Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2013
(ICMERE2013), 1 - 3 May 2014, Chittagong, Bangladesh

ICMERE2013-PI-005

APPLICATION OF A SHUNT ACTIVE FILTER FOR COMPENSATION OF CURRENT HARMONICS AND REACTIVE POWER UNDER DISTORTED SUPPLY

Papan Dey[1,*], Toufiq Ahmed[2], C. M. F. S. Reza[3], Md. Mahbubur Rahman[4], Afaz Uddin Ahmed[5] and Fayeem bin Aziz[6]

[1-6]Chittagong University of Engineering and Technology (CUET), Chittagong 4349, Bangladesh

[1,*]papantec@gmail.com,[2]toufiq.ahmed71@gmail.com, [3]sushan_hbk@yahoo.com, [4]mahbub.rahman336@gmail.com, [5]afazbd@gmail.com, [6]imtarit@gmail.com

Abstract- *This paper proposes a shunt active power filter (SAPF) in order to compensate harmonics in distorted grid and nonlinear load condition. ICOSϕ algorithm is adopted here to compute the reference current and a phase lock loop (PLL) based system introduced here for generation of unit vector to control Active filter under non-ideal mains provision. Discrete PWM controller is used to generate switching signals of the voltage source inverter. The complete modeling and simulation of the proposed algorithm using MATLAB/SIMULINK has been presented. The performance of the APF is significantly improved when compared to that of the conventional control strategy. The responses of the active filtering system prove the effectiveness of suggested method with low total harmonic distortion (THD) and high-quality power factor.*

Keywords: PLL, Active power filter, Power quality, Harmonic, THD

1. INTRODUCTION

In the last years the high increase of problems in the electric power distribution networks due to the presence of harmonics has become well known. Loads that use switching control with semiconductor devices are the main cause. At the moment, one of the most important tools for correcting the lack of electric power quality are the active power filters (APF), that, thanks to the recent development of signal processing and power converters, are a growing reality. The APFs are widely used to control harmonic distortion in power systems. The APFs use power electronics converters in order to inject harmonic components to the electrical network that cancel out the harmonics in the source currents caused by non-linear loads. Besides harmonics compensating capability, APFs are also used in the solution of reactive power compensation and load balancing. They have a significant advantage over the passive filters since they do not cause resonance problems in the network [1]. But it is restricted by high cost and low capacity of switching devices. The series active filter construction is complex due to transformer so a parallel active filter is considered here for its reduction of the overall cost of compensating circuit, effectiveness, reliability and simplicity.

A safe and reliable operation of such compensation demands a high performance current control and a robust synchronization with the grid. A conceptual survey on APF topologies, control methods and practical applications can be found in the literature [1]. In the process of harmonic compensation, detection of the load current harmonics is one part, while the generation of compensating harmonic currents by means of converter switching is the other part of APF. The performance of active power filters depends on the harmonic detection methods for generating current references, current control method, and dynamic characteristics of APF power converter circuit. Instantaneous PQ theory, synchronous detection algorithm, dc-bus voltage algorithm, and synchronous reference frame theory are some of the widely used three-phase shunt active filtering algorithms [2].

The next important considerations are the grid synchronization method and DC voltage regulation. A large number of synchronization methods are discussed in the recent literature. The commonly used strategy in three phase systems is synchronous reference frame (SRF) based phase locked loop (PLL) technique [3]. In this paper a modified PLL based ICOSϕ algorithm base controller is proposed for achieving effective harmonic and reactive power compensation for distorted source condition.

This paper is organized as follows. Section 2 gives details of the modified PLL and its design procedure. Section 3 deals with the closed loop control strategy for the 3phase 4-wire power converter in brief. The simulation evaluations of the power converter and the PLL are detailed in section4. Section 5 presents the conclusion of this work.

