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Simulation results of a shunt active power filter using p-q Theory Power Components Calculations

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Abstract: The active power filters have gained much more attention because of its excellent performance to mitigate the harmonic and reactive power issues. A shunt active power filter with Instantaneous active and reactive power theory (P-Q theory) has been proposed for its performance and ability to compensate the harmonics and reactive power.. It has been investigated through simulations that even under unbalanced and distorted conditions of AC distribution supply voltage and unbalanced loading, shunt active filter is able to produce the unity power factor and mitigate the Total Harmonic Distortion (THD) specified by power quality standards. Matlab/Simulink is used as a simulation tool for analysing.

Keywords: Shunt Active Power filter, Instantaneous Power Theory, PI controller, Reactive power, Hysteresis Current Controller HCC).

I. INTRODUCTION

The use of non-linear loads at the consumers end in the form of power electronic converters, UPS, electric arc furnaces, and growing use of adjustable speed motor drives is increasing day by day[1][2][3]. These power electronic loads inject harmonic currents and reactive power into the supply grid having significant impact on voltage and power quality, thus polluting the electric distribution network and also effect the operation of power electronic interface[4] . The presence of harmonics due to widespread use of power electronic loads results in an increased deterioration of the power systems voltage and current waveforms, because of line impedance, the voltage at the point of common coupling (PCC) is no longer remains sinusoidal[6] . The impact of non-linear loads on distribution power system. With a network then dominated by nonlinear components (power electronics coupling for generators and loads), non-sinusoidal regimes will be a common situation. It will be then the task of the power electronics interfaces to provide for the control features that can achieve an acceptable level of power quality required by the system operator or standards (given sensitive loads connected to the system). Among the features requested, sinusoidal currents, constant power supply, minimum current or minimum reactive power flow and load unbalance compensation will be the most demanding ones. But this work is concentrated on harmonics and unbalance compensation under unbalanced and distorted regimes.

II. NEED FOR SHUNT ACTIVE FILTER

The growing number of power electronics base equipment has produced an important impact on the quality of electric power supply. Both high power industrial loads and domestic loads cause harmonics in the network voltages. At the same time, much of the equipment causing the disturbances is quite sensitive to deviations from the ideal sinusoidal line voltage. Therefore, power quality problems may originate in the system or may be caused by the consumer itself. Harmonic distortion has traditionally been deal with by the use of passive LC filters. However, the application of passive filters for harmonic reduction may result in parallel resonances with the network impedance, over compensation of reactive power at fundamental frequency, and poor flexibility for dynamic compensation of different frequency harmonic components. Therefore, the increased severity of power quality in power networks demands for the development of dynamic and adjustable solutions to the power quality problems. Switching compensators called Active filters or active power line conditioners provide an effective alternative to the conventional passive LC filers. They are able to compensate current and voltage harmonics and reactive power, regulate terminal voltage, suppress flicker, and improve voltage balance in three phase systems. The advantage of active filtering is that it automatically adapts to changes in the network and load fluctuations.

III. Shunt Active Filter with Controller Based on Instantaneous p-q theory

The concept of Shunt Active Filtering was first introduced by Gyugyi and Strycula in 1976 [6]. Nowadays, a Shunt Active Filter is not a dream but a reality, and many SAFs are in commercial operation all over the world. The controllers of the Active Filters determine in real time the compensating current reference, and force the power converter to synthesize it accurately. In this way, the Active Filtering can be selective and adaptive. In other words, a Shunt Active Filter can compensate only for the harmonic current of a selected nonlinear load, and can continuously track changes in its harmonic content. The Instantaneous active and reactive power theory or simply the *p-q* theory is based on a set of instantaneous values of active and reactive powers defined in the time domain. There are no restrictions on the voltage or current waveforms, and it can be applied to three-phase systems with or without a neutral wire for three-phase generic voltage and current waveforms. Thus, it is valid not only in the steady state, but also in the transient state [16]. This theory is very efficient and flexible in designing controllers for power conditioners based on power electronics devices. Other traditional concepts of power are characterized by treating a three-phase system as three single-phase circuits. The *p-q* Theory first uses Clarke transformation to transforms voltages and currents from the *abc to αβ0* coordinates, and then defines instantaneous power on these coordinates. Hence, this theory always considers the three-phase system as a unit, not a superposition or sum of three single-phase circuits [16].

