

## APF for Harmonic Elimination of BLDC Drive

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### **Abstract:**

Power system harmonics are a menace to electric power systems with disastrous consequences. The line current harmonics cause increase in losses, instability, and also voltage distortion. Active filters have been used near harmonic producing loads or at the point of common coupling to block current harmonics. Shunt filters still dominate the harmonic compensation at medium/high voltage level, whereas active filters have been proclaimed for low/medium voltage ratings. With diverse applications involving reactive power together with harmonic compensation, passive filters are found suitable. With the widespread use of harmonic generating devices, the control of harmonic currents to maintain a high level of power quality is becoming increasingly important. An effective way for harmonic suppression is the harmonic compensation by using active power filter. This paper presents a comprehensive survey of active power filter (APF) control strategies put forward recently. It is aimed at providing a broad perspective on the status of APF control methods to researchers and application engineers dealing with harmonic suppression issues. The three techniques analyzed are the Synchronous Reference Frame Theory (SRF), SRF theory without synchronizing circuit like phase lock loop (PLL) also called instantaneous current component theory and finally modified SRF theory. Simulation results are obtained under sinusoidal balanced voltage source balanced load condition. The comparison and effectiveness of all the methods is based on the theoretical analysis and simulation results obtained

with MATLAB employing a three phase three wire shunt active filter test system. Finally shunt active power filter is applied to BLDC drive application. THD plots with and without APF is presented.

**Keywords-** Synchronous Reference Frame, instantaneous current component theory, Modified SRF, Active Filter, Harmonics. BLDC Drive.

### **1.INTRODUCTION**

The growing use of non-linear and time-varying loads has led to distortion of voltage and current waveforms and increased reactive power demand in ac mains. Harmonic distortion is known to be source of several problems, such as increased power losses, excessive heating in rotating machinery[1], significant interference with communication circuits and audible noise, incorrect operation of sensitive loads. Passive filters are traditional method to eliminate harmonics, but with recent developments in power semiconductor switches and converters, coupled with developments in control techniques and analog and digital implementations, active filters are becoming an effective and commercially viable alternative to passive filters[2]. Active filter offer the following advantages: able to cover a wide range of harmonic frequencies; do not contribute resonant frequencies to the network; harmonic attenuation is network impedance dependent. Among the various topologies the shunt active power filter based on voltage source inverter (VSI) is the most common one because of its efficiency[3]. The performance of active power filters depends on the adoptive control approaches. Various current detection methods, such as instantaneous reactive power theory, synchronous reference frame

method . The commonness of these methods is the request for generating reference current of APF, either with the load current or the mains current. The commonness of these methods is to control VSI with the difference between real current and reference current. Conventionally passive L–C filters were used to reduce harmonics and capacitors were employed to improve the power factor of the ac loads. The increased severity of power quality problems and other problems associated with the passive filters such as large size and weight, higher cost, fixed compensation ,and resonance problems with loads and networks have required a focus on a power electronic solution, that is, active power filters (APF) as shown in Fig.1. In recent years, many publications [4] have also appeared on the harmonics suppression using active power filters. Selection of a control method and proper topology of harmonic suppression, best suited to particular conditions, requires that advantages, disadvantages and limitations of these devices, which exhibit a very broad range of properties.

