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Article *in* Australian Journal of Basic and Applied Sciences · March 2014

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Australian Journal of Basic and Applied Sciences, 8(2) February 2014, Pages: 71-77

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

A Two Level Shunt Active Power Filter without PLL for Industrial Loads

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ARTICLE INFO

Article history:
Received 23 December 2013
Received in revised form 25 February 2014
Accepted 26 February 2014
Available online 15 March 2014

Keywords:
Unit Vector Generation, Shunt Active Power Filter, Phase Locked Loop, Harmonic Reduction, Power Factor

ABSTRACT

Background: To improve the quality of the electrical power to the consumers, many power electronic based solutions are available. In the case of active power factor compensation, grid tied voltage source inverter based Shunt Active Power Filter is one of the versatile solution. But in this system most of the control strategies demand generation of unit vector based on the grid voltage for vector orientation. But presence of harmonics in grid voltages and the level of noise in the grid voltage sensing circuits will make estimation of unit vector difficult and PLL circuits will become a necessity. This paper presents a simple and efficient method to evaluate the unit vector without the use of PLL or any hardware filter. This method was used in d-q reference frame control strategy for shunt active filter and was simulated with a 100 kVAR system. The MATLAB/SIMULINK simulation results are presented to validate the effectiveness of this control strategy.

To Cite This Article: Elangovan, S., Thanushkodi, K., Neelakantan, P.N.., A Two Level Shunt Active Power Filter without PLL for Industrial Loads. ***Aust. J. Basic & Appl. Sci.,*** *8(2): 71-77, 2014*

INTRODUCTION

Process industries use wide range of variable speed motor drives, ac plants, UPS systems and various power electronic converters to improve system efficiency and hence the productivity. These loads draw reactive power from the grid. Excess reactive power will result in poor voltage regulation and poor utilization of ac network, mainly the distribution transformer for the plant. These constraints make it necessary to compensate reactive power. Traditionally, passive elements like ac capacitor banks are used for reactive power compensation. But the effectiveness of these capacitors is limited. Moreover they have some disadvantages like drawing fixed amount of leading reactive power irrespective of the load requirements. For continuously varying load, which is the case in most of the process industries, these fixed capacitor banks fail to control the power factor effectively.

Thyristor switched or mechanically switched capacitor banks are also used to improve this situation. But they too cannot maintain the power factor near unity when the load varies rapidly. Also, the life span of these passive elements is less due to load harmonics, current sinking and these results in regular maintenance. Due to these limitations of passive filters, various active filters have been reported for reactive power compensation.

In this paper, synchronous d-q reference frame based control strategy is presented for a 100 kVAR two-level shunt active filter. The control law is derived for the compensation of reactive power drawn from grid. This paper also presents a simple and efficient method of unit vector generation, which will minimize the effect of harmonics and noise present in the grid voltage feedback

Shunt Active Power Filter:

The basic block diagram of a three phase shunt active filter is shown in Fig. 1. This STATCOM is primarily a voltage source inverter connected to Point of control, Several control strategies, such as Instantaneous reactive power based hysteresis current controller (Akagi, H., 1984), sliding mode controller (Saetieo, S., 1997; Marthinus, G.F., 2004), synchronous reference frame controller (Sensarma, P.S., 2000) etc. have been proposed and developed for a three phase voltage source inverter based shunt compensator. Most of these control strategies require computations using the grid voltage sensed at PCC.

But the source harmonics and the noise in the feedback circuit for grid voltage restrict direct use of the voltage signals in the control algorithm. The harmonics present in the grid voltage can be filtered using hardware band-pass filter (Sensarma, P.S., 2000). But, it is very difficult to design such a filter with precise choice of cut-off frequency that would separate out the fundamental without appreciable phase errors. Some

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work has been reported on the use of PLL to remove the effect of harmonics and noise in the grid voltage. But the design of a high performance PLL is not so easy when various non-idealities like multiple zero crossing in the grid voltage are occurring.

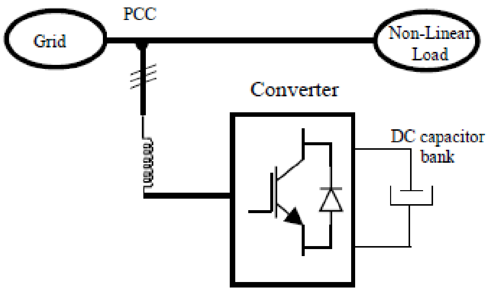

Fig. 1: Grid tied VSI based Shunt Active Power Filter.