A. THE CLARKE TRANSFORMATION

The *αβ0* transformation or the Clarke transformation converts the three-phase instantaneous voltages in the *abc* phases, va, *vb and vc* into the instantaneous voltages on the αβ0 axes *v0, vα, and vβ.* The Clarke Transformation of three-phase generic voltages is given by:

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (3.1)$$

and its inverse transformation:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} \qquad (3.2)$$

Similarly, three-phase generic instantaneous line currents, *ia*, *ib*, and *ic*, can be transformed on the αβ0 axes by:

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (3.3)$$

and its inverse transformation:

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \tag{3.4}$$

The advantage of using the *αβ0* transformation is to separate zero-sequence components from the *abc*-phase component since α *and* β axes make no contribution to zero-sequence components.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & 1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{3.5}$$

and its inverse transformation:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{3.6}$$

Similar equations hold for the line currents. The transformation of equation (3.5) & (3.6) can also be shown in Figure 3.4.The instantaneous values of phase voltages and line currents referred to the *abc* stationary axes are transformed into the αβ0 stationary axes, or vice-versa. They are stationary axes and should not be confused with the concepts of voltage or current phasors. The, *b*, and *c* axes are spatially shifted by 120° from each other while the α and β axes are orthogonal, and the α axis is parallel to the *a* axis. The direction of the β axis is chosen in such a way that if voltage or current spatial vectors on the *abc* coordinates rotate in the *abc* sequence, they would rotate in the *αβ* sequence on the *αβ* coordinates.

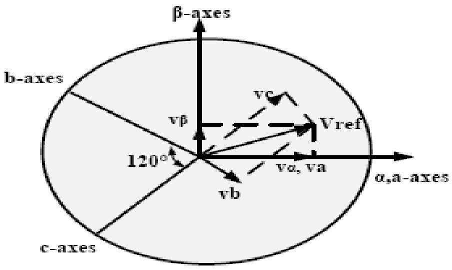

Fig. .1- Graphical Representation of Clarke Transformation

B. THE INSTANTANEOUS P-Q THEORY IN THREE-PHASE THREE WIRE SYSTEMS

The Clarke Transformation and its inverse transformation are power invariant and this property is very helpful when dealing with the analysis of instantaneous power in three phase systems.

The three phase instantaneous active power is given by:

$$p = v_a i_a + v_b i_b + v_c i_c$$

If current and voltages from αβ variables are replaced to their equivalent abc variables then the instantaneous imaginary power will be:

$$q = v_\alpha i_\beta - v_\beta i_\alpha$$

$$q = \frac{1}{\sqrt{3}} [(v_a - v_b)i_c + (v_b - v_c)i_a + (v_c - v_a)i_b]$$

$$q = \frac{1}{\sqrt{3}} [v_{ab} i_c + v_{bc} i_a + v_{ca} i_b]$$

Let us consider a three phase system with voltages *va*, *vb*, and *vc* are the instantaneous phase voltages and *ia*, *ib*, and *ic* the instantaneous line currents. Since zero sequence power in threephase three wire system is always zero .According to p-q theory real and reactive powers can be written as:

$$p = \tilde{p} + \bar{p}, q = \tilde{q} + \bar{q} \,\&p_0 = v_0 i_0$$

where

p = The active power for a three phase system with or without neutral conductor in steady state or during transients and it representing the total instantaneous energy flow per second between source and load.

q = The imaginary power and proportional to the quantity of energy that is being exchanged between the phases of the system. It does not contribute to energy transfer between source and load at any time.

p0= Active power due to zero sequence components.

p□ = Alternating value of the instantaneous real power exchanged between the power source and the load through the a-b-c coordinates. Since alternating value of the instantaneous real power does not involve any energy transference from the power source to load, it must be compensated. It is due to harmonic currents.