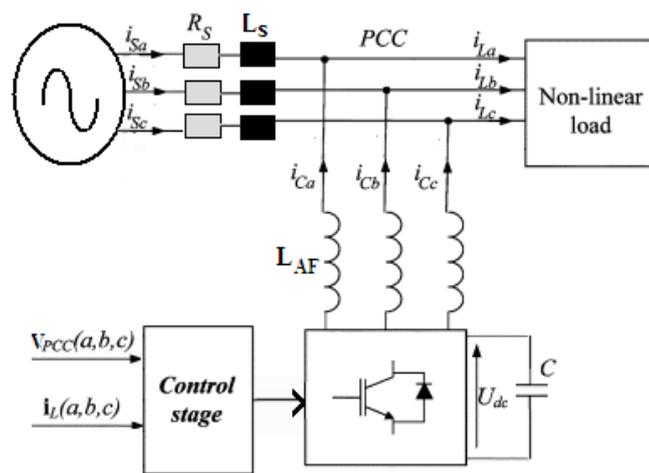


Figure. 1 Basic principle of shunt current compensation in active filter

The control strategy for a shunt active power filter generates the reference current, that must be provided by the power filter to compensate reactive power and harmonic currents demanded by the load. This involves a set of currents in the phase domain, which will be tracked generating the switching signals

applied to the electronic converter by means of the appropriate closed-loop switching control technique such as hysteresis or deadbeat control.

Several methods including instantaneous real and reactive power theory have been proposed for extracting the harmonic content [5]. All these methods work well under steady state, balanced and sinusoidal conditions of supply voltage. Among all the methods presented in the literature, the Synchronous Reference Frame method (SRF) is one of the most common and probably it is the best method. It is based on the fact that harmonics change their frequency in a rotating reference frame, and so they are better isolated with high pass filters[6]. The method presents excellent characteristics but it is a little difficult to implement. This paper presents a different modification based on the same principle and compares its performances with sinusoidal source and balanced load condition. The Modified SRF method called, in this paper, Filtered Modified Reference Frame Method (FMRF), because it uses filters and is based on the modified reference frame method [8].

## II SRF METHODS

Among the several methods presented in the literature, the Synchronous Reference Frame method (SRF) is one of the most common and probably it is widely used method. This section is organized as to describe succinctly the SRF methods. The three methods presented in this section with some results obtained with the above mentioned methods. The nonlinear load considered is a three-phase diode bridge rectifier.

### A Synchronous Reference Theory (SRF)

In the SRF [5], the load current signals are transformed into the conventional rotating frame d-q. If theta is the transformation angle, the transformation is defined by:

$$\begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ -\sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{4\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}$$

Fig.2 shows the basic configuration of synchronous reference frame. In the SRF is a time varying angle that represents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase ac voltages. In the SRF is a time varying angle that represents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase ac voltages. To implement the SRF method some kind of synchronizing system should be used. In [6] phase-locked loop (PLL) is used for the implementation of this method. In this case the speed of the reference frame is practically constant, that is, the method behaves as if the reference frame's moment of inertia is infinite. The fundamental currents of the d-q components are now dc values. The harmonics appear like ripple. Harmonic isolation of the d-q transformed signal is achieved by removing the dc offset. This is accomplished using high pass filters (HPF). In spite of a high pass filter, a low pass filter is used to obtain the reference source current in d-q coordinates.

