A comparative study of 3Φ SAPF with Different reference current generation

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Abstract: In this paper three phase shunt active filter (SAF) with a control algorithm of unit vector template method is compared with power synchronous detection for reference current generation. For gate pulse generation modulated hysteresis current controller is used. The capacitor voltage is maintained constant by using PI controller. The current waveform injected by the active filter is able to compensate the reactive power and the load current harmonics and to balance asymmetrical loads. The active filter is designed in PSIM software and control of active filter is done in Simulink environment. PSIM and MATLAB software is linked by Sim coupler. Simulation results with PSIM software show that the designed active filter is very effective in improvement of quality of power.

Keywords: Active filter, Modulated hysteresis current control, Power synchronous detection (PSD), Unit vector template, Current harmonics, Pulse width modulation, PSIM software.

1. INTRODUCTION

The increase of nonlinear loads due to the use of power electronic equipment causes power quality problem in the power system .Harmonic current which are drawn from a supply by the nonlinear load results in the distortion of the supply voltage, current waveform at the point of common Coupling (PCC) due to the source impedance. Both distorted current and voltage may cause end-user equipment especially sensitive equipment to malfunction, conductors to overheat and may reduce the efficiency and life expectancy of the equipment connected at the PCC. J.C. Das et al have proposed a methodology in which passive power filter is used to eliminate current harmonics when it is connected in parallel with the load(Akagi a, 2005).But the usage of this passive filter has some disadvantage such as the compensation characteristics heavily depend on the system impedance because the filter impedance has to be smaller than the source impedance in order to eliminate source current harmonics (Akagi b et al., 2007). Overloads can happen in the passive filter due to the circulation of harmonics coming from nonlinear loads connected near the connection point of the passive filter. They are not suitable for variable loads, since, on one hand, they are designed for a specific reactive power, and on the other hand, the variation of the load impedance can detune the filter and make harmonic resonance (Akagi c, et al.,1995). Literature survey shows different topologies applied to power system to compensate the system harmonics. The voltage , current related harmonics eliminated by different topologies like passive, active, and hybrid with shunt, series for two-wire single phase, three-wire three-phase and four-wire three-phase power filtering systems. The performances of an active filter mainly depend on the reference current generation strategy. Several papers explained the performance of power filter and compared with different reference current generation technique. The reference current generation technique is classified in to two major classifications that are frequency domain method and time domain method. In this frequency domain method Fourier transform, DFT, FFT, RDFT are used for extracting harmonic component from polluted voltage and current signals. In Time domain method p-q theory, Instantaneous reactive power theory, Synchronous reference frame theory, p-q-r theory, power synchronous detection method, Unit vector template method are used to generate reference current and voltage (Kazmierkowski et al., 1998). In this paper, reference currents are generated by power synchronous detection (PSD), Unit vector template (UVT) method, current controlled by Non – linear hysteresis current controller and finally comparison made between two proposed methods.

2. CONFIGURATION OF SHUNT ACTIVE POWER SYSTEM

According to configuration, the active filter is classified into series, shunt, and hybrid active filter. Among all configuration shunt active filter is superior for reduction of current harmonics present in the system (Gyugyi et al., 1976). Figure .1 presents the shunt active filter topology based on a three phase voltage source inverter, using IGBT switches, connected in parallel with the a.c three-phase three-wire system through three inductors *LF*. The capacitor C is used in the dc side to smooth the d.c terminal voltage. The non-linear load used in the analysis is a three-phase diode rectifier supplying a RL load. This load generates harmonic currents in the supply system.

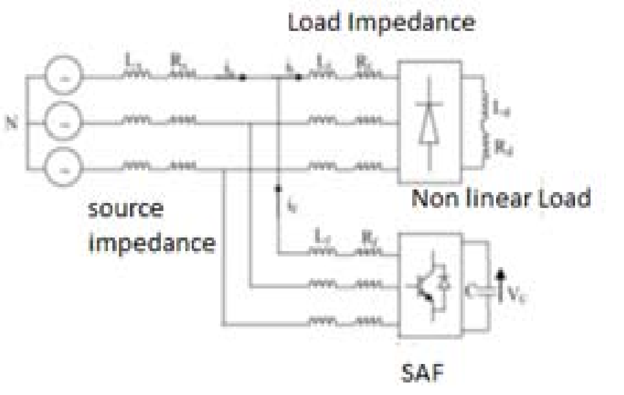

Fig. 1. Block Diagram of Three Phase APF with nonlinear Load.

3. CONTROL STRATERGY

The first part of control strategy has reference current generation and the second part has current control of the power converter. The controller generates the suited switching pattern to drive the IGBTs of the inverter.