q□ = Alternating value of the instantaneous imaginary power exchanged between system phases and does not imply transfer of energy between power source and load. Since alternating value of the instantaneous imaginary power is unwanted, it must be compensated. It is also due to harmonic currents. All these powers are explained in Fig.2

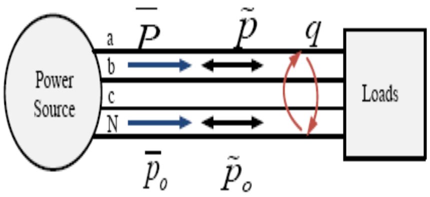

Fig. .2- Concept of different powers which are transferred and exchanged between power source and load [14]

IV. SIMULATION MODELLING

Simulation is very important and powerful tool to reduce development time and study the dynamics of the systems. In this work *MATLAB/SIMULINK* is used as a simulation tool to implement the proposed active filter and study the operation of the active power filter under different operating conditions. The *MATLAB/SIMULINK* tool is very effective as it offered an integrated environment between the designed control algorithm and the electrical network models.

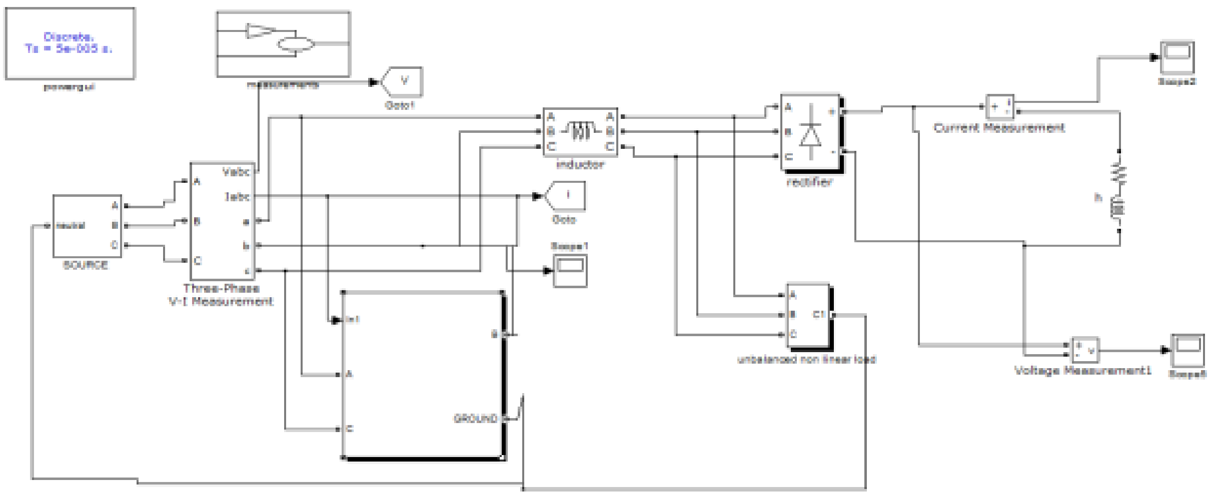

Fig.1- Complete diagram of Shunt Active Filter

A. MODELLING OF THE P-Q THEORY

The *p-q* theory model is modelled and is shown in the Figure 2. The inputs to the *p-q* controller are the currents form the non-linear load. The outputs are the three phase reference currents that are send to the *PWM* current controller where these currents are compared with the actual currents of the active filter to get the driving pulses of the inverter.

