International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:8, No:7, 2014

Design of Active Power Filters for Harmonics on Power System and Reducing Harmonic Currents

Düzgün Akmaz, Hüseyin Erişti

***Abstract*—**In the last few years, harmonics have been occurred with the increasing use of nonlinear loads, and these harmonics have been an ever increasing problem for the line systems. This situation importantly affects the quality of power and gives large losses to the network. An efficient way to solve these problems is providing harmonic compensation through parallel active power filters. Many methods can be used in the control systems of the parallel active power filters which provide the compensation. These methods efficiently affect the performance of the active power filters. For this reason, the chosen control method is significant. In this study, Fourier analysis (FA) control method and synchronous reference frame (SRF) control method are discussed. These control methods are designed for both eliminate harmonics and perform reactive power compensation in MATLAB/Simulink pack program and are tested. The results have been compared for each two methods.

***Keywords*—**Harmonics, Harmonic compensation, Parallel active power filters, Power quality.

I. Introduction

THE electrical energy is one of the most prominent requirements of today's social and economic life. Nowadays evolving technology, growing population with rising living standards has increased the demand of energy. At the same time transmission of the generated energy must be transmitter completely and must be used efficiently. But in recent years with increasing of power electronics applications, the use of non-linear loads is also increasing. These non-linear loads create harmonic currents in power lines and this situation causes some problems such as reactive power load, overheating, low power quality [1], [2].

Passive filters have been traditionally used to eliminate harmonics and improve quality of power. However, these filters have some disadvantages such as massiveness, carrying a risk of resonance and providing a fixed compensation [3].

With the development of control techniques and semiconductor technology, design of active power filter (APF) has come to the forefront to overcome problems of passive filters and to eliminate harmonics.

APF offers an important kind of way for harmonic compensation. APFs automatically satisfy frequency and impedance changes [4]. These filters have many functions such as reactive power compensation, compensation of harmonic currents, voltage regulation, frequency regulation and balancing three phase currents [5]-[7].

Düzgün Akmaz and Hüseyin Erişti are with the Tunceli University, Turkey (phone: +904282131794; e-mail: dzgnakmaz@gmail.com, huseyineristi@gmail.com).

Engineers of power electronics and power systems have made significant efforts together to resolve the problem of total harmonic distortion (THD) and power quality, to develop dynamical adjusting solutions. The tools used to solve these problems are called APFs [2]. APFs are composed of some power electronic circuits and passive elements such as coils, capacitors. These filters can be used for many purposes such as current harmonic compensation, reactive power compensation, neutral line current compensation, elimination of harmonic voltages, suppressing voltage waveforms, balancing three-phase system [2], [5]-[9].

According to topological structure, APFs are divided into sections; parallel, serial, hybrid and unified power quality regulators [10]. The parallel active power filters (PAPF) of these topologies are connected to grid in parallel. This class of filter configuration is the most important and widely used structure in industrial business [11]. These filters are suitable for elimination of the type of current harmonic such as compensation of harmonic currents, reactive power compensation, load balancing current and neutral current compensation [2], [12]-[14]. PAPFs operate by transmitting harmonics to power lines in opposite direction.

Different control methods can be used to find current harmonics in the system. In this study, Fourier analysis (FA) control method and synchronous reference frame (SRF) control method are discussed.

II. Shunt Active Filters

A. Fourier Analysis Control Method on Parallel Active Power Filters

Any non-sinusoidal waveform can be separated into pure sine waves. These pure sine waves have frequency which is on the multiples of fundamental frequency. This pure sine wave is called the harmonic components. FA is used to determine magnitude and frequency of harmonic components [15]-[17].

Harmonics in the system are found by taking the Fourier transform of load current. And these harmonics are combined to create reference signal. With this transformation, desired harmonic component or components can be calculated in the system.