3.1. Reference current Generation

The critical problem of Shunt active filter is to find the methodology to pick accurate harmonic current (Chang et al., 2005). There are many algorithms in time domain and frequency domain among them frequency domain algorithm requires large computational delay compare to time domain. However, traditional controllers in time domain include many disadvantages such as fixed compensation, bulkiness, and electromagnetic interference, possible resonance etc (George et al., 2007; Ginn et al., 2006). In this paper two methods are developed for reference current generation. The algorithms of above two methods are explained in the following Figs.2,3. The main part of the APF system is the IGBT based Voltage Source Inverter (VSI). A dc capacitor is used to deliver power for the VSI. For the good operation of APF, capacitor voltage should be at least 150% of maximum Line-line supply voltage (Massoud et al., 2009; Montero et al., 2007)

3.1.1 Unit Vector Template Method

UVT method is basically used to find out the amplitude of the source currents (Hong-Seok et al., 1999). It requires lesser number of sensor counts and computational delay (Ginn et al., 2006). The source is connected to a diode bridge rectifier (non-linear) load. This nonlinear load current contains fundamental component and higher order of harmonic components. For this system, the instantaneous load current is written as

$$I_l(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n) \quad (1)$$

$$= I_1 \sin(\boldsymbol{\omega t} + \phi_1) + \left(\sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n)\right) \quad (2)$$

The instantaneous load power can also be written as

$$p_l(t) = I_s(t) * v_s(t) \quad (3)$$

$$= v_m \sin^2\omega t * \cos\Phi_1 + v_m \sin\omega t * \cos\omega t * \sin\Phi_1 + v_m \sin\omega t * \left(\sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n)\right) \quad (4)$$

$$= p_f(t) + p_r(t) + p_h(t) \quad (5)$$

Where $P_f(t)$- fundamental component of power, $P_r(t)$- reactive power, $P_h(t)$- harmonic power .From the above equation the real power drawn by the load is

$$p_f(t) = v_m i_1 \sin^2\omega t * \cos\Phi_1 \quad (6)$$

The source current drawn from the mains after compensation should be sinusoidal; this is represented as

$$i_s(t) = \frac{p_f(t)}{v_s(t)} = i_1 \cos\Phi_1 \sin\omega t = i_{max} \sin\omega t \quad (7)$$

If the active power filter provides the total reactive and harmonic power, source current i_s (t) *is* will be in phase with the utility voltage and would be sinusoidal. At this time, the active filter must provide the compensation current:

$$i_c(t) = i_l(t) - i_s(t) \quad (8)$$

The active power filter estimates the fundamental and compensates the harmonics and reactive power. The DC side capacitor voltage is sensed and compared with a reference value. The error equation is

$$e = V_{dc_{ref}} - V_{dc}(t) \quad (9)$$

At the n^{th} sampling instant is used as input for PI controller. The error signal allows only fundamental frequency with the help of low pass filter (LPF). The LPF filter (Butterworth) has a cutoff frequency (fundamental power frequency) set at 50 Hz. The PI controller is used to control the dc side capacitor voltage of the voltage source inverter (Rastogi et al., 1993). The PI controller is estimates the magnitude of peak reference current max i_{max} by control the dc side capacitor voltage of the inverter. The peak reference current multiplied with PLL output generates desired reference current.

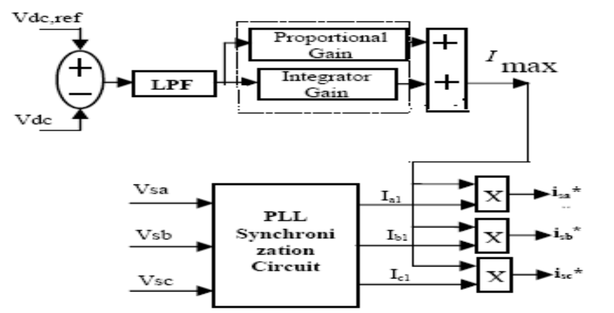

Fig. 2. Control system for reference current generation (UVT method).

3.1.2 Power synchronous Method

Compare to UVT method this method is very simple method. It reduces the complexity of calculating reference current (George et al., 2007). The instantaneous voltage, input voltage, load current are measured by voltage and current sensor in the input and output side. The real power P (t) consumed by the load could be calculated from the instantaneous voltage and load current. The input side voltages V_{sa}, V_{sb}, V_{sc} are measured by voltage sensor and load current I_{la}, I_{lb}, I_{lc} is measured by current sensor.

$$P(t) = [V_{ab}(t)\ V_{bc}(t)\ V_{ca}(t)] \begin{bmatrix} I_{la}(t) \\ I_{lb}(t) \\ I_{lc}(t) \end{bmatrix} \quad (10)$$

Whereas $V_{sa}(t)$, $V_{sb}(t)$, $V_{sc}(t)$ are the instantaneous values of supply voltages and $I_{la}(t)$, $I_{lb}(t)$, $I_{lc}(t)$ are the instantaneous values of load currents. The average value P_{dc} is determined by applying P (t) to a low pass filter. The real power in the three phases is calculated by the formula is:

$$P_a = P_b = P_c = \frac{P_{dc}}{3} \quad (11)$$

$$i_{sa}(t) = \frac{2V_{sa}(t)P_a}{V_{sma}{}^2} \quad (12)$$

$$i_{sb}(t) = \frac{2V_{sb}(t)P_b}{V_{smb}{}^2} \quad (13)$$

$$i_{sc}(t) = \frac{2V_{sc}(t)P_c}{V_{smc}{}^2} \quad (14)$$

$$i_{ca}\ (t) = i_{sa}\ (t) - i_{la}\ (t) \quad (15)$$

The control system of above method is explained in the following Fig.3.2.

