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# Mitigation of Harmonics by Evaluation of Control Algorithms for Shunt Active Filter

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***Abstract: - Shunt Active Filter produces the reference current that must be supplied by the power filter to compensate harmonic currents demanded by the load. This paper presents different types of SRF methods for real time regeneration of compensating current for harmonic mitigation. 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. The performance of Shunt Active Power Filter in terms of THD (Total Harmonic distortion) of voltage and current is achieved with in the IEEE 519 Standard. The comparison of all methods is based on the theoretical analysis and simulation results obtained with MATLAB/SIMULINK***

**Index terms—*Synchronous Reference Frame, instantaneous current component theory, Modified SRF, Active Filter, Harmonics.***

## I. INTRODUCTION

The increasing use of power electronic based loads (adjustable speed drives, SMPS, etc) to improve system efficiency and controllability is increasing concern for harmonic distortion levels in end use facilities and on overall power system. The power electronic switching is useful to generate harmonic currents in active power filters that cancel harmonic content from non – linear loads. Over the recent years, power quality has been given attention due to the intensively use of power electronic Controlled applications in all groups of engineering, such as controlling or converting AC power to feed electrical loads.

The non-linear loads have led to the concerns over the allowable amounts of harmonic distortion injected into the supply system. Standards such as IEEE-519 have emerged to set and impose limits and recommended practices so that the harmonic distortion levels are kept in check, thereby promoting better practices in the design and operation of power system and electric equipment.

Based on observations from various references, a practical limit of less than 5% of the total harmonic distortion (THD) must be employed by any system designers and/or end-users to ensure compliance with the established standards. Many efforts have been expended to develop active power filters and conditioner that can soften the power quality problems.

One of the cornerstones of the active filter is its control strategy that is implemented in the active filter controller. The performance of an active filter depends mainly on the selected reference generation scheme.

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. 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.

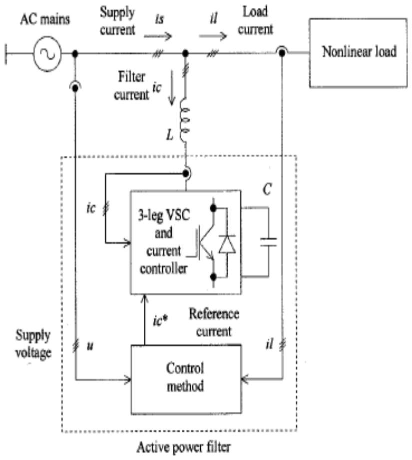


**Fig. 1**: Basic principal of shunt current compensation in active

## 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. SRF methods Are described concisely in this. 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, the load current signals are transformed into the conventional rotating frame d-q. Below equation shows the transformation angle as θ.
The transformation is defined by:

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

….1

Where voltages or currents are denoted by x.

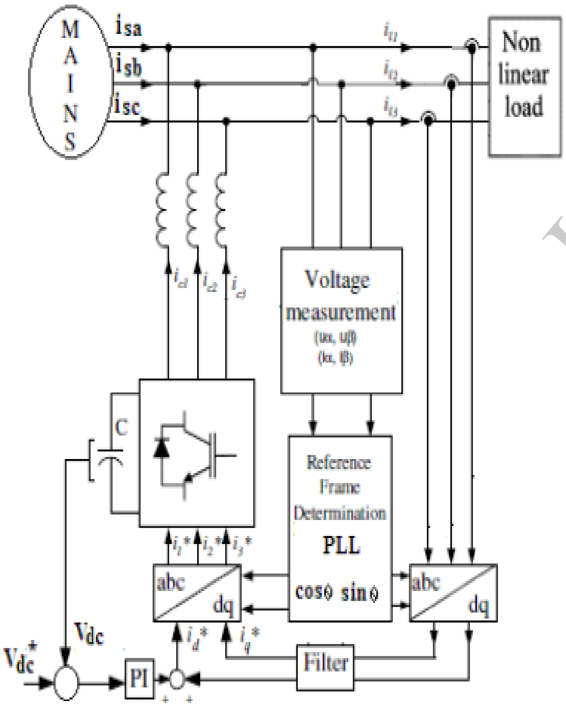


**Fig. 2**: Basic Synchronous Reference Frame Configuration

In the synchronous reference frame (SRF) method θ 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 individual phase ac voltages. To implement the SRF method some kind of synchronizing system should be used. Phase-locked loop (PLL) is used to implementation of this method. In this case the speed of the reference frame is nearly stable, that is, the method behaves as the reference frame's moment of inertia is infinite. The d-q components fundamental currents are now dc values. The harmonics come into view like ripple. By removing the dc offset we can achieve Harmonic isolation of the d-q transformed signal. high pass filters (HPF) were used to accomplish this task. In spite of a high pass filter, a LPF filter is used to gain the reference source current in d-q coordinates. Fig 2 illustrates a configuration of the SRF method. There is no need to supply voltage waveform for a SRF based controller. On the other hand voltage information is useful to find the phase position angle. The SRF harmonic detection method can be reasonably summarized as a block diagram as shown in Fig.3.