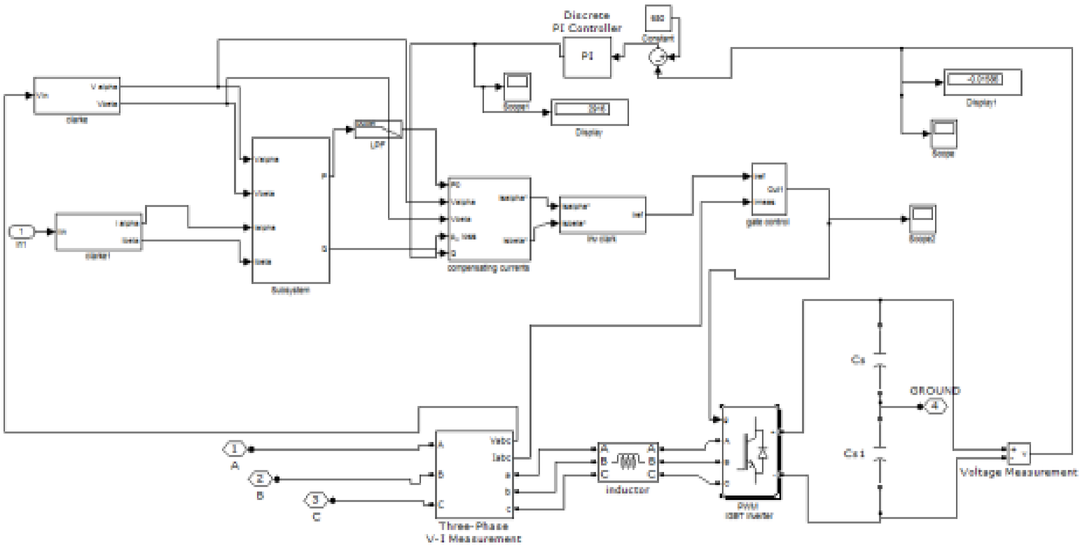

Fig.2- Subsystem of shunt active filter

V. SIMULATION RESULTS

A number of simulations have been performed to check the working of the shunt active power filter under various non-linear loadings (w.r.t connection of the loads at the PCC) and nonideal supply. The analysis of the results show that the working of the active filter is very satisfied to compensate the harmonics and reactive power even under unbalanced and distorted conditions of distribution supply

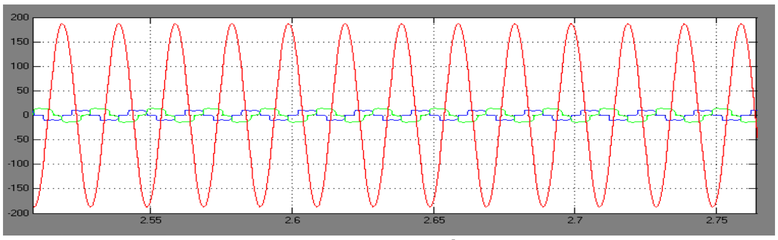

Fig.1- source current without SAF

Fig.1 shows source current without shunt active filter. Due to the presence of the non linear load, so the current waveform is in distorted manner. The current is taken along the Y-axis and time is taken along the X-axis.

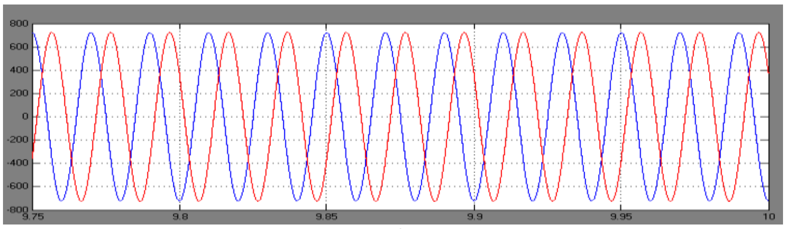

Fig.2- Iref current

Fig.2 shows Iref current which is simulated using MATLAB. By inverse Clarke transformation Iref current is calculated and in order to generate the gate pulse.

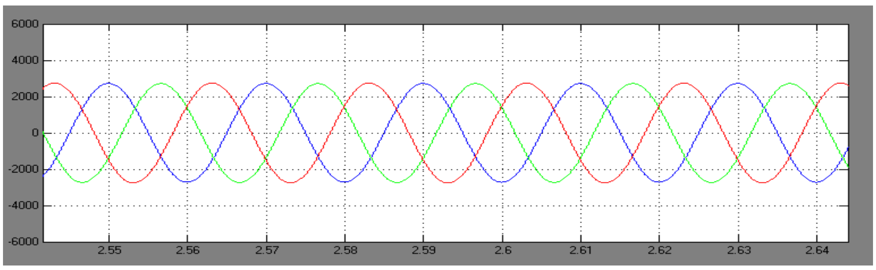

Fig.3- Source current with SAF

Fig.3 shows the sinusoidal waveform of the source current due to the implementation of the shunt active filter. The harmonic which gets induced due to the presence of the non linear load gets reduced and forming the nearby sinusoidal current.