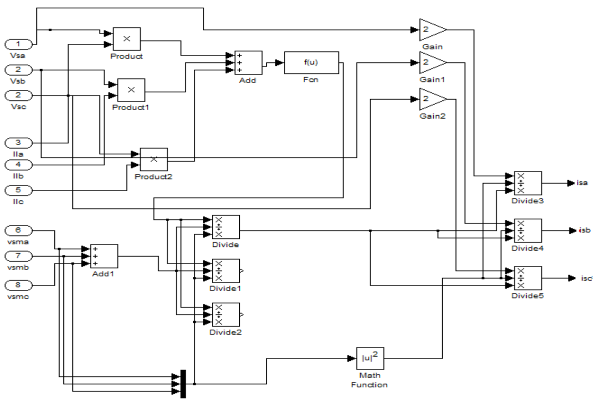

Fig. 3. Control system for reference current generation (PSD method).

3.2. Control scheme of shunt Active Power Filter

Linear current controller with pulse width modulation technique having constant switching frequency but its dynamic property is limited. Compared with other controllers, non-linear based on hysteresis strategies allows faster dynamic response and better robustness with respect to the variation of the non-linear load (Gonzalez et al., 2007; Green et al., 2005; Herrera et al., 2007). Nevertheless, with non-linear current controllers, the switching frequency is not constant and this technique generates a large side harmonics band around the switching frequency. In literature number of solution is available to fix switching frequency; one among them is using a variable hysteresis bandwidth. But this variable band hysteresis controller needs the knowledge of system model and its parameter; this implies difficulty in making hardware implementation. Here, we implemented a non-linear current controller, i.e. modulated hysteresis current controller (Peng et al., 1999). In this method the carrier frequency is chosen which is equal to the desired switching frequency for the voltage source inverter. The resulting signal (*H*) constitutes then the new reference of a classical hysteresis controller with a bandwidth of $2B_h$. The outputs of the hysteresis block are the switching pattern to the voltage source inverter. Fig.4 shows the block diagram of hysteresis current controller. To control the active filter at fixed switching frequency, the triangular signal amplitude A_{tr} and the hysteresis bandwidth B_h for the modulated hysteresis current controller must be carefully selected (Pomilio et al., 2007).

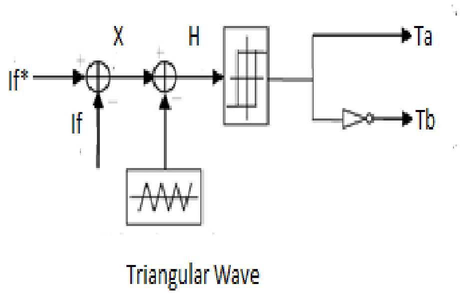

Fig. 4. Hysteresis current control.

4. SIMULATION RESULTS

Figs.5, 6 shows the simulation diagram for the system under sinusoidal voltage conditions. The active filter model is designed in PSIM; the proposed algorithms are designed using Mat lab and its tools Power System Blocks set and Simulink. The PSIM model and Simulink environment is coupled with Sim coupler developed in Matlab library browser. Simulation results are obtained under with APF and without APF. The essential parameter selected for simulation study are given in the Table 1.The total harmonics distortion (THD) of the load current is approximately equal to 36.2% in phase A, 37.2 % in phase B, 38.2% in phase C at APF off condition and equal to 13.6% (PSD method), 11.31 % (UVT method) in phase A; 15.4% (PSD method), 16.6 % (UVT method) in phase B; 12.4% (PSD method), 17.8 % (UVT method) in phase C; at APF on condition. The THD of the supply current equal to 28.3% in phase A, 30.17 % in phase B, 29.07% in phase C at APF off condition and equal to 2.32% (PSD method), 2.1 % (UVT method) in phase A; 2.45% (PSD method), 2.2 % (UVT method) in phase B; 2.5% (PSD method), 2.3 % (UVT method) in phase C; at APF on condition.THD of the Load currents and source currents, Source voltages difference in before and after compensation is noticed in Fig.6 – Fig.30.The simulation results verify the effectiveness and performance of APF with two different algorithm.

Table 1. Power system parameters

System Frequency	*50 Hz*
System Voltage	$230V_{max}$
System Resistance R_s	25 ohm
System Inductor : L_s	0.3mH
Load side Resistance R_l	10 ohm
Load side Inductor : L_l	0.1mH
Filter side Resistance R_f	20 ohm

Filter side Inductor : L_f	0.1mH
Load Resistance (single phase)R_d	50 ohm
Load Inductor(single phase) : L_d	40 mH
Load Resistance (Three phase) : R_d	100 ohms
Load Capacitor (Three phase) : L_d	100µF