Non-sinusoidal voltage or current waveforms, as indicated in the formulas below (1), (2), can be shown as a sum of sinusoidal signals of different frequency and different size.

$$V_{sn}(t) = \sum_{n=1}^{k} V_n \sin(nwt + \theta_n) \quad (1)$$

$$I_{Ln}(t) = \sum_{n=1}^{k} I_n \sin(nwt + \theta_n) \quad (2)$$

$I_{L1} = I_1 sin(wt + \theta_1)$ shows basic component of harmonic currents. If this fundamental current component is removed from load current, only current harmonics are obtained.

$$\begin{aligned} I_{Load\ current(a)} &= I_{1.harmonic(a)} + I_{2.3.4...harmonic(a)} \\ I_{Load\ current(b)} &= I_{1.harmonic(b)} + I_{2.3.4...harmonic(b)} \\ I_{Load\ current(c)} &= I_{1.harmonic(c)} + I_{2.3.4...harmonic(c)} \end{aligned} \quad (3)$$

Using (3), we can get;

$$\begin{aligned} I_{Load\ current(a)} - I_{1.harmonic(a)} &= I_{2.3.4...harmonic(a)} \\ I_{Load\ current(b)} - I_{1.harmonic(b)} &= I_{2.3.4...harmonic(b)} \\ I_{Load\ current(c)} - I_{1.harmonic(c)} &= I_{2.3.4...harmonic(c)} \end{aligned} \quad (4)$$

If harmonics which derived from using (4), are pressed to the system in an opposite and equal magnitude, harmonic compensation is achieved. Magnitude of fundamental harmonic and phase angle of fundamental harmonic is calculated by using FA. Magnitude of fundamental component and phase angle of fundamental component can be obtained by using the following formulas.

$$f(t) = A_0 + \sum_{n=1}^{\infty}(A_n sinnt + B_n cosnt) \quad (5)$$
$$f(t) = A_0 + \sum_{n=1}^{\infty} C_n sin(nt + \theta_n)$$

For fundamental harmonic, A_1 coefficient and B_1 coefficient are found as follows.

$$A_1 = \frac{2}{m}\sum_{k=1}^{m} y_k sin(\theta_k) \quad (6)$$
$$B_1 = \frac{2}{m}\sum_{k=1}^{m} y_k cos(\theta_k)$$

C_1 is magnitude of the fundamental harmonic and Θ_1 is the phase angle of fundamental harmonic.

$$C_1 = \sqrt{A_1^2 + B_1^2} \quad (7)$$
$$\theta_1 = tan^{-1}(\frac{B_1}{A_1})$$

After calculating the phase angle, the phase locked loop (PLL) produces sinusoidal wave components. Fundamental harmonic current magnitude is multiplied by sinusoidal waves. Thus, fundamental current harmonic value of each load phase can be calculated. But current losses of the inverter (I_{LOSS}) should be given back to system [18].

For n=1;

$$I_1 = I_1 + I_{Loss} \quad (8)$$

$$\begin{aligned} I_{1'harmonic(a)} &= ((I_1 + I_{Loss}) * sin(wt + \theta_{1a})) \\ I_{1'harmonic(b)} &= ((I_1 + I_{Loss}) * sin(wt + \theta_{1b})) \\ I_{1'harmonic(c)} &= ((I_1 + I_{Loss}) * sin(wt + \theta_{1c})) \end{aligned} \quad (9)$$

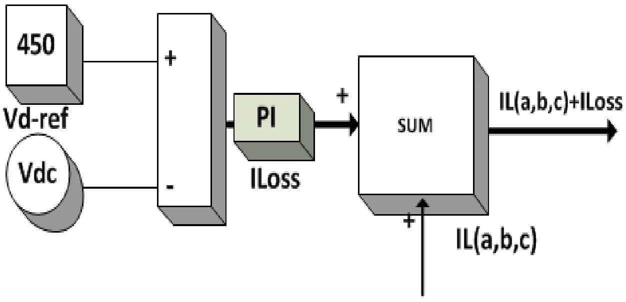

Fig. 1 FA Control method, giving back Iloss current to the system

Lastly, for each phase obtained first harmonic components remove from load currents. Thus harmonic currents can be found in the power lines. These harmonic currents are reversed so that the reference signals are generated. Fig. 3 shows the steps required to create reference signal.