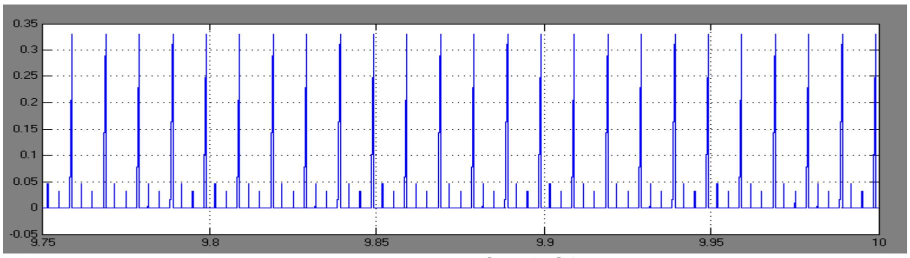

Fig.4-Capacitor voltage(Vdc)

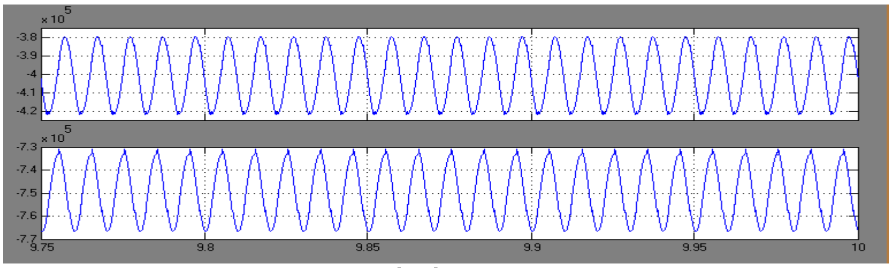

Fig.5-Real and Reactive power

The voltage of the capacitor at the voltage source converter, real and reactive power is shown in fig.4&5. The voltage maintained at the constant value by maintaining a constant voltage at the capacitor side.

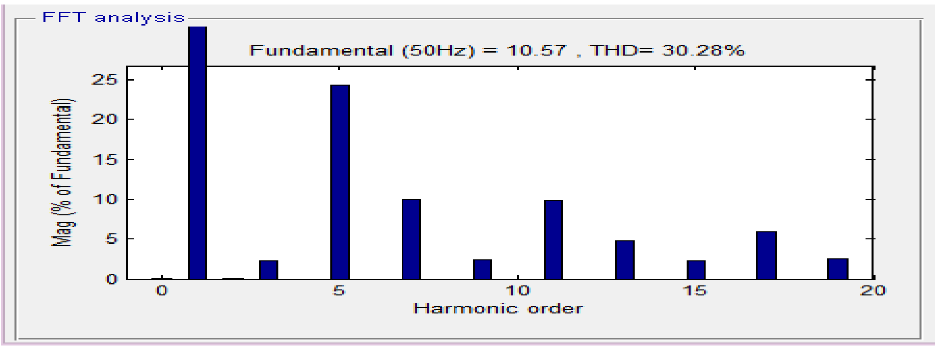

Fig.6- THD in source current before SAF

The following fig.6 shows the THD analysis of source current without SAF. THD is found to be 30.28% respectively due to nonlinear load which creates harmonics in the three phase system the IEEE standard THD value should be less than 2%. Inorder to reduce the THD the proposed system is implemented