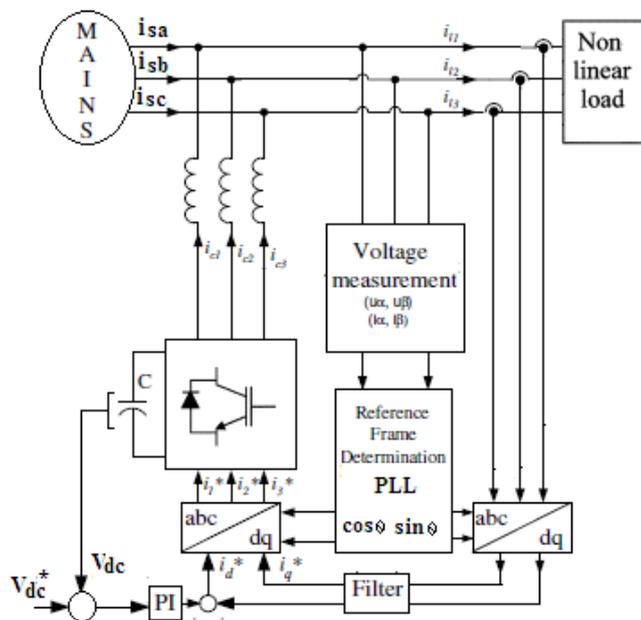


Figure. 2 Basic principal of SRF

**B. Instantaneous Current Component (id-iq) Theory**

The Modified Synchronous Frame method is presented in [7]. It is called the instantaneous current component (id-iq) method. This is similar to the SRF frame method. The transformation angle is now obtained with the voltages of the ac network. The major difference is that, due to voltage harmonics and imbalance, the speed of the reference frame is no longer constant. It varies instantaneously depending of the waveform of the three phase voltage system. In this method the compensating currents are obtained from the instantaneous active and reactive current components and of the nonlinear load. In the same way, the mains voltages V(a,b,c) and the polluted currents il(a,b,c) in  $\alpha$ - $\beta$  components must be calculated as given by (2), where C is Clarke Transformation Matrix. However, the load current components are derived from a synchronous reference frame based on the Park transformation, where represents the instantaneous voltage vector angle (3).

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = [C] \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix}$$

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix}, \theta = \tan^{-1} \frac{V_{\beta}}{V_{\alpha}}$$

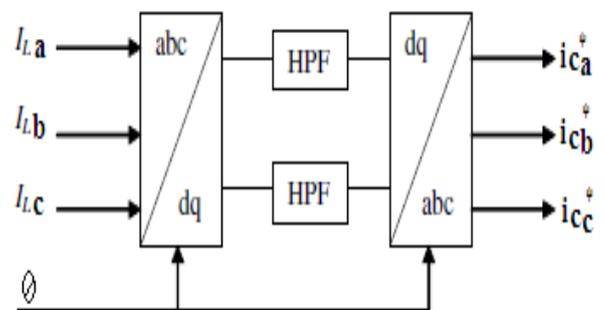


Figure.3 Principal of the synchronous reference frame method

Fig. 3 shows the block diagram SRF method. Under balanced and sinusoidal mains voltage conditions angle  $\theta$  is a uniformly increasing function of time. This transformation angle is sensitive to voltage harmonics and unbalance; therefore  $d\theta/dt$  may not be constant over a mains period. With transformation (2) and (3) the direct voltage component is

$$\begin{bmatrix} il_d \\ il_q \end{bmatrix} = \frac{1}{\sqrt{V_\alpha^2 + V_\beta^2}} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix}$$

$$\begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix} = \frac{1}{\sqrt{V_\alpha^2 + V_\beta^2}} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} ic_d \\ ic_q \end{bmatrix}$$

$$\begin{bmatrix} I_{comp,a} \\ I_{comp,b} \\ I_{comp,c} \end{bmatrix} = [C]^T \begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix}$$

**C. Modified (id-iq) Theory**

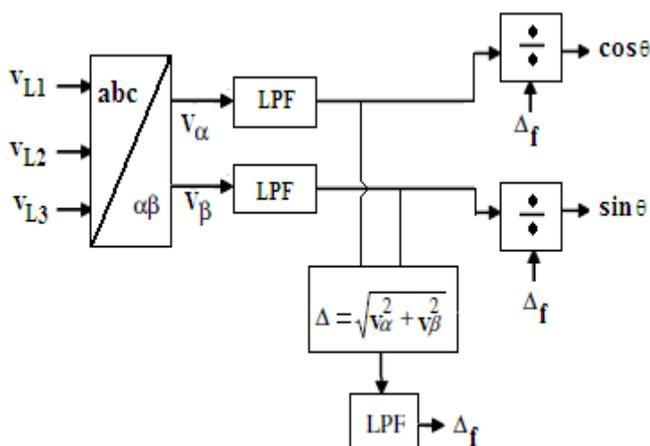


Figure.4 Principal of modified (id-iq) method

The method suggested in this section is based on the modified (id-iq) method (FMRF). The principle is the same. However there are two differences in the determination of the instantaneous position of the rotating reference frame. In spite of using the voltages to calculate the transformation angle, low pass filters (LPF) are used to reduce harmonics of the network signals, and consequently use on the control process

approximate sinusoidal waveforms, “Fig.4”. This filter is important because the method becomes more insensitive to harmonics on the mains. It will be verified also that the behaviour of the filter will be different concerning to on symmetrical and unsymmetrical conditions.