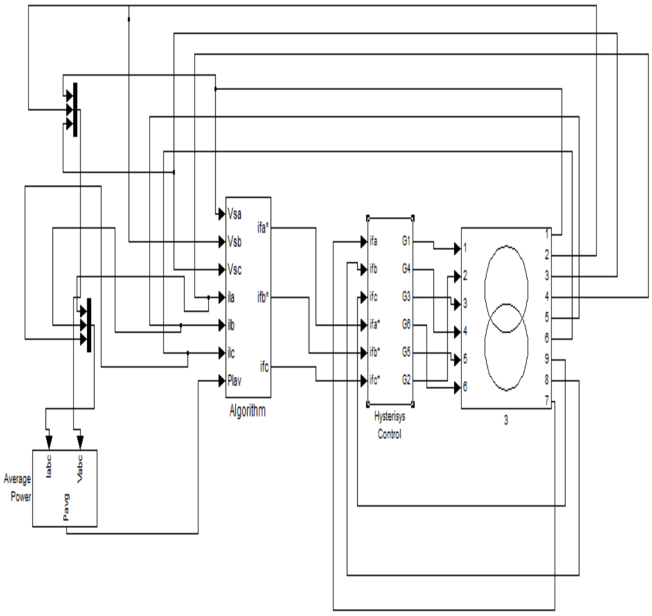

Fig. 5. PSIM coupled Simulink diagram (PSD Method).

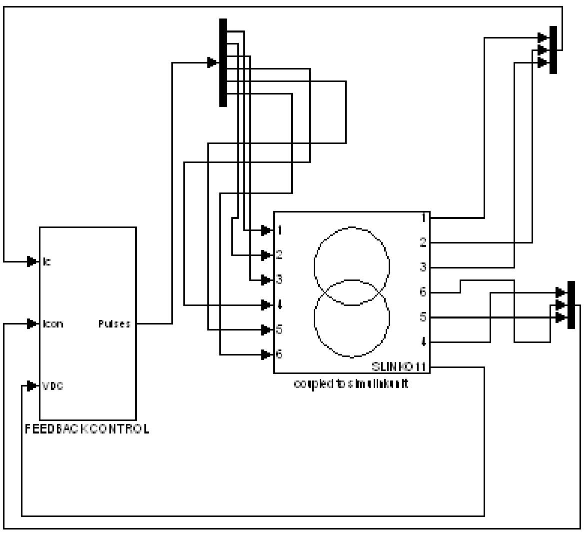

Fig. 6. PSIM coupled Simulink diagram (UVT Method).

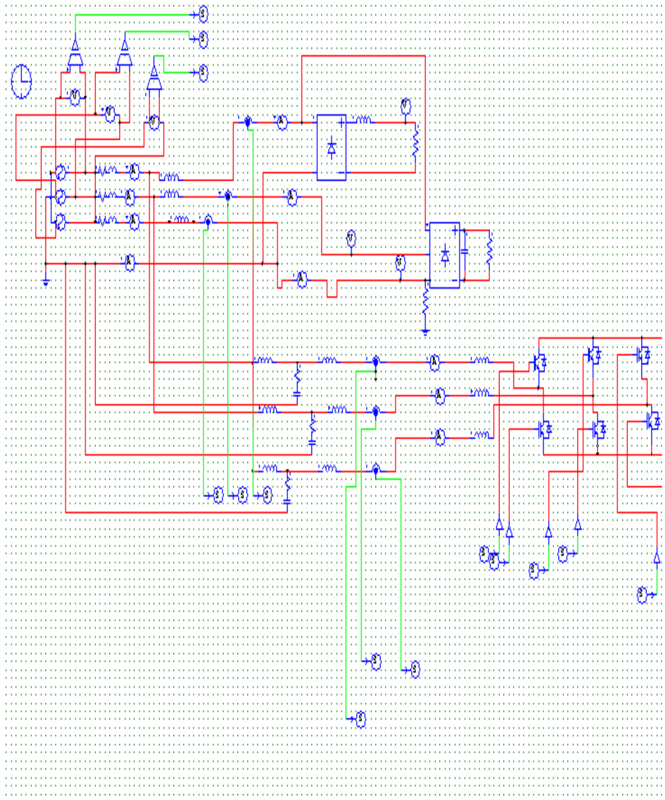

Fig. 7. Simulation diagram of Active filter in PSIM.

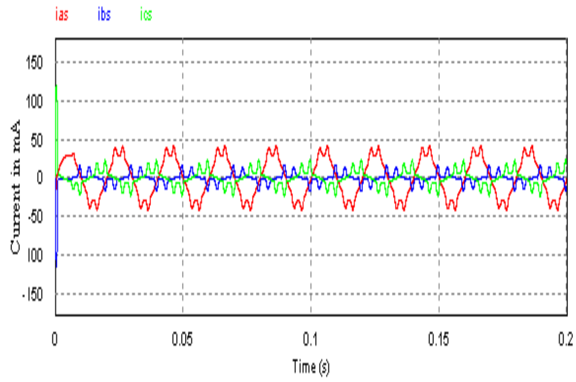

Fig. 8. Source current before compensation.

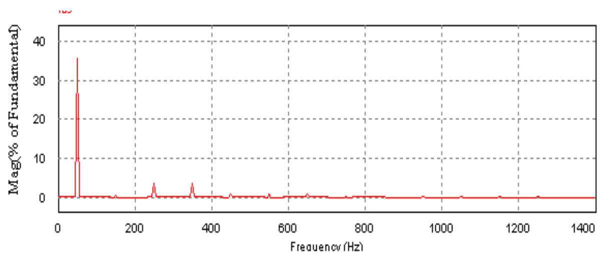

Fig. 9. Source current THD spectrum of phase A before compensation.