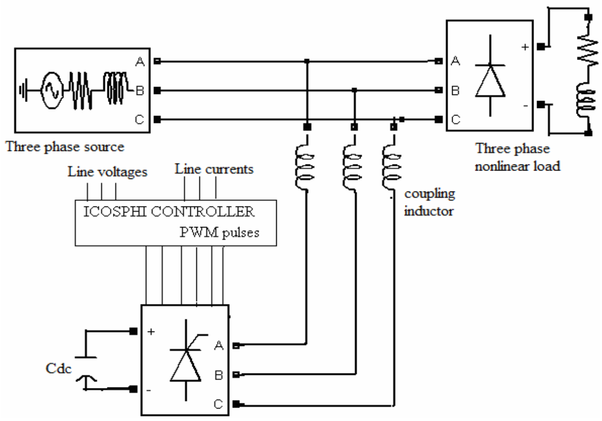


Fig. 1: Three-phase system model of the with Icosφ controller based shunt active filter

2. PLL ALGORITHM

SRF PLL is a common and conventional control technique for grid synchronization. This PLL ensues high dynamic and steady state performance with balanced input voltage condition [4].However, if the grid voltage is unbalanced and distorted in nature, a double the fundamental frequency component gets superimposed with the DC part of D and Q axis quantities (Vgd and Vgq). This phenomenon highly limits the performance of the SRF-PLL. To suppress the frequency component, a low pass filter is used in the loop as shown in Fig.2. The SRF-PLL converts three phase voltages from stationary reference frame to synchronous reference frame(D-Q domain) by Park's transformations. The grid angle position is estimated by a feedback loop which regulates the D-axis grid voltage component to zero. But during distorted voltage conditions, the SRF-PLL fails to maintain the desired performance. In order to improve the detection precision, usually low pass filter (LPF) is used to filter out the double frequency component in D-axis voltage (due to unbalanced voltages) before giving it to the controller.

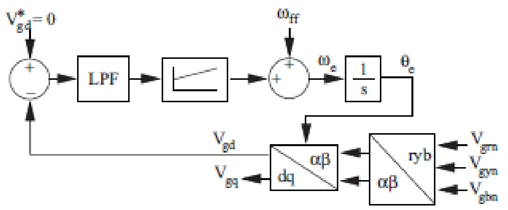


Fig. 2: PLL with low pass filter

3. CONTROL STRATEGY

3.1 ICOSΦ Algorithm

The magnitude I.cos*Φ* is deduced as the magnitude of the fundamental component of the active part of the load current where 'I' is the amplitude of the fundamental component of load current and 'cos*Φ*' is the displacement power factor of the load. A multiplier is used to derive the desired mains current as the product of the magnitude I.cos*Φ* and the unit amplitude sinusoidal wave in phase with the mains voltage. In case the mains voltages are distorted, PLL is synchronized with the grid and the fundamental components of the mains voltages are extracted using second-order low pass and used as the templates [5]. The voltage fluctuations at the dc-bus capacitor of the AF are used to calculate the extra power loss in the inverter and the interface transformer. The reference compensation currents for the shunt active filter are thereafter computed as the difference between the actual load currents and the desired mains currents for the three phase's .The schematic diagram of the I.cos*Φ* control algorithm is shown in Fig.3.

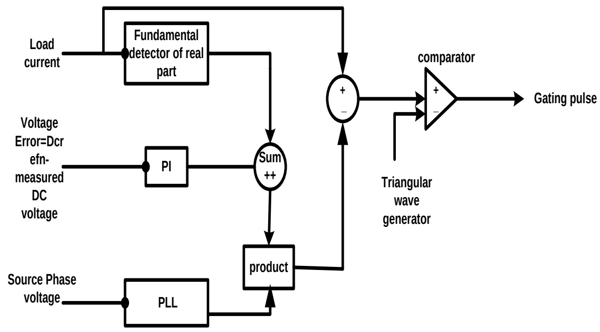


Fig. 3: Block diagram of the I.cos*Φ* control circuit

For this controller following equations are used:

Is(ref) = Re(ILa)

isa(ref) = Is(ref) ×Ua = Is(ref) .sinωt

isb(ref) = Is(ref) ×Ub = Is(ref) .sin(ωt −120)

isc(ref) = Is(ref) ×Uc = Is(ref) .sin(ωt +120)

ia(comp) =iLa −isa(ref) ; ib(comp) =iLb −isb(ref) ;

ic(comp) =iLc −isc(ref) ;

A second-order low pass filter (which has 50 Hz as its cutoff frequency) is used to extract the fundamental load current with an inherent phase shift. This filter is actually a universal filter that has three portions that act as low pass, high pass, and band pass filters as explained in [6]. The low pass filter is being used here. A zero crossing detector (ZCD) is used to detect the negative going zero crossing of the corresponding phase voltage. The fundamental component of the phase voltage is extracted using a low pass filter before being fed to the ZCD to make it immune to any distortions in the incoming voltage. The ZCD has been designed with a tolerance of 5% to ensure that any oscillations around the zero-crossing are taken care of. The phase-shifted fundamental current goes as the "sample" input and the ZCD output pulse goes as the "hold" input to the "sample and hold" circuit whose output is the magnitude. The average of these values in the three phases is then derived using a summing amplifier with a gain of 1/3 [7].

3.2 DC Link Voltage Control

The SAPF can build and regulate the dc voltage across dc capacitors by itself and thus no any external dc power supply is required. If the APF produce no loss inside, only little amount of active power is needed to keep dc voltage stable. Compared to traditional pure APF, the dc voltage of HAPF can be largely reduced as *CF* sustained most of the fundamental voltage [8-9]. Usually, the dc voltage of pure APF is designed to be as high as 800 V, thus resulting in the use of general 1200 V IGBTs for active filters. The voltage fluctuations at the DC bus capacitor of the filter are used to calculate the extra power loss in the inverter and the interface transformer. The corresponding current amplitude is calculated using a suitably tuned PI controller and added to active component of the fundamental load current [10].

3.3 Switching Signal Generation

Control strategy of active power filter plays a vital role in the overall performance. Rapid detection of disturbance signal with high accuracy, fast processing of the reference signal and high dynamic response of the controller are the prime requirements for desired compensation. Finally, the appropriate gating signals for the solid-state devices of the APF are generated using sinusoidal PWM, without estimating proper switching signals, the overall performance of the active filter could be seriously degraded. This control is realized using discrete analog and digital devices or advanced programmable devices such as single-chip microcomputers, DSPs or FPGA implementation [11-12]. This current control technique is also called linear current control. The modulation signal achieved by a current regulator from the current error signal is intersected with the triangle wave and the pulse signals obtained are the principle of PWM control. The technique has fast speed of response and simple implementation. But the current loop gain crossover frequency must be kept below the modulation frequency [13]. To overcome this limitation, this paper presents an effective scheme in fig.4where filter currents are subtracted from reference currents and go through PI controller. Comparator selects definite level for the signal. Choosing proper K_P and Ki values are very important for good operation.

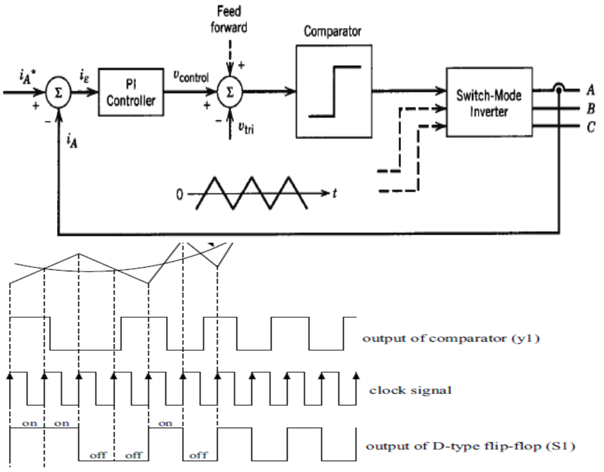
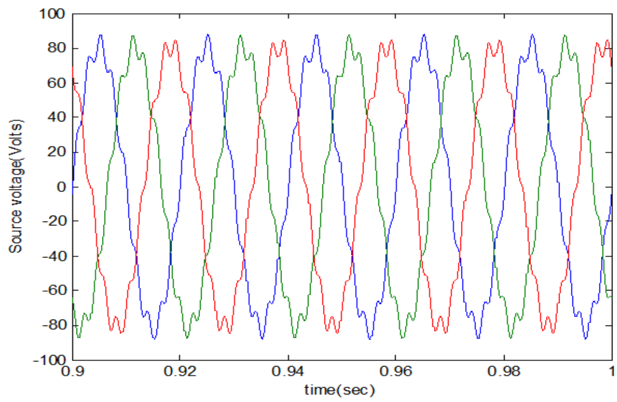