**III MATHAMATIAL MODELING OF BLDC**

The three phase star connected BLDC motor can be described by the following four equations in bipolar mode of operation.

$$v_{ab} = R(i_a - i_b) + L \frac{d}{dt}(i_a - i_b) + e_a - e_b \quad (1)$$

$$v_{bc} = R(i_b - i_c) + L \frac{d}{dt}(i_b - i_c) + e_b - e_c \quad (2)$$

$$v_{ca} = R(i_c - i_a) + L \frac{d}{dt}(i_c - i_a) + e_c - e_a \quad (3)$$

$$T_e = B\omega_m + j \frac{d\omega_m}{dt} + T_L \quad (4)$$

The symbol  $v$ ,  $i$  and  $e$  denote the phase to phase voltages, phase currents and phase back EMF’s respectively, in three phases a, b and c. The resistance  $R$  and the inductance  $L$  are per phase values and  $T_e$  and  $T_L$  are the electrical torque and the load torque.  $J$  is the rotor inertia,  $B$  is a friction constant and  $\omega_m$  is the rotor speed. The back EMF’s and the electrical torque can be expressed as

$$e_a = \frac{K_e}{2} \omega_m F(\theta_e) \quad (5)$$

$$e_b = \frac{K_e}{2} \omega_m F(\theta_e - \frac{2\pi}{3}) \quad (6)$$

$$e_c = \frac{K_e}{2} \omega_m F(\theta_e - \frac{4\pi}{3}) \quad (7)$$

$$T_e = \frac{K_t}{2} \left[ F(\theta_e)i_a + F(\theta_e - \frac{2\pi}{3})i_b + F(\theta_e - \frac{4\pi}{3})i_c \right] \quad (8)$$

$K_e$  and  $K_t$  are the back EMF and torque constants.

## IV MATLAB/SIMULINK MODELING AND SIMULATION RESULTS

Fig. 5 shows the Matlab/Simulink model of Shunt active power filter. Here simulation is carried out for four cases. In case one APF is simulated using Synchronous Reference Theory (SRF), and case two APF is simulated in BLDC drive application.