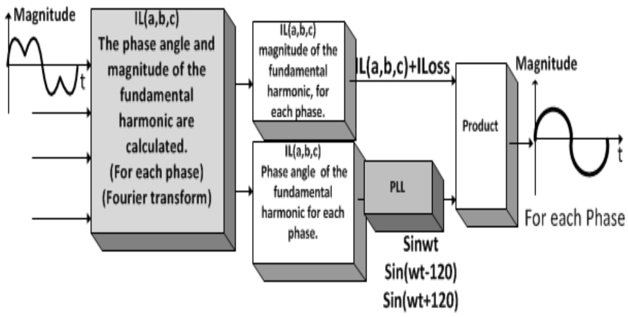

Fig. 2 FA Control method to find the phase angle and magnitude of the fundamental harmonic

Error signal is generated by subtracting the reference currents from active filter currents. This error is sent to hysteresis band to eliminate harmonic current. This error signal is controlled according to hysteresis band limit. So that, the trigger signals are produced for semiconductor elements in pulse width modulation (PWM). Inverter switches are opening or closing according to the trigger signal of PWM. Compensation of harmonic currents are thereby provided.

B. Synchronous Reference Frame Control Method on Parallel Active Power Filters

In Synchronous Reference Frame control method APF applications, currents or voltages in three-phase a-b-c coordinate are converted synchronous rotating reference frame with the system voltage. In SRF control method and the case of non-linear load, harmonics and reactive currents drawn by load are identified. Compensation provides current harmonics which have equal but opposite magnitude by pressing to power line [19].

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:8, No:7, 2014

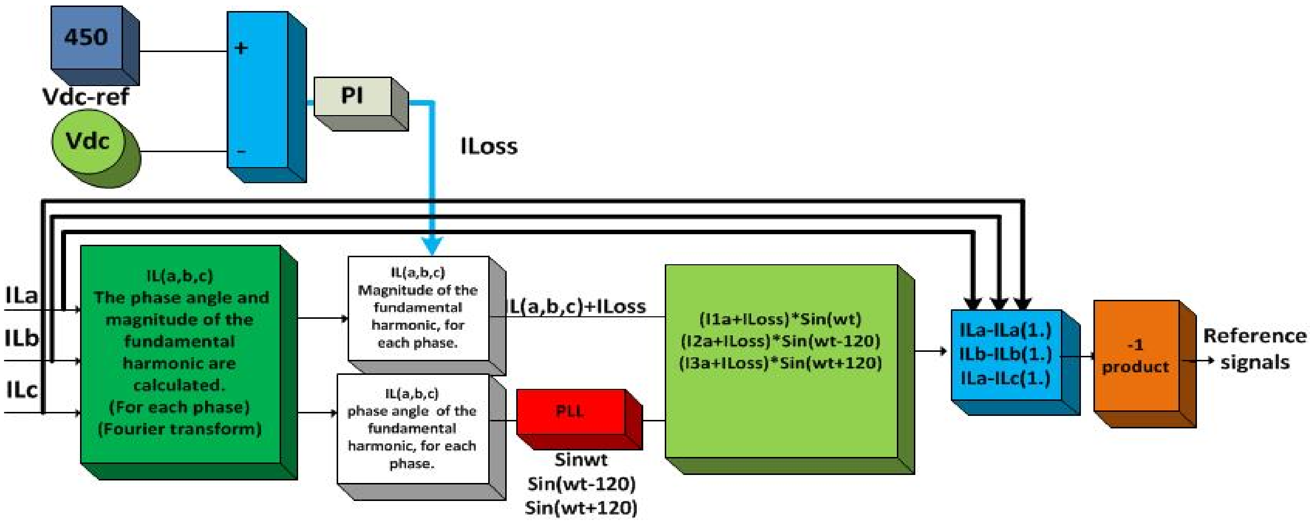

Fig. 3 General algorithm of FA control method

α- β- 0 axes in stable reference frame do not rotate. Rotating reference frame is rotated synchronously with system voltage. Thus the angular position of system voltage vector also shows the angular position of the synchronous reference frame. SRF control method mainly consists of three steps. Firstly by using (10), three-phase systems in Ia, Ib, Ic load currents are converted to the rotating synchronous reference frame [20].

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \tag{10}$$

Id and Iq currents have only DC component when linear load is used. However Id and Iq currents will have alternating current component (AC) and direct current (DC) component when using a non-linear load.

$$I_q = \bar{I}_q + \tilde{I}_q \qquad I_d = \bar{I}_d + \tilde{I}_d \tag{11}$$

Id and *Iq* are used for different types of compensation. For example, AA components $(\widetilde{Id}, \widetilde{Iq})$ of Id and Iq currents are only used for harmonic compensation. Required current components for different types of compensation are showed in Table I [19].