Proposed Scheme:

As mentioned earlier, the three phase shunt active filter is a fully controlled three phase boost converter, which is connected to the grid through a three-phase series choke. This converter supplies the required reactive power to the load to maintain the grid side power factor unity. The series choke separates the two voltage sources namely grid and inverter. The capacitor voltage is maintained at a constant value by closed loop control, which regulates the active power drawn from the grid and caters to the internal losses of the system.

Synchronous d-q reference frame based control strategy is proposed to control this converter. This control strategy requires sensing of grid voltage and generation of unit vectors for the orientation along the grid voltages. Fig. 2 explains the method adopted to reduce the effect of harmonics and noise in the grid voltage feedback.

The sensed grid voltages are filtered using a first order digital low pass filter whose corner frequency isω_c. In the present work, ω_c is chosen to be equal to the nominal grid frequency (50 Hz). So, after filtering, the percentage of hth order harmonics of the sensed grid voltage is reduced by a factor of $\sqrt{\frac{2}{(h^2+1)}}$ (assuming fundamental voltage is always 100%. It is clear that 5th and higher order harmonics, which can normally be present in the line-to-line grid voltage, are reduced considerably using this low pass filter. High frequency noise gets eliminated almost completely. Finally, dividing the filter output signals with their magnitude generates the required unit vectors.

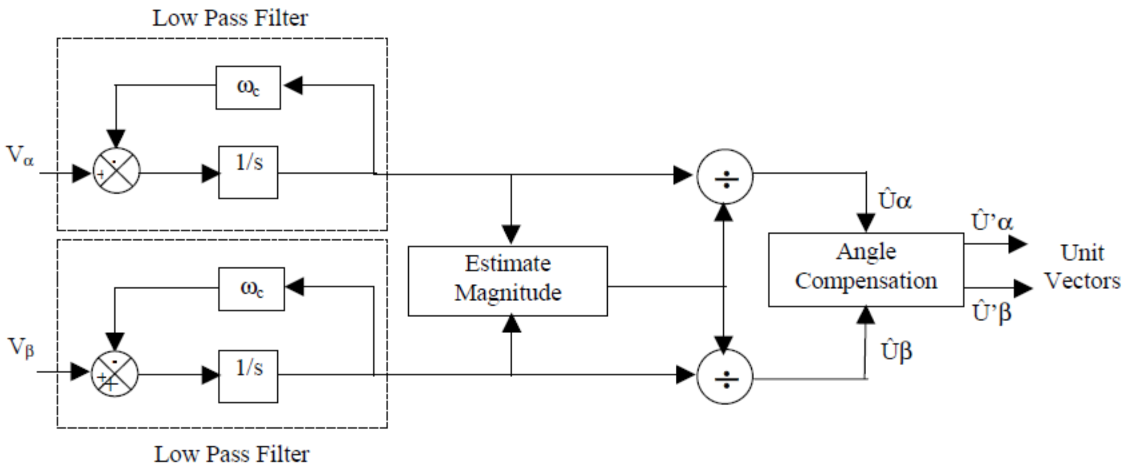

Fig. 2: Block diagram of Unit Vector generation.

However, this low pass filter introduces a phase lag to the unit vector generation. For nominal grid frequency (50Hz), this phase lag is 45^0 and can be easily compensated (Fig. 2). However, the grid frequency varies with a small range (±2.5 Hz). So, there is a small phase error in unit vector generation if constant phase compensation is done. In the next section, synchronous d-q frame based control strategy is explained using this unit vector.

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Control Strategy:

The control scheme is presented in Fig. 3. The three phase currents of the load and the converter are transformed into the synchronously rotating reference frame using (1) and (2).