### A. Case one

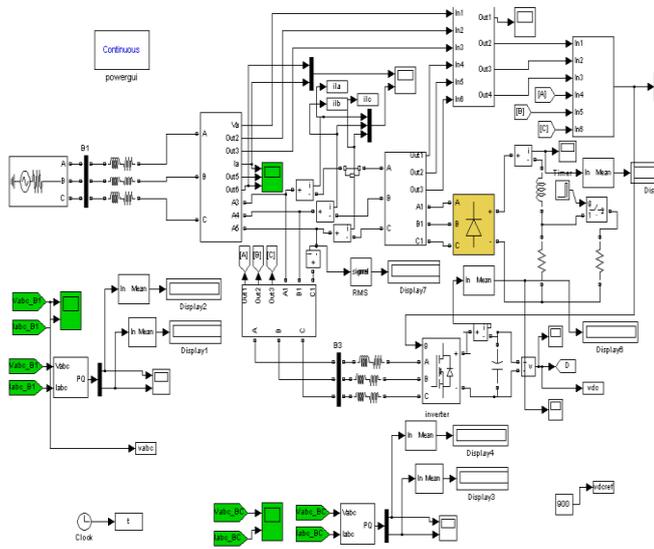


Figure.5 Matlab/Simulink Model of Shunt Active Power Filter

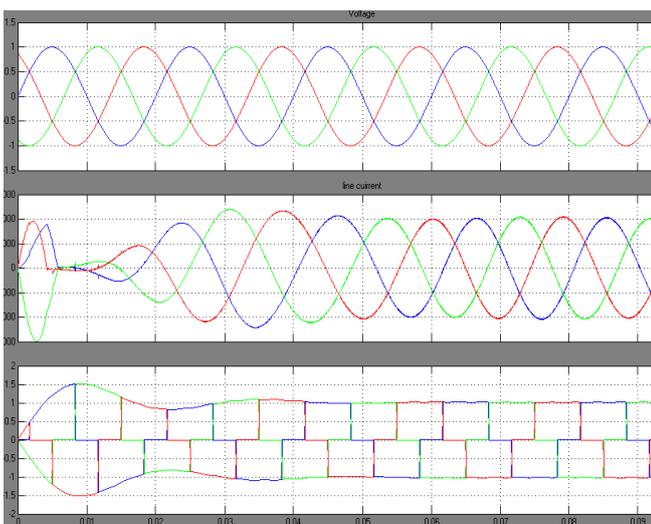


Figure. 6 Simulation results for Synchronous Reference Theory (SRF) Fig.6 shows the simulation results for SRF theory. It shows three phase source

voltage, three phase source currents and three phase non sinusoidal load currents.

### B Case two

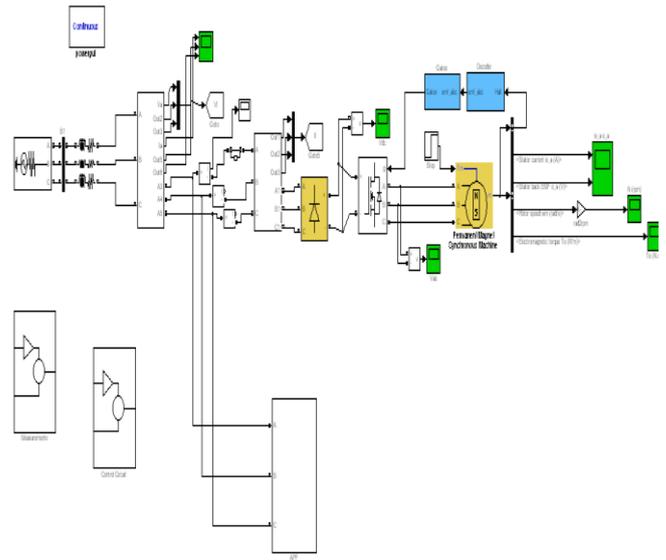


Figure. 8 Matlab/Simulink model of APF BLDC Drive

Fig.8 shows the Matlab /Simulink model of APF BLDC drive.

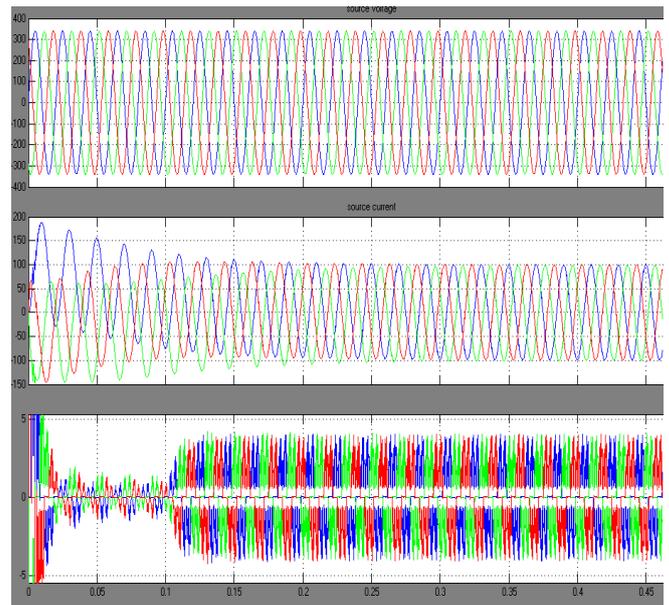


Figure. 9 Simulation results of APF BLDC drive

Fig. 9 shows the simulation results APF. It shows three phase source voltage, three phase source currents and three phase non sinusoidal load currents.