Fig. 4: PWM controller and pulse generation

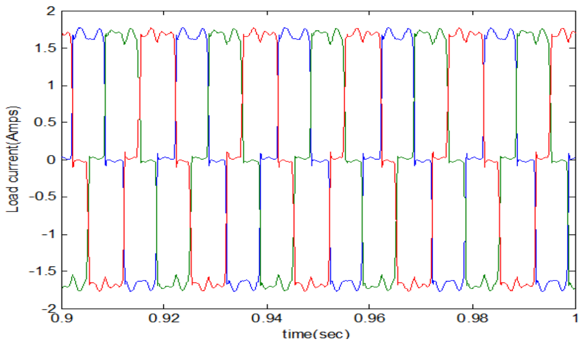
4. SIMULATION RESULTS

A three-phase 80 V, 50 Hz balanced supply is given to a 15kW AC-DC Diode bridge rectifier feeding a variable inductive load.

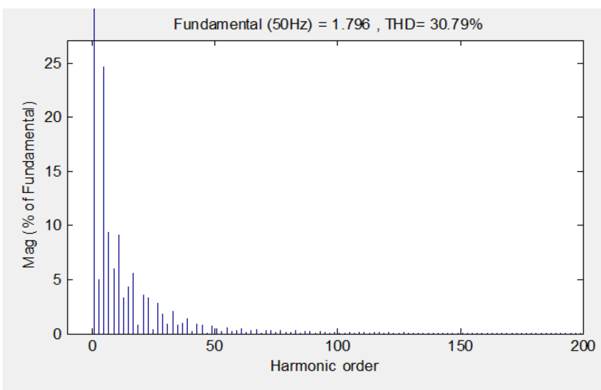
Distortion in the supply system is a more common factor. These distortions also affect the source current performance in terms of % THD value. When 3-phase mains voltage are distorted, supply voltage contain harmonic components including the fundamental component. The system was simulated distorted source and balanced load conditions. For simulation purpose, supply voltage is taken distorted with nearly 10% distortion of 5^{th} and 6% distortion of 7^{th} harmonic and total THD of the supply voltage is about 13%. The load current is highly distorted without any compensation which is shown in Fig.5.



(a)



(b)

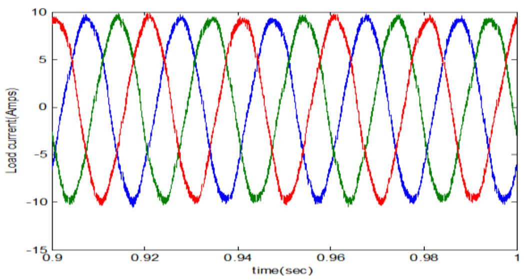


(c)

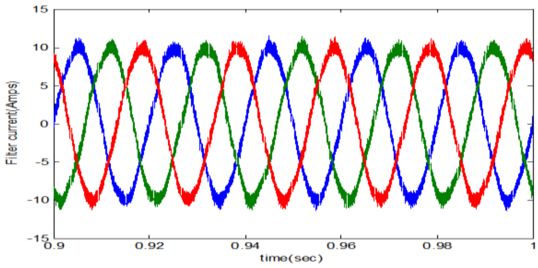
Fig. 5:Load current and THD without any compensation

In the next stage, the simulation is repeated with the shunt active filter in the system. The circuit for ICOSφ algorithm was simulated in MATLAB/SIMULINK and installed in the system.