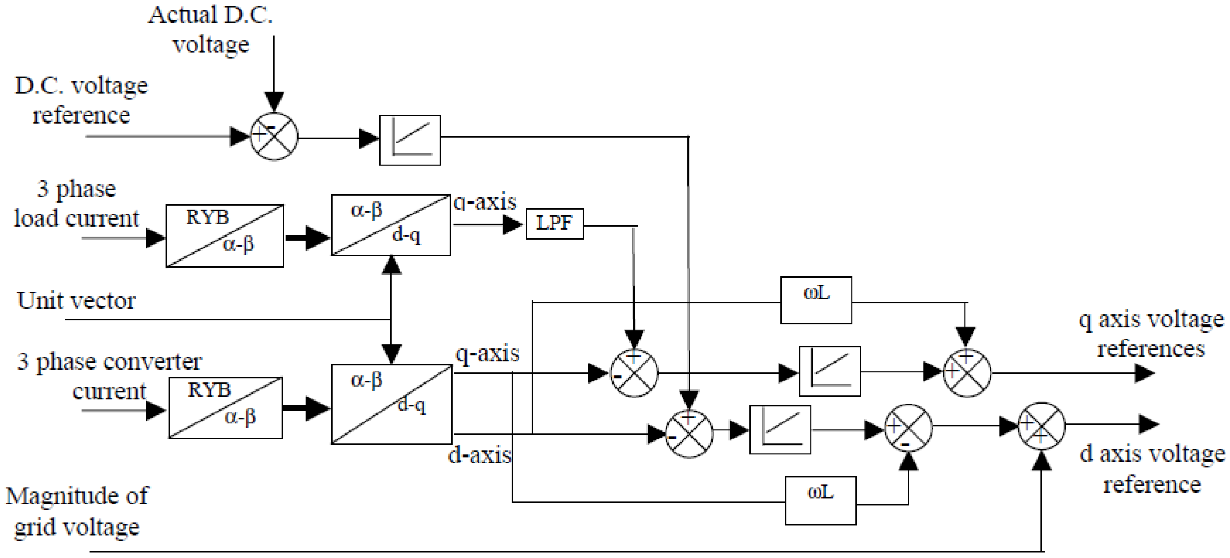

Fig. 3: Control Scheme for Shunt active power filter.

The Unit vector required for the transformation is generated with grid voltages as described earlier. In other words the first step in the control scheme is orienting the converter and grid current along the grid voltage. The load current will be a composite current containing the fundamental and harmonics. After orientation, the fundamental components of d-axis and q-axis currents are the active and reactive parts respectively of the fundamental load currents. For grid reactive power compensation, this fundamental q-axis load current is used as the reference of q-axis current controller of the converter. There is a closed loop PI controller to maintain the dc bus constant. The output of this controller generates the reference of d-axis current controller of the converter.

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

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} cos\omega t & -sin\omega t \\ sin\omega t & cos\omega t \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{2}$$

The control law [6]-[7] along the d and q axis is given below:

$$\mathrm{V_d} = \mathrm{i_d R} + \mathrm{L}\frac{\mathrm{di_d}}{\mathrm{dt}} - \omega \mathrm{Li_{q+}V_g} \tag{3}$$

$$V_q = i_q R + L\frac{di_q}{dt} - \omega L i_d \tag{4}$$

Here R and L are the resistance and inductance of the series choke. Vd and Vq are d and q axis voltage commands respectively. There are two PI current controllers to control the d-axis and q-axis current of the converter. The outputs of these current controllers are added with feed forward terms based on (3) and (4) to generate the d-axis and q-axis voltage references for the converter. Finally, d-q voltage references are transformed back to 3-phase stationary voltage references using the unit vectors. These reference signals are fed to the PWM modulator to generate the gate pulses for the converter.

Simulation:

The whole system is simulated in MATLAB. The three-phase source voltages are assumed to be balanced and sinusoidal. A load with highly nonlinear characteristics is considered for the load compensation.