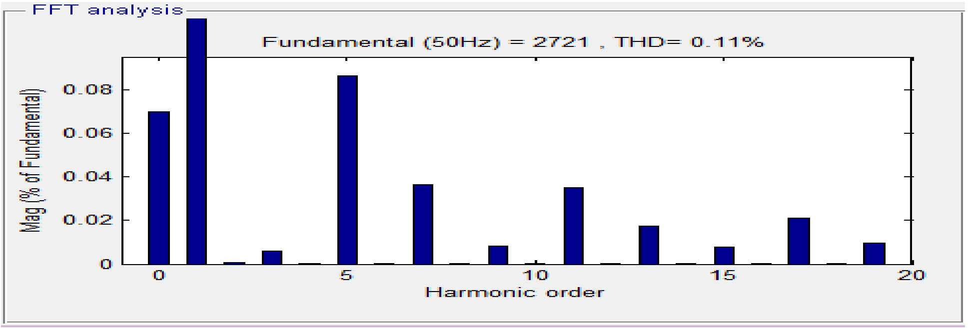

Fig.7- THD in source current after SAF

The following fig.7 shows the THD analysis of source current with SAF. THD is found to be 0.11% respectively.

TABLE.I

COMPARISON OF THD IN SOURCE CURRENT

THD IN SOURCE CURRENT BEFORE SHUNT ACTIVE FILTER	THD IN SOURCE CURRENT AFTER SHUNT ACTIVE FILTER
30.28%	0.11%

VI. CONCLUSION AND SCOPE OF FUTURE WORK

A. Conclusions

The three phase three wire shunt active filter with controller based on instantaneous active and reactive power (p-q) theory is simulated in MATLAB/SIMULINK to compensate the problems of the harmonics and reactive power which are encountered from power electronic non-linear loads. The performance of the shunt active power filter is investigated under different scenarios. It is investigated that the p-q theory based active filter manages to compensate the harmonics and reactive power of the power distribution network even under unbalanced and distorted supply voltages. The active power filter is able to reduce the THD in source current at a level well below the defined standards specified by power quality standards. The THD in source current after the active filtering is not exactly zero. It is because internal switching of the compensator itself generates some harmonics. In each of the case studied, the source current after the working of the active filter becomes perfectly sinusoidal, free from harmonics and in-phase with voltage of the main supply maintaining the unity power factor. In each simulation studied, multiple non-linear loads have been used to investigate the time response of the active filter. In each case it has noted that filter is successfully able to follow the reference currents with one power cycle with change in loads. It has been noted that if voltage unbalance or distortion or both are present in the system, the simple p-q theory didn't work well. It give rise the demand of the fundamental positive sequence voltage detector to extract the fundamental positive voltage form the unbalanced or distorted voltage. Once the fundamental positive sequence voltage is extracted, the theory worked very well. Even though the p-q theory has managed to compensate the harmonics and reactive power of the system and to produce the sinusoidal source current with unity power factor and free from harmonics.

B. Future Work

The scope of the future work can be to look for the solution of the following points:

- This work is based on three phase three wire system and the active filter does not work well if there is a zero sequence in the supply voltage. In future, a detailed analysis can be carried out for a 3 phase four wire filter in order to compensate the zero sequence present in the system.
- The work done in this thesis can be verified in the laboratory and further experimental study can be done to implement the APF for the compensation of harmonics and zero sequence.

References

1. G.Tsengenes, G. Adamidis, "A New Simple Control Strategy for Shunt Active Power Filters under Non Ideal Mains Voltages," SPEEDAM 2010 International Symposium on Power Electronics, Electrical Drives, Automation and Motion.
2. Dannana Santosh, Banoth Madhu and Manjeet V Kanojiya, "Instantaneous Active and Reactive Current Component Method for Active Filters under Balanced & Unbalanced mains Voltage Conditions for 3-ph 3-wire System," Thesis 2011-2012.
3. Ahmed M. Mohammad, "Analysis and Simulation of Shunt Active Filter for Harmonic Cancellation of Non Linear Loads", 03.06.2010.
4. Elisabetta Tedeschi, "Cooperative Control of Distributed Compensation Systems in Electric Networks Under Non-Sinusoidal Operations" Thesis.
5. Surajit Chattopadhyay, Madhuchhanda and Mitra Samarjit Sengupta, "Electric Power Quality," December 2010
6. Mohd Izhar Bin A Bakar, "Active Power Filter with Automatic Control Circuit for Neutral Current Harmonic Minimization Technique", june 2007.
7. N. Mohan, T. Undeland, W. Robbins, "Power Electronics: Converters, Applications, and Design," J. Wiley & Sons, 2003.
8. Santoso, Surya and Grady, W. M. Understanding Power System Harmonics. IEEE Power Engineering Review. 2001. 21 (11): 8-11.