The second step in Synchronous Reference Frame control method is determining the current components of Id and Iq according to the types of compensation of APFs are supposed to do. In this study to ensure harmonic and reactive power compensation, AC component of Id current should be found. AC component of Id current is obtained by passing Id current through high pass filter (HPF).

TABLE I
FUNCTION OF CURRENT COMPONENTS IN SRF CONTROL METHOD

Compensation Type	The required current components
Reactive Power Compensation	I_q
Harmonic Current Compensation	$\tilde{I}_d$, $\tilde{I}_q$
Harmonic Current and Reactive Power Compensation	$\tilde{I}_d$, I_q

I = current.

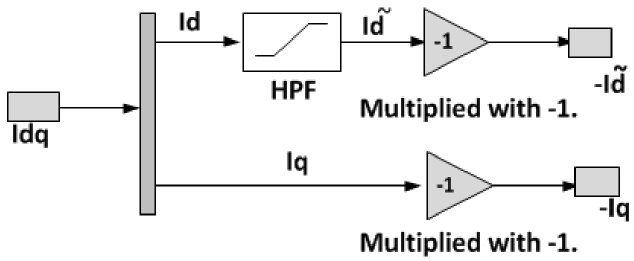

Fig. 4 Obtaining AC current component of Id

$$\begin{bmatrix} I_{ref(a)} \\ I_{ref(b)} \\ I_{ref(c)} \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta \\ \sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) \\ \sin\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} -\tilde{I}_d + I_{Loss} \\ -I_q \end{bmatrix} \tag{12}$$

Last step of SRF control method acquires reference signal by using (12), [20]. General algorithm of SRF control method is provided in Fig. 5. The obtained reference currents to eliminate harmonics in power line are sent to hysteresis current controller as fourier transform.

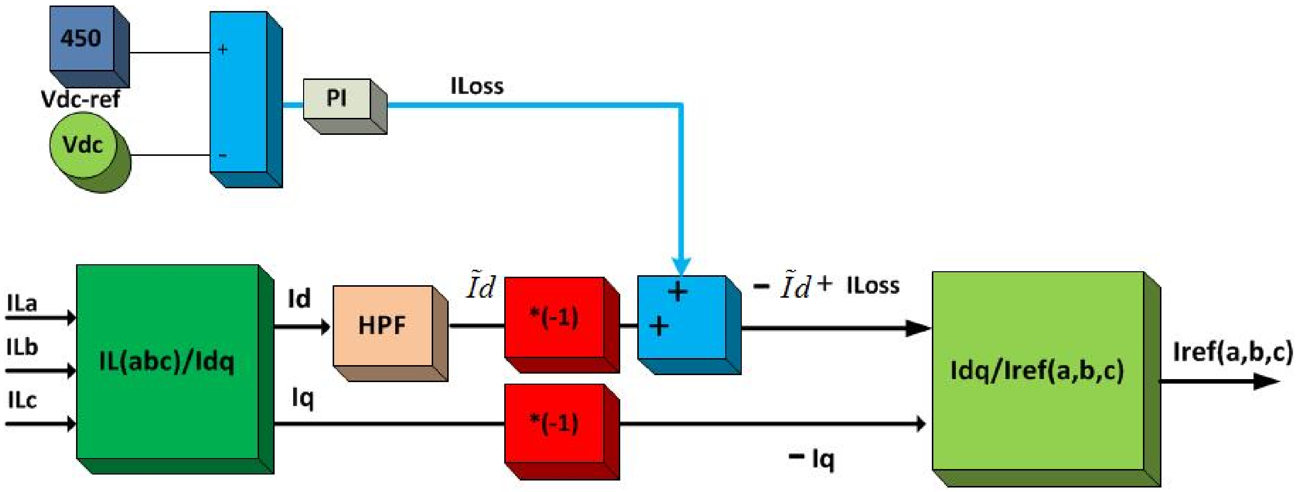

Fig. 5 General algorithm of SRF control method

III. Simulations

The Matlab / Simulink simulations of both methods have been performed in Power System Toolbox to compare FA control method and SRF control method. These simulations have been performed by using the same load and the same voltage. Three-phase diode rectifier has been selected as non-linear load. System parameters are shown in Table II.