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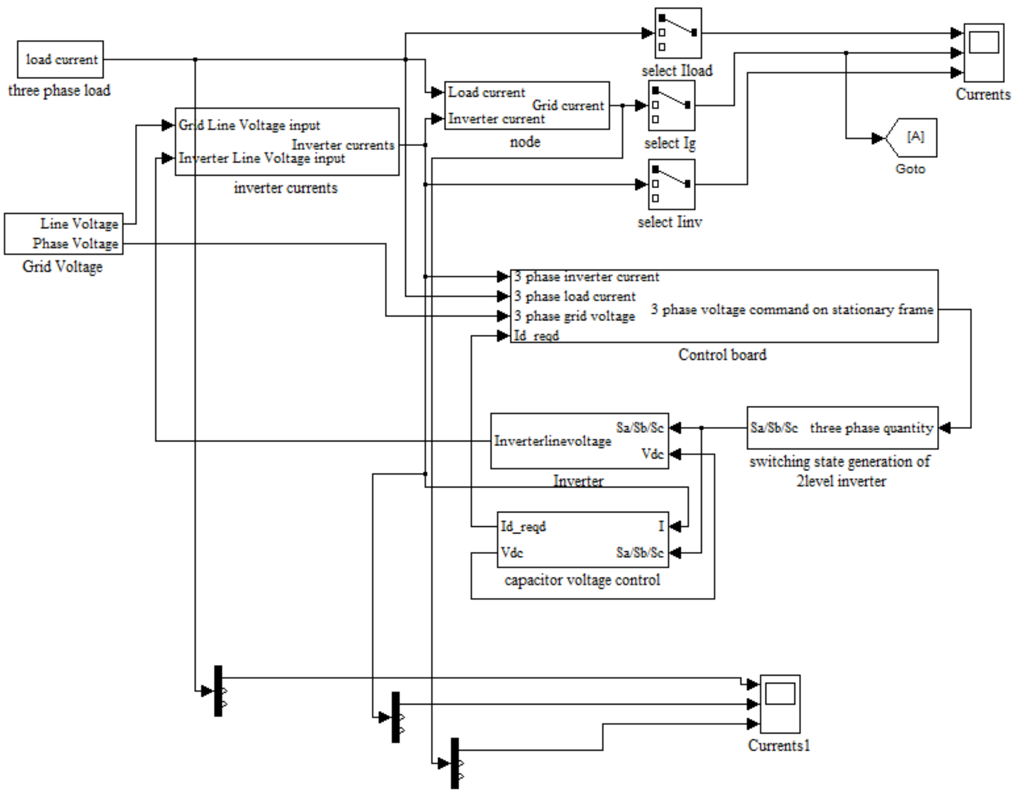

Fig. 4: MATLAB/SIMULINK diagram of the overall system of Shunt active power filter.

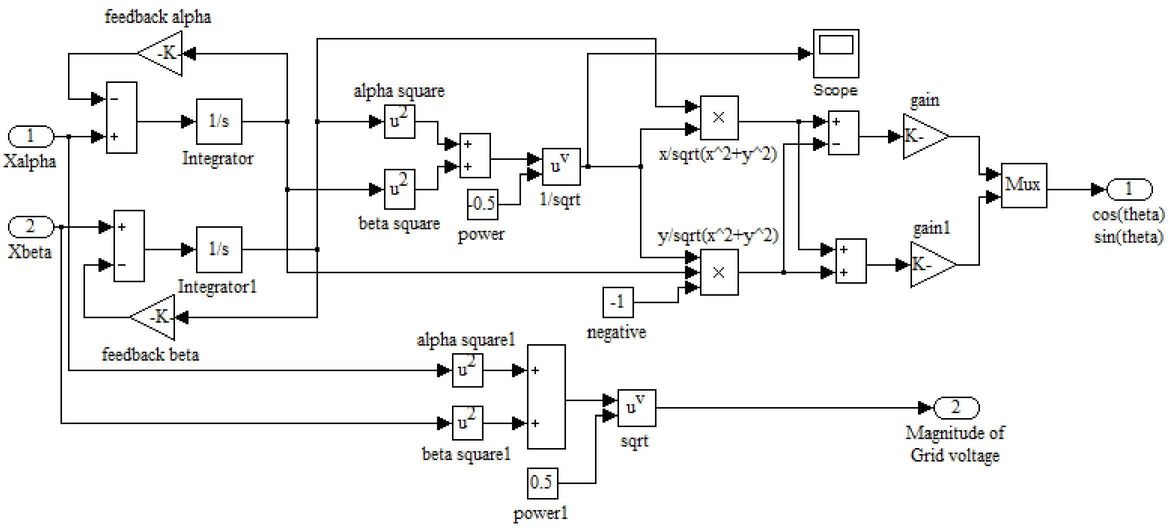

Fig. 5: MATLAB/SIMULINK diagram of Unit vector generation.

Results and Analysis:

The simulation result clearly shows that the control algorithm improves the power factor and the grid current is sinusoidal and so it can viewed that the harmonics are reduced as shown in the Fig.6.