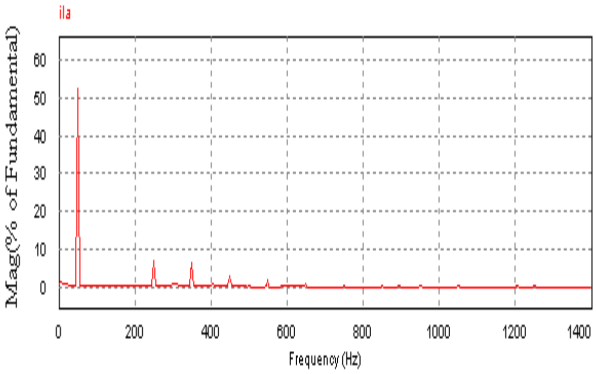

Fig. 10. Load current THD spectrum of phase A before compensation.

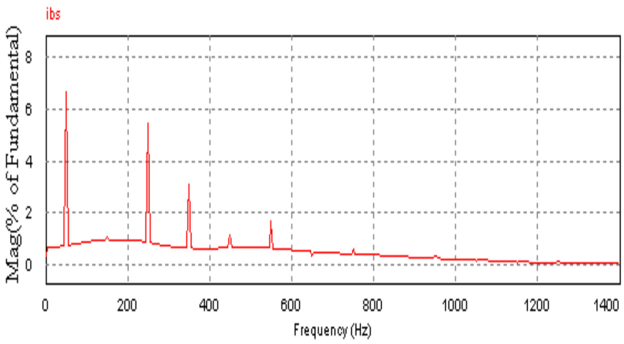

Fig. 11. Source current THD spectrum of B phase of phase B before compensation.

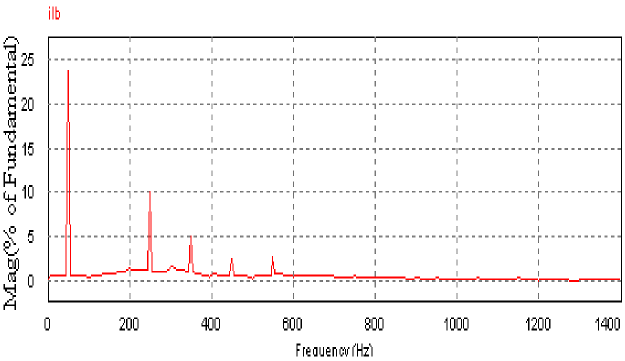

Fig. 12. Load current THD spectrum of phase B before compensation.

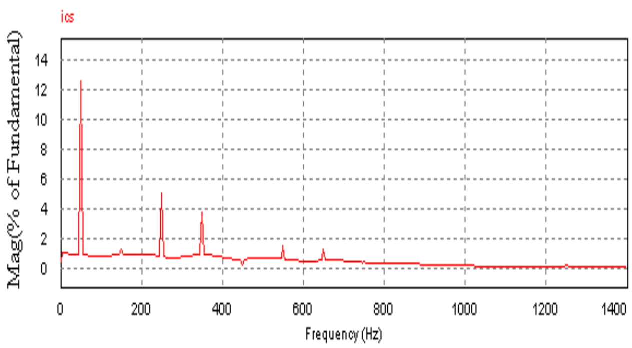

Fig. 13. Source current THD spectrum of phase C before compensation.

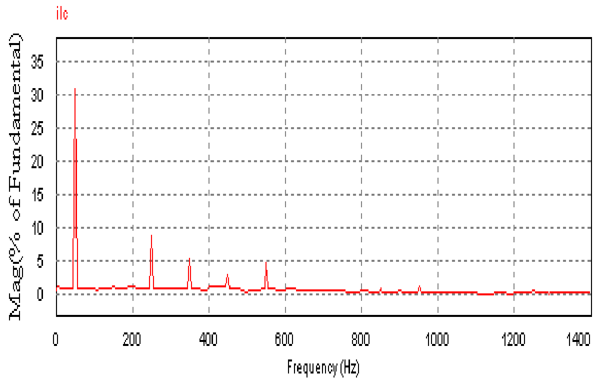

Fig. 14. Load current THD spectrum of phase C before compensation.

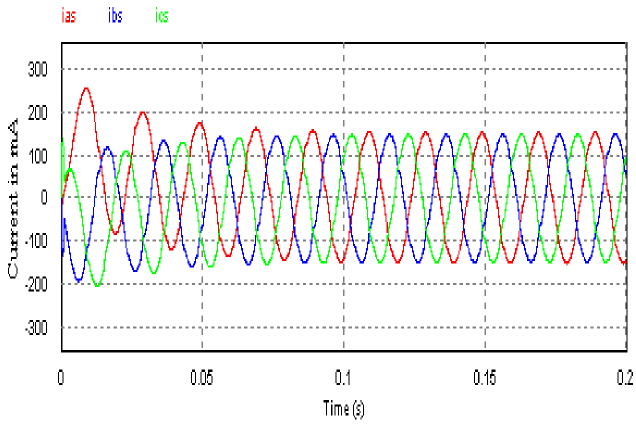

Fig. 15. Source current after compensation (PSD Method).