TABLE II
MATLAB/SIMULINK PARAMETERS OF FA AND SRF CONTROL ALGORITHMS

Specifications	Parameters	Values
Source	Voltage	220V
	Frequency	50Hz
Load	Resistance (R_L)	15 Ω
	Inductance (L_L)	1mH
Parallel Active	Capacitors	3000µF
Power	DC Ref Voltage(V_{DC})	450V
Filters	Hysteresis band gap	0.8 A
	Resistance (R_F)	0.1 Ω
	Inductance (L_F)	1Mh
	PI Parameters	0.77, 28

V=voltage, Hz=hertz, Ω=ohm, H=henry, F=faraday, A=ampere.

TABLE III
THD VALUES OF LINE CURRENT

Specifications	% THD	Reactive Power drawn by load	
Line Current	% 29.11	≈ 4100	-3800 VAr
THD value of line current (After FA control method PAPF has been connected)	% 2.30	≈ 0	750 VAr
THD value of line current (After SRF control method PAPF has been connected)	% 2.32	≈ 0	780 VAr

VAr=voltage ampere reactive.

IV. Results and Analysis

Fig. 6 shows values of current shape of line before parallel active power filter is connected to power line. As seen in these figures, the line current includes high amounts harmonics. Fig. 7 shows values of line current after parallel active power filter based on FA control method has been connected to power line. Also Fig. 8 shows values of line current after parallel active power filter based on SRF control method has been connected to power line. Line current has been very close to pure sinusoidal waveform as seen from Figs. 7 and 8.