The simulation results at other two phases namely phase B and phase C have also shown similar results as in the figures 7 and 8.

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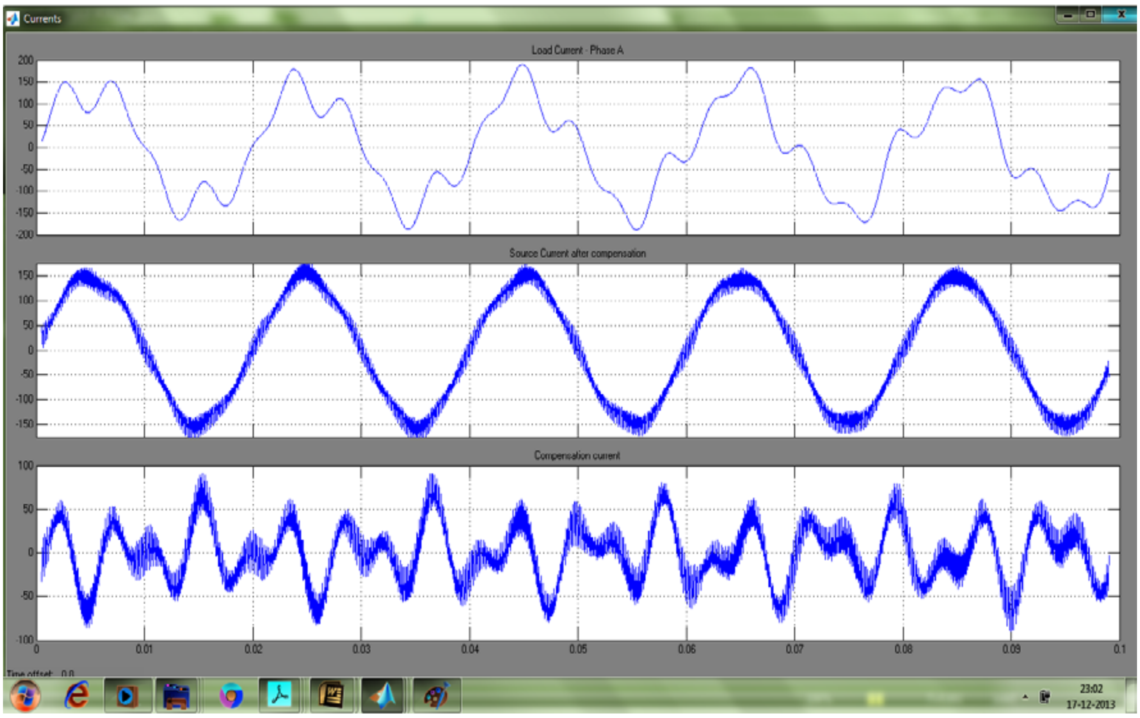

Fig. 6: MATLAB/SIMULINK result of phase 'A' showing the a) load current for 100kVAR load b) source current after compensation c) compensation current injected by the filter into to the point of common coupling.