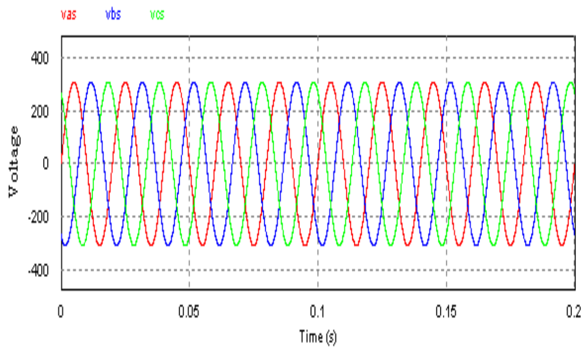

Fig. 16. Source voltage after compensation (PSD Method).

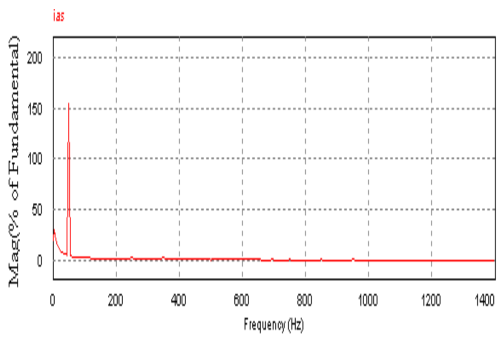

Fig. 17. Source current THD spectrum of phase A after compensation (PSD Method).

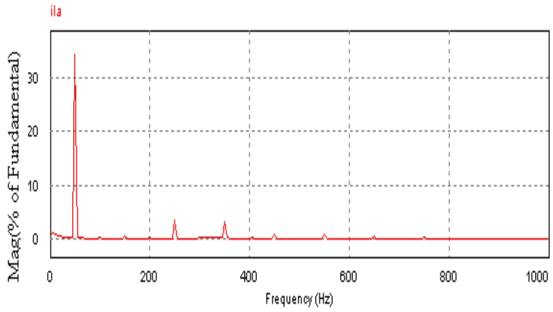

Fig. 18. Load current THD spectrum of phase A after compensation (PSD Method).

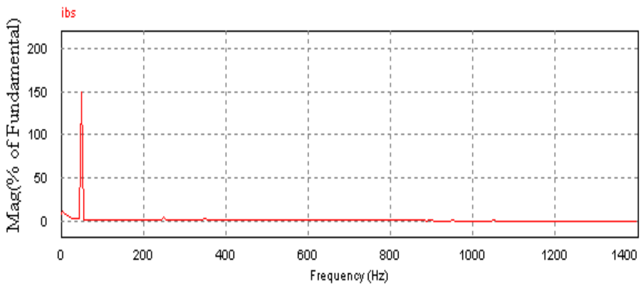

Fig. 19. Source current THD spectrum of phase B after compensation (PSD Method).

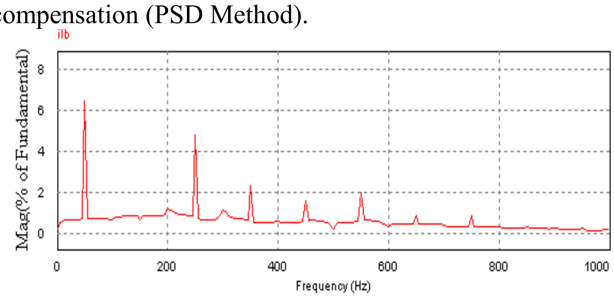

Fig. 20. Load current THD spectrum of phase B after compensation (PSD Method).

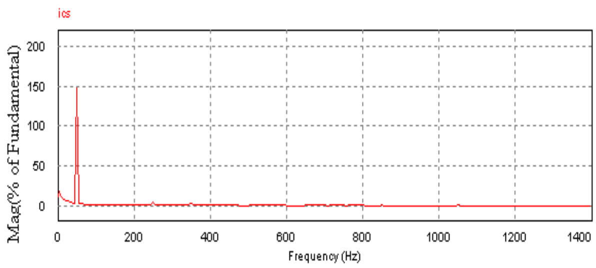

Fig. 21. Source current THD spectrum of phase C after compensation (PSD Method).

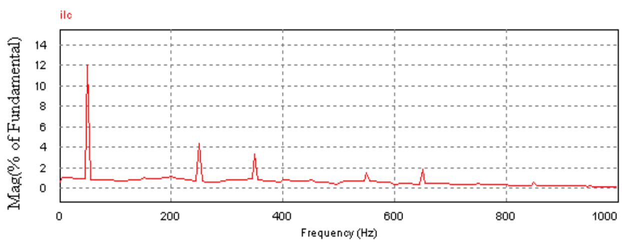

Fig. 22. Load current THD spectrum of phase C after compensation (PSD Method).

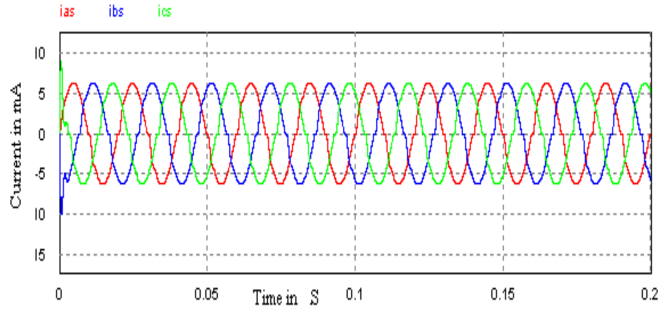

Fig. 23. Source current after compensation (UVT method).

