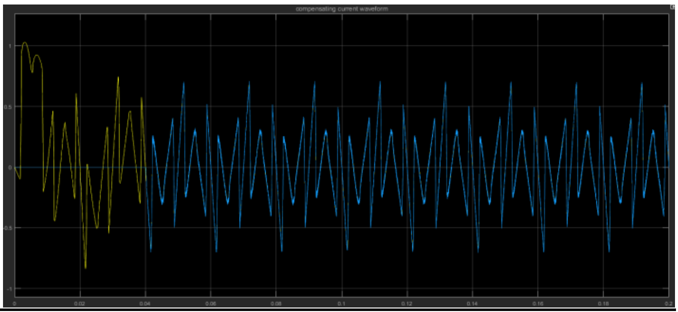

Figure: 10 Compensating Current Waveform

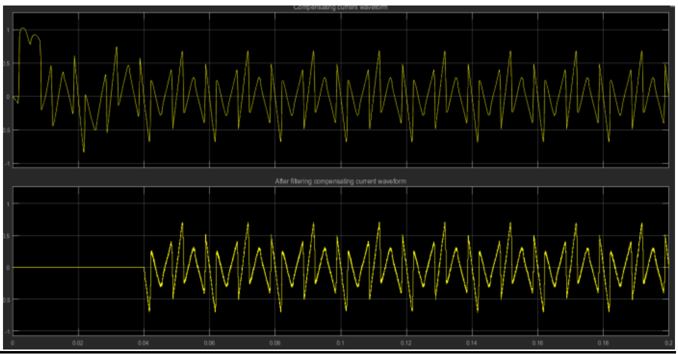

Figure: 11 Before and After filtering Compensating Current Waveform

6. FFT Analysis

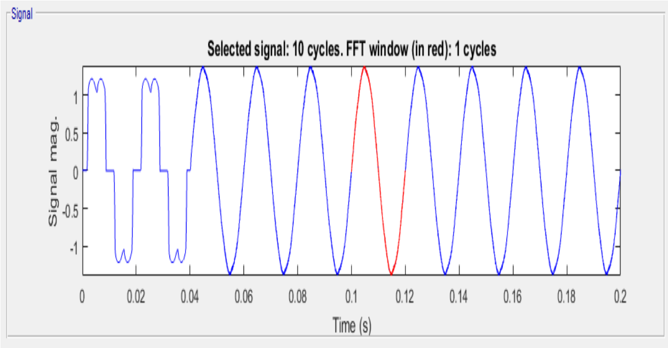

Figure: 12 FFT analysis signal of APF

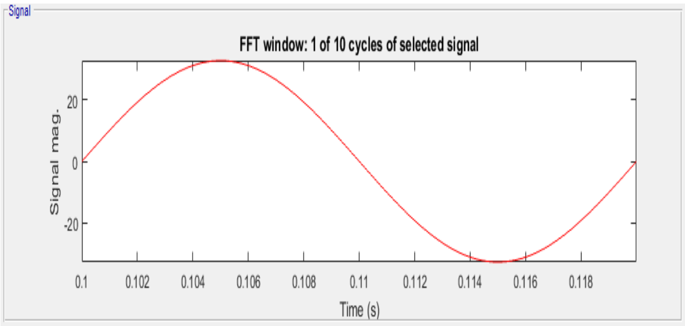

Figure: 13 FFT window

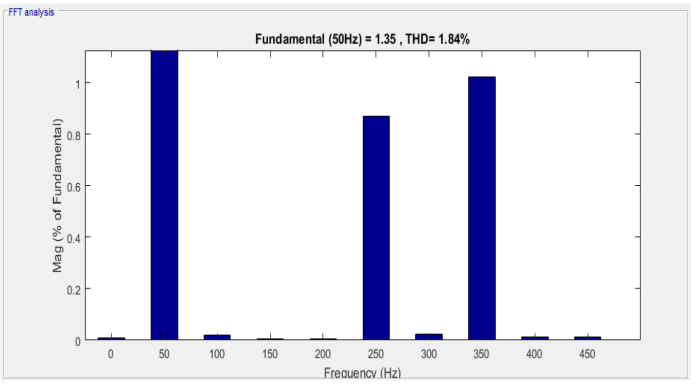

Figure: 14 FFT analysis Bar type (Relative to Fundamental)