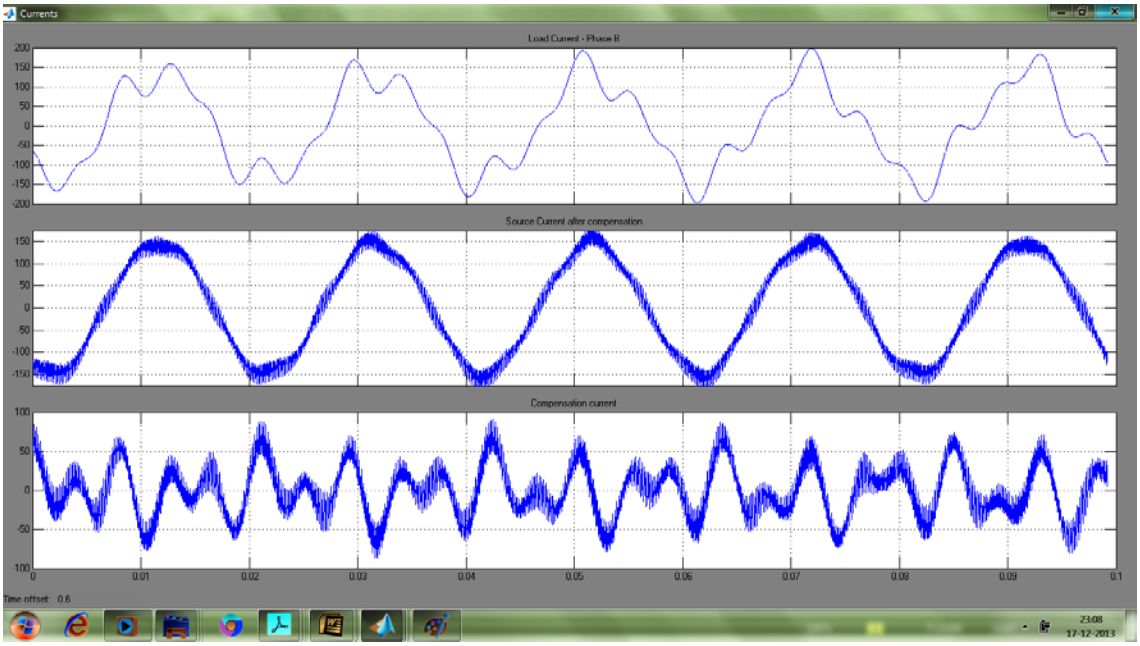

Fig. 7: MATLAB/SIMULINK result of phase 'B' showing the a) load current for 100kVAR load b) source current after compensation c) compensation current injected by the filter into to the point of common coupling.

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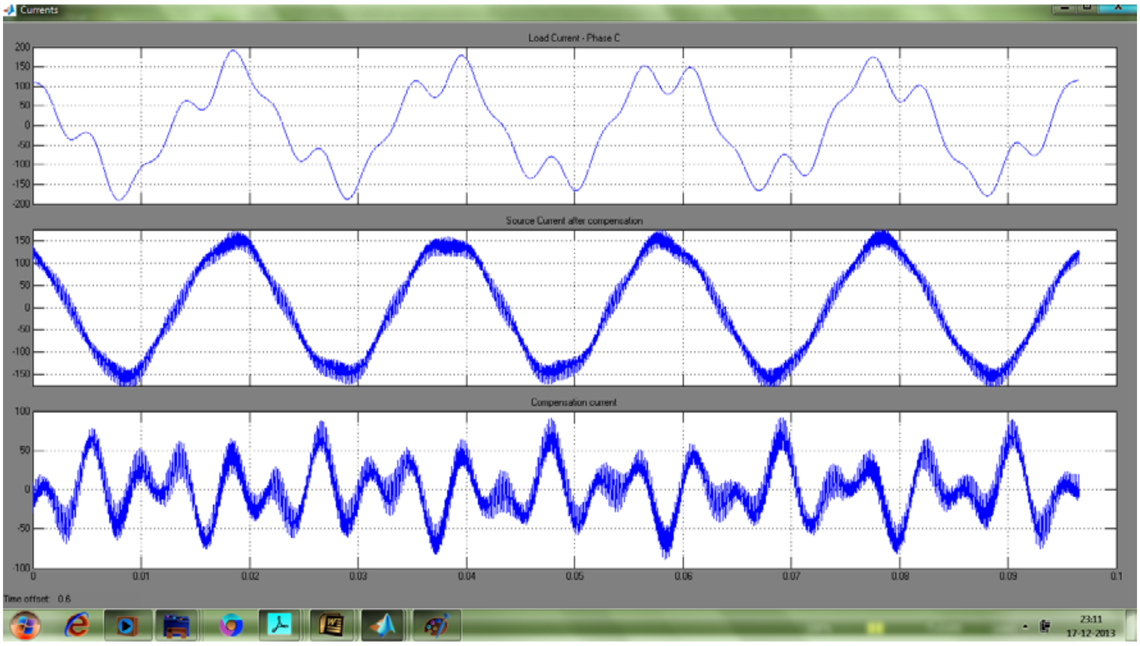

Fig. 8: MATLAB/SIMULINK result of phase 'C' showing the a) load current for 100kVAR load b) source current after compensation c) compensation current injected by the filter into to the point of common coupling.

Conclusion:

This paper proposed an improved algorithm to generate unit vector from the sensed grid voltage with a reduced effect of harmonics and noise present in the feedback signal. This simplified algorithm was used in synchronous d-q reference frame method for the control of shunt active power filter.