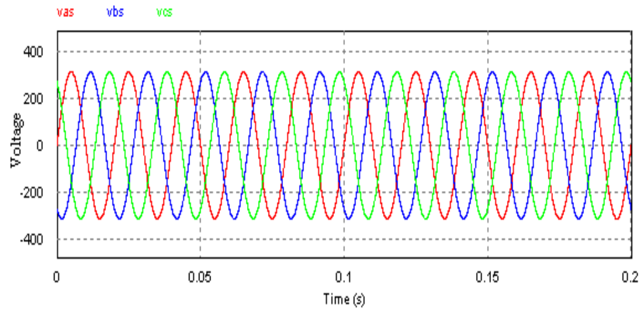

Fig. 24. Source Voltage after compensation (UVT method).

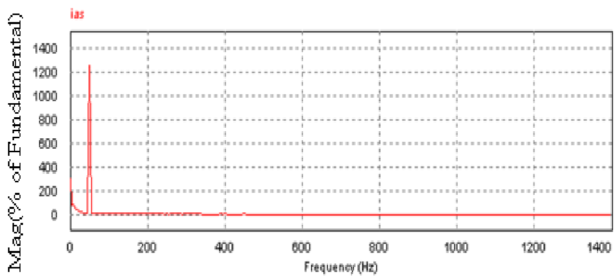

Fig. 25. Source current THD spectrum of phase A after compensation (UVT Method).

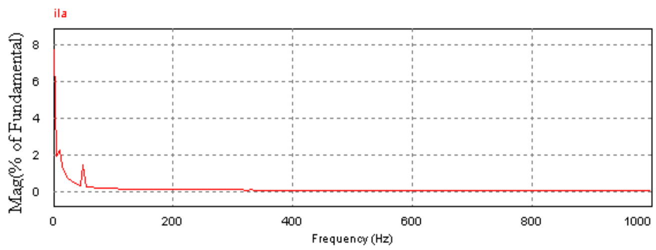

Fig. 26. Load current THD spectrum of phase A after compensation (UVT Method).

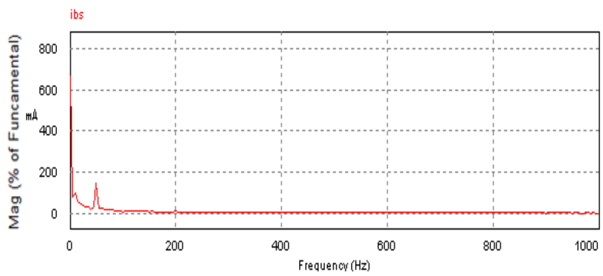

Fig. 27. Source current THD spectrum of phase B after compensation (UVT Method).

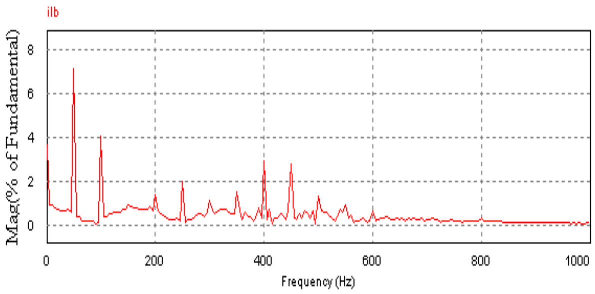

Fig. 28. Load current THD spectrum of phase B after compensation (UVT Method).

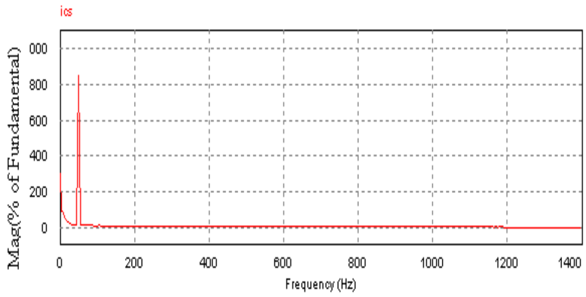

Fig. 29. Source current THD spectrum of phase C after compensation (UVT Method).

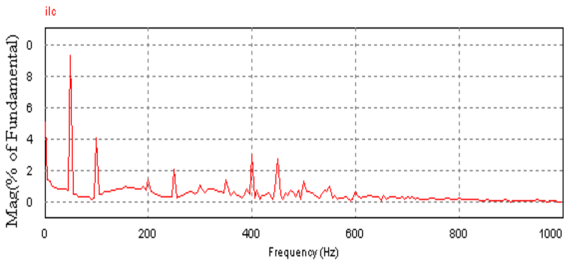

Fig. 30. Load current THD spectrum of phase C after compensation (UVT Method).

The total harmonic distortion (THD) is measured in source side current and load side current of all the phases. The values are compared and tabulated and presented in Table 2.