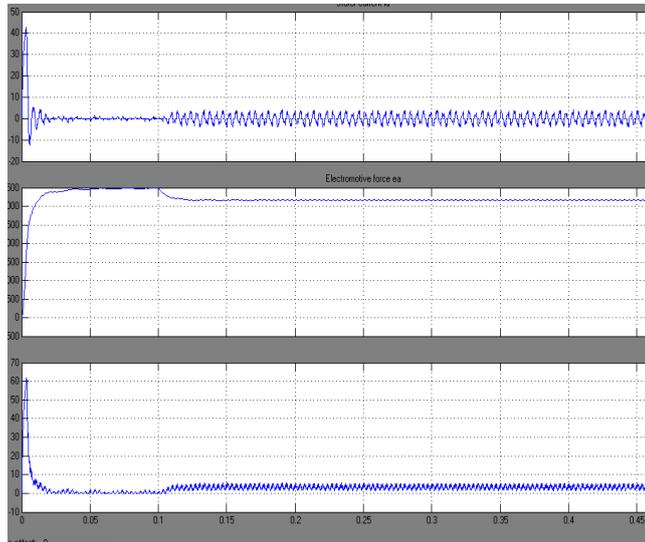


Figure. 10 Simulation results of BLDC

Fig.10 shows the simulation results of APF BLDC Drive it consists of stator currents, motor speed and electromagnetic torque.

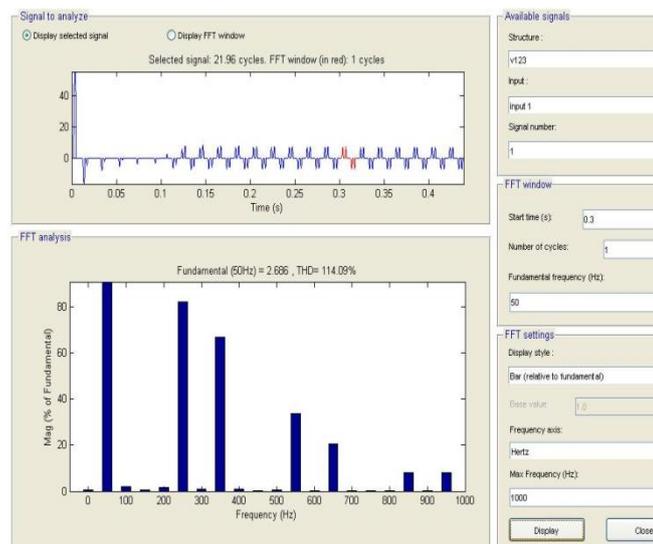


Figure. 11 FFT analysis of source current without APF

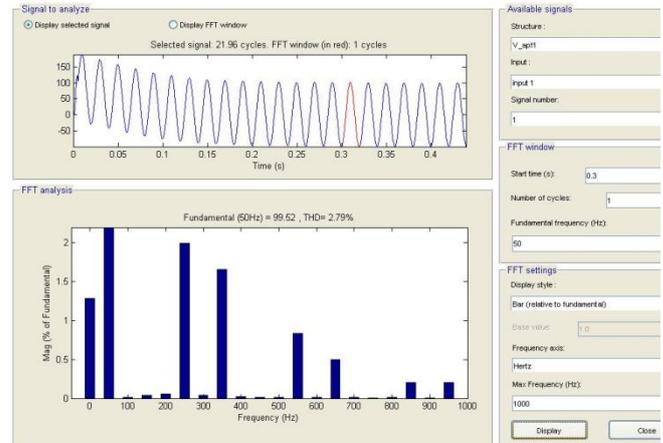


Figure. 12 FFT analysis of source current with APF

Fig.11 shows the source current without APF and harmonic spectrum. Since BLDC motor require square wave current the THD in source current without APF is very high (112%). Fig. 12 shows the source current with APF and harmonic spectrum. From this figure it is clear that with APF the THD is reduced to 2.9%.