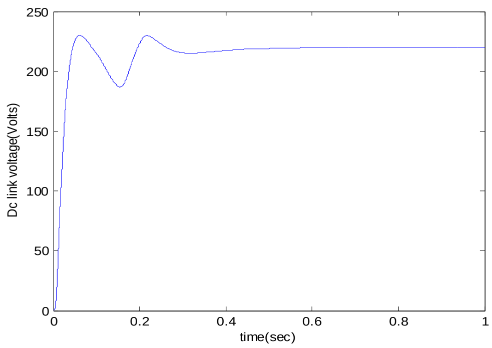
Simulation results with addition of active filter are shown in Fig.6.The harmonics in load current is highly reduced and THD is within standard limits. The source voltage and source current are in phase and sinusoidal, and implies perfect reactive compensation. Certainly, it takes time delay more than 1 cycle for perfect compensation.



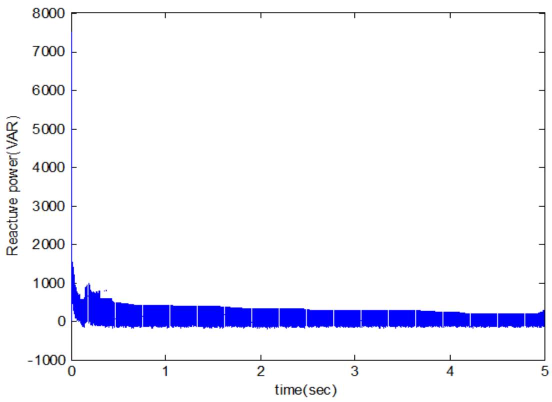
(a)



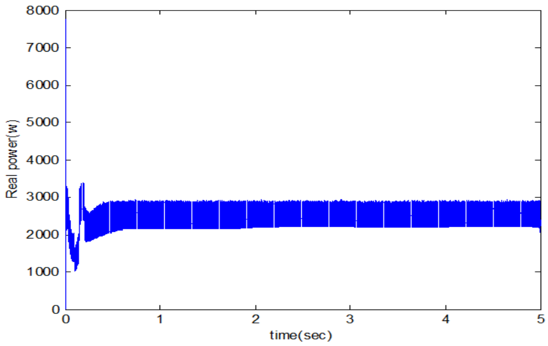
(b)



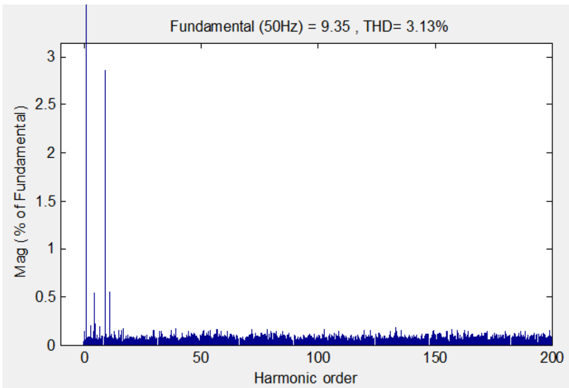
(c)



(d)



(e)



(f)

Fig. 6: Load current THD and reactive power with shunt compensation

The load currents in the three phases after compensation are expected to be purely sinusoidal and in phase with the mains voltages. The results obtained for all the three phases for both the above-mentioned control algorithm show that the shunt compensation has been achieved fairly well. The FFT analysis of the load currents before and after compensation in the two cases show that the harmonics decrease drastically from about 30.79% to less than 5% after compensation.