Table 2. Comparison of Two methods

Various Parameters (THD)	APF OFF	APF with PSD Method	APF with UVT Method
Input Source current(A phase)	28.07	2.32	2.1
Load side Current(A phase)	36.2	13.6	11.31
Input Source current(B phase)	28.07	2.45	2.2
Load side Current(B. phase)	38.2	15.42	16.6
Input Source current(C phase)	28.07	2.50	2.3
Load side Current(C phase)	37.2	12.4	17.8

5. CONCLUSION

This paper has provided a comparative analysis of two different reference current strategies of shunt active filter installed in three-phase three-wire systems with harmonic distortion and/or imbalance. In this paper, unit vector template, power synchronous methods are used for reference current generation and modulated hysteresis current controller is used for gate pulse generation.The proposed SAF compensates the current harmonics, Reactive power at PCC. The proper operation of the presented topology and control algorithms is validated through computer simulation results developed with PSIM 9.1 software package.The performance of SAF in steady state condition is evaluated with and without active filter. The obtained results demonstrate that the performance of APF with both algorithms gives better results under undistorted main voltage condition.Both methods are simple one and it reduces the number of equations for generating reference compensating current. It does not require any transformation such as a-b-c to d-q and d-q to a-b-c transformations for controlling real and reactive components of load current. In comparison of THD in the both method, UVT method has less value compare to PSD. The control algorithm is developed in Simulink and active filter model developed in PSIM package. Both software packages are connected through sim coupler. The results show that with both algorithms the THD meets the recommended harmonic standards such as IEEE 519 and IEC 61000-3 where, the PSD with SAF achieved the best performance in terms of active Filtering.

REFERENCES

Akagi H. a, (2005), Active harmonic filters. *Proc. IEEE, 93(12),* 2128–2141.

Akagi H., b, Watanabe E. H., Aredes M., (2007), Instantaneous Power Theory and Applications to Power Conditioning. Hoboken, NJ: *Wiley-IEEE Press*.

Akagi H.,c and Fujita H., (1995), A new power line conditional for harmonic Compensation in power systems. *IEEE Trans. Power Del.,* 10(3), 1570–1575.

Chang G.W., and Yeh C.M., (2005), Optimisation-based strategy for shunt active power filter control under non-ideal supply voltages. *IEEE Proceedings Electric Power Applications,152(2).*182–190.

Das J. C., (2004) Passive filters-potentialities and limitations. *IEEE Trans. Ind. Appli., 40(1),* 232–241.

George S., and Agarwal V., (2007), A DSP based optimal algorithm for shunt active filter under non sinusoidal supply and unbalanced load conditions. *IEEE Transactions on Power Electronics, 22(5),* 593–601.

Ginn H. L., Czarnecki L. S., (2006), An optimization based method for selection of resonant harmonic filter branch parameters, *IEEE Trans. Power Del., 21(3),* 1445–1451.

Gonzalez S.A. and Garcia-Retegui R., (2007), Benedetti M., Harmonic computation technique suitable for active power filters, *IEEE Transactions on Industrial Electronics,54(5),* 2791–3279 .

Green T.C. and Marks J.H., (2005). Control techniques for active power filters. *IEEE Proceedings Electric Power Applications*, *152(4).*369–381.

Gyugyi L., Strycula E., (1976), Active AC power filters. *Conf. Rec. IEEEIAS Annu. Meeting*, *Chicago,* 19, 529–535.

Herrera R. S., and Salmeron P., (2007), Instantaneous reactive power theory: A comparative evaluation of different formulations. *IEEE Trans. Power Del.*, 22(1). 595–604.

Hong-Seok S., Hyun-Gyu P., Kwanghee N., (1999), An instantaneous phase angle detection algorithm under unbalanced line voltage condition. *IEEE 30th Annual Power Electronics Specialist Conference PESC'99*, 1(3).3..533–537.

Kazmierkowski M. P., and Malesani L. (1998), Current control techniques for three-phase voltage source PWM converters: a survey. *IEEE Transactions on Industrial Electronics*, *45(5),* .691–703.

Massoud A. M., Finney S. J., Williams B. W., (2009), Review of Harmonic Current Extraction Techniques for an Active Power Filter.IEEE *Transactions on Power Electronics,.23(3).*218–236.

Montero M., Cadaval E. R., Gonzalez F., (2007). Comparison of control strategies for shunt active power filters in three-phase four-wire systems. *IEEE Transactions on Power Electronics.22(6).*.229–236.

Peng F. Z. and Adams D. J., (1999), Harmonics sources and filtering approaches. *IEEE Proceedings Industry Applications, 1*, 448–455.

Pomilio J. A. and Deckmann S. M., (2007), Characterization and compensation of harmonics and reactive power of residential and commercial loads. *IEEE Trans. Power Del., 22(2),* 1049–1055.

Rastogi M., Naik R. Mohan N., (1993), Comparative evaluation of harmonic reduction techniques in three phase utility interface of power electronic loads, *Proc. IEEE/IAS Annu. Meeting Toronto Canada*, *1(2),* 971–978.

Rondineli Rodrigues Pereira and Carlos Henrique da Silva, (2011), New Strategies for Application of Adaptive Filters in Active Power Filters..*IEEE trans. Ind.Appli, 47(3).* 1136-1141.

Singh B., Al-Haddad, Chandra A., A review of active filters for power quality improvement. *IEEE Transactions on Industrial Electronics,*.46(5).960–971 Oct.1999.