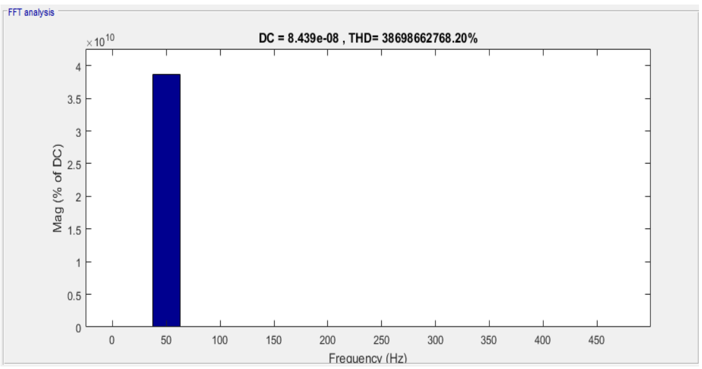

Figure: 15 FFT analysis bar type (Relative to DC link)

6.1 Comparative Analysis

The comparative analysis between system without SAPF and with SAPF using p-q & d-q current control method based on FFT analysis is shown in table 3 and 4. Table 3 shows the % of individual harmonics distortion with respect to fundamental present in the system and table 4 shows the Total Harmonic Distortion (THD) of the system before and after using filter. As seen from the table 3 and 4 the system with SAPF having d-q control strategy gives the better result as compare to the system without filter & SAPF with p-q control strategy.

Harmonic Order	System without SAPF	System with SAPF using 'p-q' method	System with SAPF using 'd-q' method
3rd order	0.03%	0.09%	0.06%
5th order	23%	0.75%	0.28%
7th order	11%	0.35%	0.16%
9th order	0.03%	0.04%	0.03%
11th order	9%	0.30%	0.12%
13th order	7%	0.26%	0.08%
15th order	0.03%	0.01%	0.01%
17th order	6%	0.24%	0.08%
19th order	5%	0.17%	0.07%

Table.3 Harmonic component as % of fundamental frequency component

System	System without SAPF	System with SAPF using 'p-q' method	System with SAPF using 'd-q' method
% THD	29.51%	0.99%	0.45%

Table.4 Total Harmonic Distortion of System with and without filter

6.2 Graphical Comparison

Graph shown in figure 16 summarize the performance of the distribution system without and with shunt active power filter.