## V CONCLUSION

In a modern power system, increasing of loads and non-linear equipment's have been demanding the compensation of the disturbances caused for them. These nonlinear loads may cause poor power factor and high degree of harmonics. In this paper the use and advantages of applying active power filters to compensation power distribution systems has been presented. This paper presents the compensation performance of all the different SRF techniques under sinusoidal voltage source condition as shown in table-1. Results are similar with gained source THD under IEEE 519, but under various filter type the chebyshev type filter is having superior performance compare to Butterworth filter for all methods. An Improved Synchronous Reference Frame Method for the control of active power filters was presented. It is called Filtered Modified Reference Frame Method (FMRF) and is based on the same principle as the Synchronous Reference Frame method. However, this new method explores the fact that the performance of the active filter to isolate harmonics depends on the speed of the system that determines the rotating reference frame,

but doesn't depend on its position. The distortion of power supply current is diminished to a satisfactorily level. Using active filter the total harmonic distortion is reduced. Compared with other methods, this new method presents some advantages due to its simplicity. Finally a BLDC drive application is considered.

## REFERENCES

- [1] IEEE Recommended Practices and Requirements for Harmonic Control of Electrical Power systems, IEEE Standards. 519-1992,1993.
- [2] H.Akagi, "New trends in active filters for power conditioning,"IEEE Industry Applications., vol. 32, No-6, pp. 1312-1322, 1996.
- [3] H. Akagi, Y. Kanazawa, and A. Nabae, "Generalized theory of the instantaneous reactive power in three-phase circuits," Proc. 1983 Int. Power Electronics Conf., Tokyo, Japan, 1983. pp. 1375-1386.
- [4] H. Akagi, Y. Kanazawa, and A. Nabae "Instantaneous reactive power compensators comprising switching devices without energy storage components," IEEE Trans. Ind Appli.,Vol. IA-20, 1984.
- [5] Bhattacharya, M. Divan, and B. Benejee, "Synchronous Reference Frame Harmonic Isolator Using Series Active Filter", 4th European Power Electronic Conference, Florence, 1991, Vol. 3, pp. 30-35.
- [6] M.J. Newman, D.N.Zmood, D.G.Holmes, "Stationary frame harmonic reference generation for active filter systems", IEEE Trans. on Ind. App., Vol. 38, No. 6, pp. 1591 – 1599, 2002.
- [7] V.Soaes,P.Verdelho,G.D.Marques," An instantaneous active reactive current component method for active filters" IEEE Trans. Power Electronics, vol. 15, no. 4, July- 2000, pp. 660–669.
- [8] G.D.Marques, V.Fernao Pires, Mariusz Mlinowski, and Marian Kazmierkowski, "An improved synchronous Reference Method for active filters," the International conference on computer as a tool,EUROCON 2007, Warsaw, September - 2007, pp. 2564-2569.
- [9] V. Soares, P.Verdelho, G. D. Marques, "Active Power Filter Control Circuit Based on the Instantaneous Active and reactive Current id-iq Method" Power Electronics Specialists Conference, Pesc'97 St. Louis, Missouri, June 22-27, 1997, pp-1096-1101.
- [10] P. Verdelho, G. D. Marques, "An Active Power Filter and Unbalanced Current Compensator" IEEE Transactions on Industrial Electronics, vol. 44, N°3 June 1997, pp 321-328.
- [11] A.Cavallani and G.C.Montarani," Compensation strategies for shunt active-filter control," IEEE Trans. Power Electron., vol. 9, no. 6, Nov. 1994, pp. 587–593.
- [12] B.Singh, K.Al-Haddad and Chandra Ambrish ," Harmonic elimination, reactive power compensation and load balancing in three phase, four wire electric distribution system supplying nonlinear loads", Electric Power System Research, Vo1.44, 1998,pp.93-100.