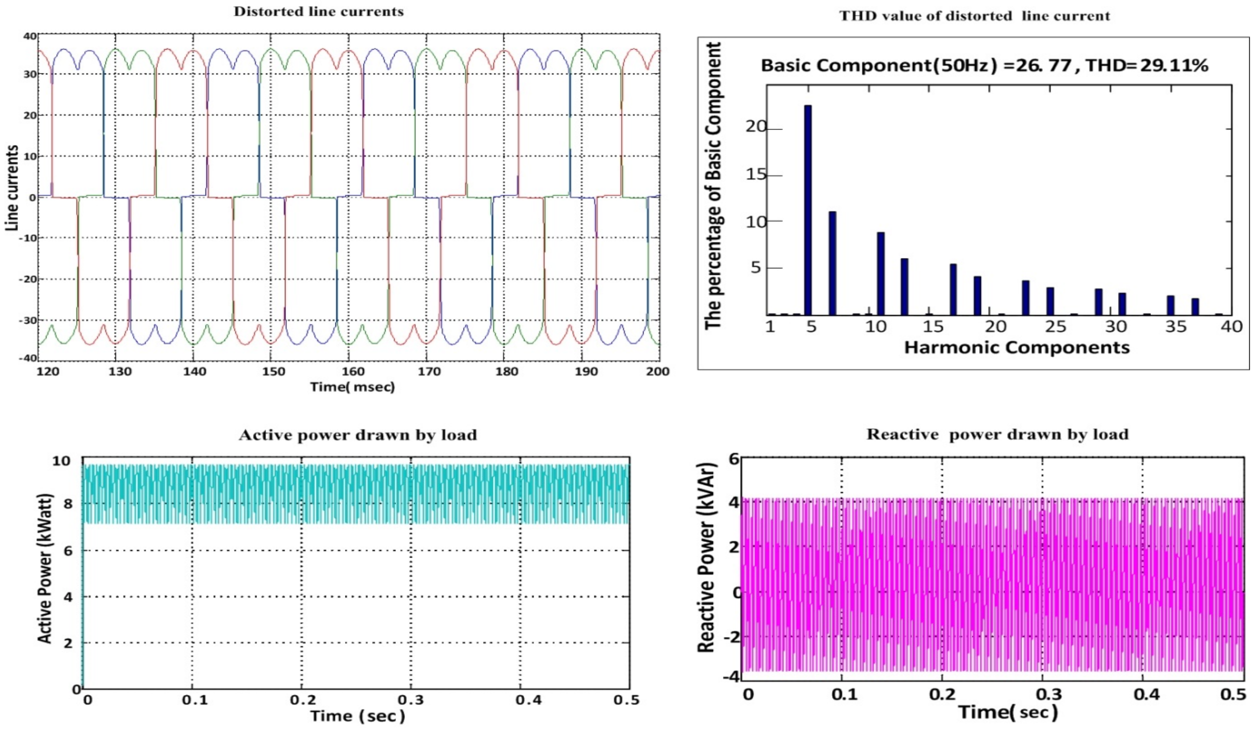

Fig. 6 Values of distorted line currents

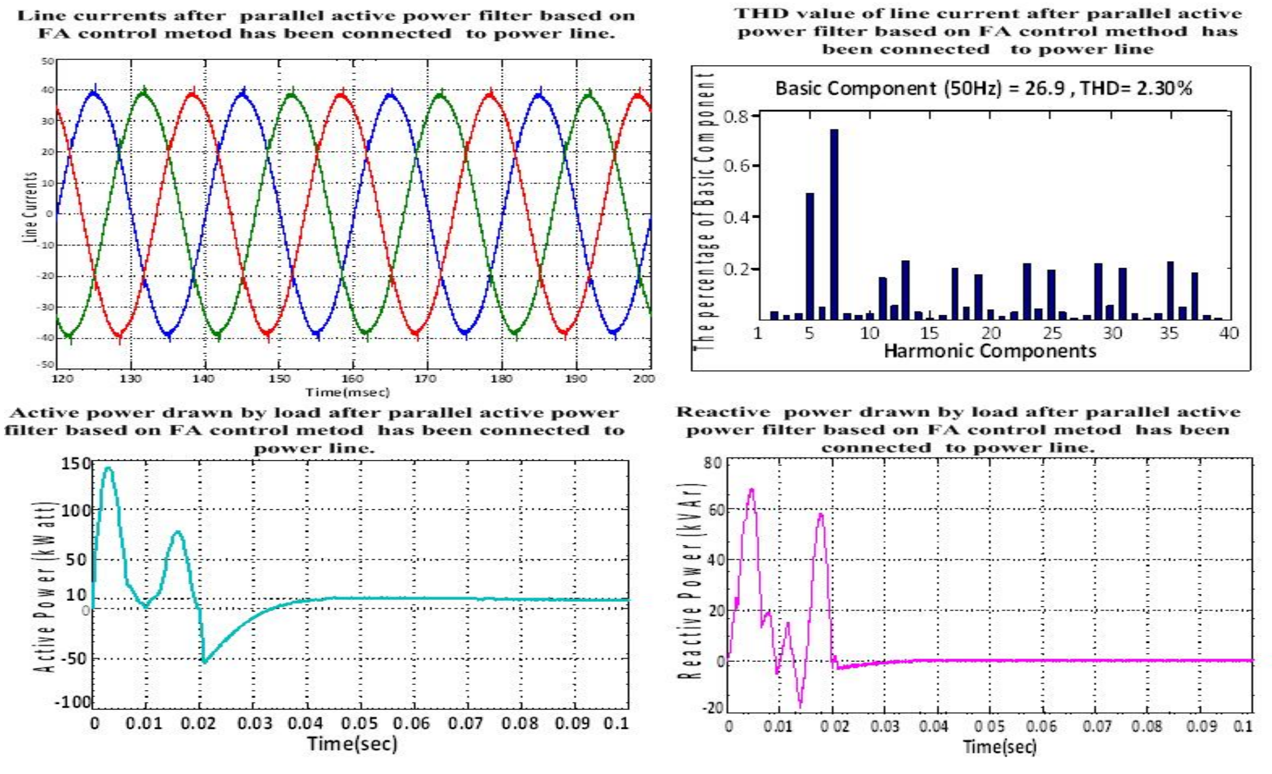

Fig. 7 Values of line currents after parallel active power filter based on FA control method has been connected to power line