REFERENCES

Akagi, H. and A. Nabae, 1986. Control strategy of active power filters using multiple voltage source PWM converters, IEEE Trans. Ind. Appl., 22(3): 460-465.

Akagi, H., 1996. New trends in active filters for power conditioning," IEEE Trans. Ind. Appl., 32(6):1312-1332.

Akagi, H., Y. Kanazawa and A. Nabae, 1984. Instantaneous reactive compensators comprising switching devices without Energy Storage components, IEEE Transactions on Industry Applications, 20(3): 625-630.

Barbieri, M.B. and P.L. Arnera, 2013. Compensation with Hybrid Active Power Filter in an Industrial Plant, Latin America Transactions, IEEE (Revista IEEE America Latina), 11(1): 447-452.

Bhattacharya, S. and D. Divan, 1996. Active filter solutions for utility interface of industrial loads, in Proc. Int. Conf. Drives and Energy Systems for Industrial Growth, 2: 1078-1084.

Chandra, A., B. Singh, B.N. Singh and kamal Al-Haddad, 2000. An Improved control algorithm of shunt active power filter for voltage regulation, harmonic elimination, power-factor correction and balancing of non-linear loads, IEEE Trans. Power Electron., 15(3).

Gary W. Chang and Tai-Chang Shee, 2004. A Novel Reference compensation current strategy for shunt active power filter control, IEEE Trans. on Power Delivery, 19(4).

Ghosh, A. and A. Joshi, 2002. A new algorithm for the generation of reference voltages of a DVR using the method of instantaneous symmetrical components, IEEE Power Eng. Rev., 2(1): 63-65.

Junyi, L., P. Zanchetta, M. Degano and E. Lavopa, 2012. Control design and implementation for high performance shunt active filters in aircraft power grids, IEEE Trans. Ind. Electron., 59(9): 3604-3613.

Karanki, K., G. Geddada, M.K. Mishra and B.K. Kumar, 2013. A Modified Three-Phase Four-Wire UPQC Topology With Reduced DC-Link Voltage Rating, IEEE Transaction on Industrial Electronics, 60(9): 3555-3566.

Labben-Ben Braiek, M., F. Fnaiech, Kamal Al-Haddad and L. Yacobi, 2002. Comparison of Direct current control techniques for a three phase shunt active power filter, Proc. IEEE conference.

Luo, A., Z. Shuai, W. Zhu and Z. John Shen, 2009. "Combined system for harmonic suppression and reactive power compensation", IEEE Trans. Ind. Electron., 56(2): 418 -428.

Australian Journal of Basic and Applied Sciences, 8(2) February 2014, Pages: 71-77

Marthinus, G.F., Gous and Hendrik J. Beukes, 2004. Sliding mode control for a three phase shunt active power filter utilizing a four leg voltage source inverter", 35th Annual IEEE power elect. Sp. Conf., Aachen, Germany.

Peng, F.Z., 1998. Application issues of active power filters, IEEE Ind. Appl. Mag., 4(5): 21-30.

Rahmani, S., A. Hamadi, K. Al-Haddad and A.I. Alolah, 2013. A DSP-based implementation of an instantaneous current control for a three-phase shunt hybrid power filter, J. Math. Comput. Simul. Model. Simul. Elect. Mach., Convert. Syst., 91: 229 -248.

Rahmani, S., A. Hamadi, K. Al-Haddad and L.A. Dessaint, 2014. A Combination of shunt Hybrid Power of Shunt Hybrid Power Filter and Thyristor-Controlled Reactor for Power Quality, IEEE Transactions on Industrial Electronics, 61(5): 2152-2164.

Rodríguez, P., J. Bergas and L. Sainz, 2002. New PLL approach considering unbalanced line voltage condition, in Proc. IEEE Int. Conf. Power and Energy Systems, 329-334.

Saetieo, S., R. Devaraj and D.A. Torrey, 1997. TI design and implementation of a three phase active power filter based on sliding mode controller", in Proc. Inst. Elect. Engg., Generation, Transm., Distrib., 144: 564-568.

Sensarma, P.S., K.R. Padiyar and V. Ramanarayanan, 2000. A STATCOM for composite power line conditioning, Proc. IEEE Int. Conf. on Industrial Technology, ICIT, Goa.