9. Galli, W., Skvarenina, T. L., Chowdhury, B. H. and Akagi, H. Power Quality and Utility Interface Issues. In: Skvarenina, T. L. The Power Electronics Handbook, United State of America: CRC Press LLC. 2002.
10. David Mark Edward Ingram, “An Evaluation of Harmonic Isolation Techniques for Three Phase Active Filtering,” Master thesis, 1998.
11. Rana Abdul Jabbar Khan, and Muhammad Akmal, “Mathematical Modeling of Current Harmonics Caused by Personal Computers,” World Academy of Science, Engineering and Technology 39 2008
12. João Afonso, Carlos Couto, Júlio Martins, “Active Filters with Control Based on the p-q Theory”, IEEE Industrial Electronics Society Newsletter Sept. 2000
13. Dinesh Khera, “Simulation of Voltage Source Converter Based Shunt Active Filter in EMTP-RV,” Master thesis august, 2010
14. Stefan Svensson, “Power measurement techniques for non-sinusoidal conditions,” Doctoral thesis, 1999
15. Shailendra Kumar Jain & Pramod Agarwal, “Design Simulation and Experimental Investigations, on a Shunt Active Power Filter for Harmonics, and Reactive Power Compensation,” Electric Power Components and Systems, 31:671–692, 2003
16. Maamar Taleb, “A New Active Filter for Power Distribution Systems,” Electric Machines and Power Systems,” 27:39–52, 1999
17. Ali I. Maswood and M.H. Haque, “Harmonics, Sources, Effects and Mitigation Techniques,” Second International Conference on Electrical and Computer Engineering ICECE 2002, 26-28 December 2002, Dhaka, Bangladesh
18. Abdelaziz Zouidi, Farhat Fnaiech and Kamal AL-Haddad, “Voltage Source Inverter Based three phase shunt active Power Filter: Topology, Modeling and Control Strategies”, IEEE ISIE 2006
19. Chennai Salim and Benchouia Mohamed Toufik, “Intelligent Controllers for Shunt Active Filter to Compensate Current Harmonics Based on SRF and SCR Control Strategies,” International Journal on Electrical Engineering and Informatics - Volume 3, Number 3, 2011
20. H. Akagi, E.H. Watanabe, and M. Aredes, "Instantaneous power theory and applications to power conditioning, “Electrical Engineering, 2007.
21. E. H. Watanabe, H. Akagi, and M. Aredes, “Instantaneous p-q Power Theory for Compensating Nonsinusoidal Systems,” International School on Nonsinllsoidal Currents and Compensation, Lagow, Poland, 2008.
22. Harnaak Singh Khalsa, “Generalised Power Components Definitions for Single and Three-Phase Electrical Power Systems under Non-Sinusoidal and Nonlinear Conditions,” Doctoral thesis, December, 2007
23. Mohamed El-Habrouk, “A New Configuration for Shunt Active Power Filters”, Phd Thesis 1998
24. M. El-Habrouk, M. K. Darwish, and P. Metha, “Active power filter: A review,” Electric Power Applications, IEEE Proceedings-, Volume 147, Issues: 5, Pages: 403-415, September 2000.
25. S. J. Chiang and J. M. Chang, “Design and Implementation of the Parallelable Active Power Filter,”
26. Nadeem Jelani, “Optimal Operation of a Distributed System with High Share of Power Electronic Loads,” Master Thesis, July 2010.
27. Muhammad H. Rashid, “Power Electronics Handbook,” Academic Press, 2001

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