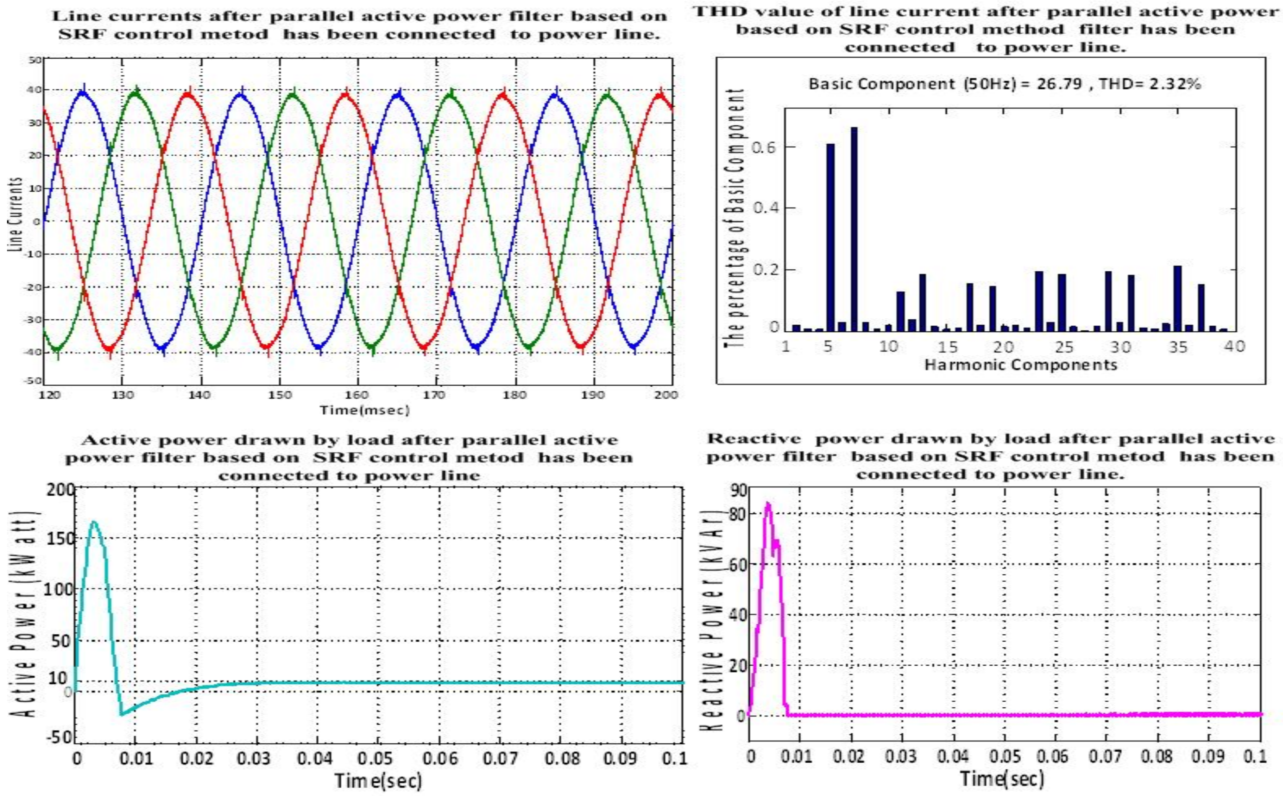

Fig. 8 Values of line currents after parallel active power filter based on SRF control method has been connected to power line

V. Conclusion

Nowadays APFs offers an effective solution method on power quality problems. Topological structure and control method of APFs are parameters to be taken into consideration to solve existing problems. In this study, parallel active power filters based on FA control method and SRF control method has been examined. Performance of both two methods have compared in terms of harmonic currents compensation and reactive power compensation. For this comparison, MATLAB / Simulink power system toolbox program has been used. With parallel active power filter based on FA algorithm, THD value of harmonic current in power line has reduced from %29.11 to %2.30. Additionally with PAPF based on Synchronous Reference Frame algorithm, THD value of harmonic current in power line has reduced from %29.11 to %2.32. The obtained simulation results have showed that compensation of both methods are successful. At the same time THD value of current harmonics is under predetermined international standards.

It has been observed that FA control method is a bit more successful in terms of both harmonic compensation and reactive power compensation.

References

[1] S.J. Huang and C.J. Wu. "A Control Algorithm for Three-Phase Three-Wired Active Power Filters Under Non ideal Mains Voltages, " IEEE Transactions on Power Electronics, vol. 14, pp. 753–760, Jul 1999.