Table1: System parameters

SYSTEM PARAMETERS	**VALUES**
Source impedance	R=0.3ohm,L=0.1mH
Load impedance	R=20ohm,L=60 mH
SAPF	R=0.001 ohm L=3.5mH,DClink,capacitor=2000e-6,DC link voltage=800v
Source voltage	80v(peak),50 HZ

Parameters of the SAPF system used in this study are listed in table1. Regarding the existence of the higher harmonics it was observed that they are well rejected by developed theory of IcosΦ controller, it is much simpler to implement in hardware. The computational steps and complexity are drastically decreased in the proposed

IcosΦ algorithm. It is also applicable in all cases of three phase systems such as balanced, unbalanced and unbalanced-distorted source voltages and reactive non-linear loads.

5. CONCLUSION

With the development of more sophisticated power electronic nonlinear devices, more and more power quality issues are initiated. A control technique based on PLL used in SAPF has performed successfully here to compensate the load current harmonics along with reactive power under distorted supply condition. All simulated figures illustrate that the actual currents are approximately agrees with the reference currents. IcosΦ algorithm for shunt active power filter design is worked effectively to maintain the power quality perfect and reliable.

6. REFERENCES

[1] S. Rahmani, A. Hamadi, K. Al-Haddad, and A.Alolah, "A DSP-based implementation of an instantaneous current control for a three-phase shunt hybrid power filters," *Mathematics and Computers in Simulation*, 2012.

[2] J. Tian, Q. Chen, and B. Xie, "Series hybrid active power filter based on controllable harmonic impedance," *IET Power Electronics*, vol. 5, pp. 142-148, 2012.

[3] N. Zaveri and A. Chudasama, "Control strategies for harmonic mitigation and power factor correction using shunt active filter under various source voltage conditions," *International Journal of Electrical Power & Energy Systems*, vol. 42, pp. 661-671, 2012.

[4] C.-S. Lam, M.-C.Wong and Y.-D. Han, "Hysteresis current control of hybrid active power filters," *IETPower Electronics*, vol. 5, pp. 1175-1187, 2012.

[5] R. Inzunza and H. Akagi, "A 6.6-kV transformerless shunt hybrid active filter for installation on a power distribution system," *IEEE Transactions on Power Electronics*, vol. 20, pp. 893-900, 2005.

[6] Y. Suresh, A. Panda, and M. Suresh, "Real-time implementation of adaptive fuzzy hysteresis-band current control technique for shunt active power filter," *IET Power Electronics*,vol. 5, pp. 1188-1195, 2012.

[7] P. Salmeron and S. P. Litrán, "A control strategy for hybrid power filter to compensate four-wires three-phase systems," *IEEE Transactions onPower Electronics*, , vol. 25, pp. 1923-1931, 2010.

[8] R. Belaidi, A. Haddouche, and H. Guendouz, "Fuzzy Logic Controller Based Three-Phase Shunt Active Power Filter for Compensating Harmonics and Reactive Power under Unbalanced Mains Voltages," *Energy Procedia*, vol. 18, pp. 560-570, 2012.

[9] M.Kesler and E. Ozdemir, "Synchronous-Reference-Frame-Based Control Method for UPQC under Unbalanced and Distorted Load Conditions," *IEEE Transactions on Industrial Electronics*, vol. 58, pp. 3967-3975, 2011.

[10] B. Indu Rani, C. Aravind, G. SaravanaIlango, and C. Nagamani, "A three phase PLL with a dynamic feed forward frequency estimator for synchronization of grid connected converters under wide frequency variations," *International Journal of Electrical Power & Energy Systems*, 2012.

[11] R. K. Sinha and P. Sensarma, "A pre-filter based PLL for three-phase grid connected applications," *Electric Power Systems Research*, vol. 81, pp. 129-137, 2011.

[12] V. F. Corasaniti, M. B. Barbieri, P. L. Arnera, and M. I. Valla, "Hybrid power filter to enhance power quality in a medium-voltage distribution network," *IEEE Transactions on Industrial Electronics*, vol. 56, pp. 2885-2893, 2009.

[13] F. Krim, "Parameters estimation of Shunt Active Filter for Power quality improvement," in *2011 5th International Power Engineering and Optimization Conference (PEOCO)*, , 2011, pp. 306-311.