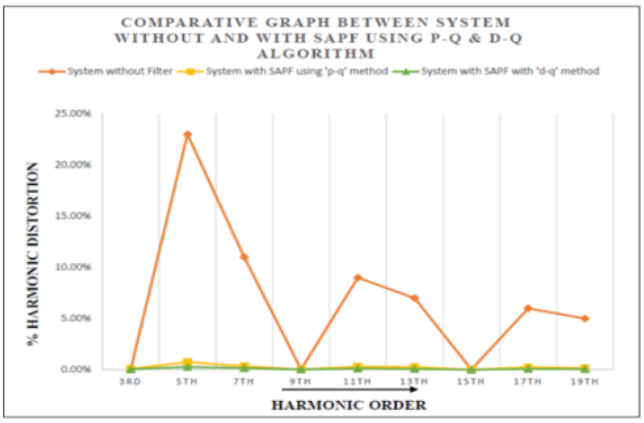

Figure: 16 Comparative Graphical analysis between System without and with SAPF

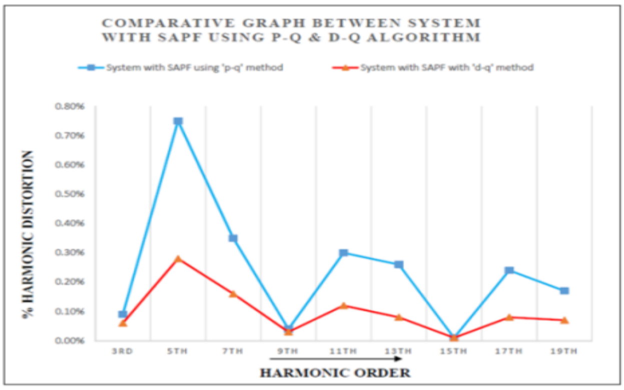

Figure: 17 Comparative Graphical analysis between p-q and d-q method

7 CONCLUSIONS

It clearly visible from the FFT analysis of the MATLAB/SIMULINK model of the circuit with and without filter that the harmonic component present in the source is compensated with use of filter. Further it is also seen that harmonic is compensated to a greater extent while using d-q control strategy instead of p-q i.e. the THD of source current is almost reduces by half while using the d-q method.

REFERENCES

[1] Grady, Mack. "Understanding power system harmonics." Austin, TX: University of Texas (2006).

[2] Morán, Luis A., et al. "Using active power filters to improve power quality." 5th Brazilian Power Electronics Conference. 1999.

[3] Jou, H-L. "Performance comparison of the three-phase active- power- filter algorithms." IEE Proceedings generation, transmission and distribution 142.6 (1995): 646-652.

[4] Chen, Chin Lin, Chen E. Lin, and C. L. Huang. "An active filter for unbalanced three-phase system using synchronous detection method." Power Electronics Specialists Conference, PESC'94 Record., 25th Annual IEEE. Vol. 2. IEEE, 1994.

[5] Singh, Ambrish Chandra, Kamal Al-Haddad, Bhim. "Computer-aided modeling and simulation of active power filters." Electric Machines &Power Systems 27.11 (1999): 1227-1241.

[6]Akagi, Hirofumi. "New trends in active filters for power conditioning." IEEE transactions on industry applications 32.6 (1996): 1312-1322.

[7] Akagi, Hirofumi. "Modern active filters and traditional passive filters." Bulletin of the Polish Academy of sciences, Technical sciences 54.3 (2006).

[8] Suresh, M., et al. "Comparison of two compensation control strategies for shunt active power filter in three-phase four-wire system." Innovative Smart Grid Technologies (ISGT), 2011 IEEE PES. IEEE, 2011.

[9] Ravindra, Sangu, et al. "Design of Shunt Active Power Filter to eliminate the harmonic currents and to compensate the reactive power under distorted and or imbalanced source voltages in steady state." International Journal of Engineering Trends and Technology 2.3 (2011): 20-24.

[10] Obulesh, Y. P., and Y. KusumaLatha. "Control strategy for 3phase shunt active power filter with minimum current measurements." (2011).

[11] Singh, Bhim, Kamal Al-Haddad, and Ambrish Chandra. "A review of active filters for power quality improvement." IEEE transactions on industrial electronics 46.5 (1999): 960-971.

[12] Mendalek, Nassar, and Kamal Al-Haddad. "Modeling and nonlinear control of shunt active power filter in the synchronous reference frame." Harmonics and Quality of Power, 2000. Proceedings. Ninth International Conference on. Vol. 1. IEEE, 2000.

[13] Kale, Murat, and Engin Ozdemir. "An adaptive hysteresis band current controller for shunt active power filter." Electric power systems research 73.2 (2005): 113-119.

[14] Charles, S., and G. Bhuvaneswari. "Comparison of three phase shunt active power filter algorithms." International Journal of Computer and Electrical Engineering 2.1 (2010): 175.

[15] Vyas, S. R., and Rajeev Gupta. "Emission Reduction Technique from Thermal Power Plant By Load Dispatch."

[16] Vyas, Sanjay R., and Ved Vyas Dwivedi. "Genetic Algorithm for Plant Generation Schedule in Electrical Power System."

[17] Vyas, S. R., and Rajeev Gupta. "Power Generation Schedule for Economical Aspects Using Evolutionary Technique."

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