[2] B. Singh, K. Al-Haddad, and A. Chandra, "A Review of Active Filters for Power Quality Improvement," IEEE Transactions on Industrial Electronics, vol.46, pp. 960–971, Oct 1999.

[3] B. Singh, K. Al-Haddad, and A. Chandra, "A New Control Approach to Three-phase Active Filter for Harmonics and Reactive Power Compensation," IEEE Transactions on Power Systems, vol.13, pp. 133–138, Feb 1998.

[4] Y.X. Xia and X. Han, "A Novel Active Power Filter for Harmonic Suppression and Reactive Power Compensation, " in Industrial Electronics and Applications (CUST), 1ST IEEE Conference on, 2006, pp. 1–3.

[5] H. Akagi, "Active and Hybrid Filters for Power Conditioning," in Industrial Electronics (ISIE), Proceedings of the 2000 IEEE International Symposium on, 2000, pp. TU26 - TU36.

[6] N. Atan and F.Z. Hussien, "An Improvement of Active Power Filter Control Methods in Non-Sinusoidal Condition," in Power and Energy Conference (PEC), IEEE 2nd International Conference on, 2008, pp. 345–350.

[7] L.H. Jou, "Performance comparison of the three-phase active-power-filter algorithms, Generation," Transmission and Distribution, IEEE Proceedings, pp. 646–652, Nov 1995.

[8] M.W. Grady, J.M. Samotyj, and H.A. Noyola, "Survey of Active Power Line Conditioning Methodologies," IEEE Transactions on Power Delivery, vol. 5, pp.1536–1542, Jul 1990.

[9] L.H. Jou, C.J. Wu, and J.Y. Chang, "A Novel Active Power Filter for Harmonic Suppression," IEEE Transactions on Power Delivery, vol. 20, pp. 1507–1513, April 2005.

[10] M. Kale, "Current Harmonic and Reactive Power Compensation with Parallel Active Power Filter,": School of Engineering Sciences, Kocaeli University; 2004.

[11] M. El-Habrouk, K.M. Darwish, and P. Mehta, "Active power filters: A review, " IEEE Proceedings on Electric Power Applications, vol. 147, pp. 403– 413. Sep 2000.

[12] D. Li and J. Tian, "A Novel Active Power Filter for the Voltage-Source Type Harmonic Source, " in Electrical Machines and Systems (ICEMS), International Conference on, pp. 2077-2080. 2008.

[13] Z.F. Peng and J.D. Adams, "Harmonic Sources and Filtering Approaches," Industry Applications Magazine IEEE, vol.7, pp. 18–25. Jul 2001.

ISSN: 2517-9438
Vol:8, No:7, 2014

[14] G.G. Terbobri, F.M. Saidon and S.M. Khanniche, "Trends of Real Tıme Controlled Active Power Fılters, " in Power Electronics and Variable Speed Drives, Eighth International Conference on (IEE Conf. Publ. No. 475), pp.410–415. 2000.
[15] D.R. Henderson and J.P. Rose, "Harmonics: The Effects on Power Quality and Transformers," IEEE Transactions on Industry Applications, vol.30, pp.528–532, 1994.
[16] K.J. Phipps, P.J. Nelson and K.P. Sen, "Power Quality and Harmonic Distortion on Distribution Systems, " IEEE Transactions on Industry Applications, vol.30, pp.476–484, Mar/Apr 1994.
[17] S.J. Subjak and S.J. McQuilkin, "Harmonics-Causes, Effects, Measurements, and Analysis: An Update, " IEEE Transactions on Industry Applications, vol.26, pp.1034–1042, Nov/Dec 1990.
[18] S. Jain, P. Agarwal, O.H. Gupta and G. Agnihotrin, "Modeling of Frequency Domain Control of Shunt Active Power Filter using MATLAB Simulink and Power System Blockset," Electrical Machines and Systems (ICEMS).Proceedings of the Eighth International Conference on, pp.1124-1129. 2005.
[19] M. Kesler and E. Özdemir, "Power Qualıty Improvement With UPQC in 3-Phase 4- Wıre Systems," vol. 25, pp. 681-691, 2010.
[20] M. Bozabalı, "Design and Simulation of Shunt Active Power Filter on Three Phase Systems": School of Engineering Sciences, Sakarya University; 2009.