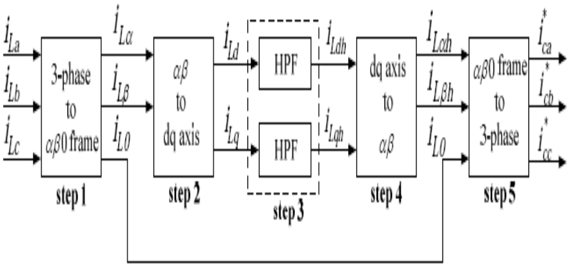


**Fig.3:** SRF harmonic detection

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

Fig.1 shows the schematic block diagram of the shunt active filter with controller. The block diagram consists of variable sensing system, Reference Estimation System, pulse width modulation signal generator and system controller.

The variable sensing block senses the system variables like supply current, load current and compensating current, DC link voltage or current. Pulse width modulation signal generator and system controller generate switching signals for converter switches based on the error produced by reference signal and actual system variables.

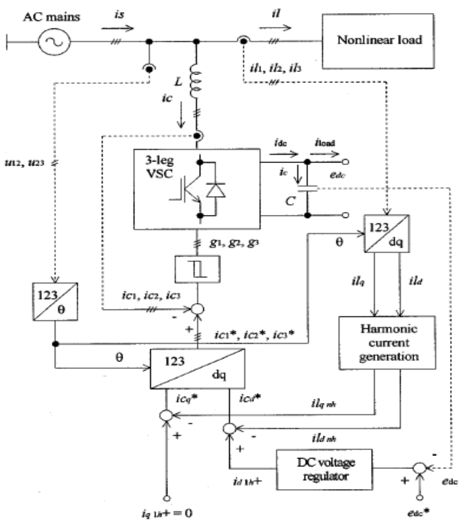


**Fig.4:** AF control system based on the instantaneous active and reactive current component Id - Iq method.

In this method the currents $I_{ci}$ are obtained from the instantaneous active and reactive current components Iℓd and Iℓq of the nonlinear load. In the same way, the mains voltages $v_i$ and the polluted currents Iℓi in αβ as in the previous method by 2 and 3. However, the load current components are derived from a synchronous reference frame based on the Park transformation, where the below equations represents the instantaneous voltage vector angle 4

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} \qquad \text{.... 2}$$

$$\begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} il_1 \\ il_2 \\ il_3 \end{bmatrix}$$

… …..3

$$\begin{bmatrix} il_d \\ il_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix}, \quad \theta = \tan^{-1}\frac{u_\beta}{u_\alpha}. \qquad \text{…..4}$$

With transformation the direct voltage component is $u_{dq}=u_{\alpha\beta}=$ $|\bar{u}_{dq}| = |\bar{u}_{\alpha\beta}| = \sqrt{u_\alpha^2 + u_\beta^2}$ and the quadrature voltage component is always null, Uq=0 , so due to geometric relations 4 becomes

$$\begin{bmatrix} il_d \\ il_q \end{bmatrix} = \frac{1}{\sqrt{u_\alpha^2 + u_\beta^2}} \cdot \begin{bmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{bmatrix} \cdot \begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix}. \qquad \text{………5}$$

Instantaneous active and reactive load currents Iℓd and Iℓq can also be decomposed into oscillatory and average terms Iℓd=I*ℓd+Iℓd , and Iℓq=I*ℓq+Iℓq . The first harmonic current of positive sequence is transformed to dc quantities, $i\ell^{+}_{dq1h}$ i.e., this constitutes the average current components. The first harmonic current, negative sequence currents & the entire higher order current harmonics, $\tilde{il}^{\pm}_{dqnh} + \tilde{il}^{-}_{dq1h}$ , are transformed to non-dc quantities and undergo a frequency shift, and so, comprise the components of oscillatory currents. These assumptions are applicable under sinusoidal mains and balanced voltage conditions. Eliminating the average current components by HPF's the currents that should be compensated are obtained, $ic_d = -\tilde{il}_d$ and $ic_q = -\tilde{il}_q$.

$$\begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix} = \frac{1}{\sqrt{u_\alpha^2 + u_\beta^2}} \cdot \begin{bmatrix} u_\alpha & -u_\beta \\ u_\beta & u_\alpha \end{bmatrix} \cdot \begin{bmatrix} ic_d \\ ic_q \end{bmatrix} \qquad \text{…..6}$$

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

The method suggested in this section is based on the modified ($i_d$-$i_q$) 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 αβ 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.6".

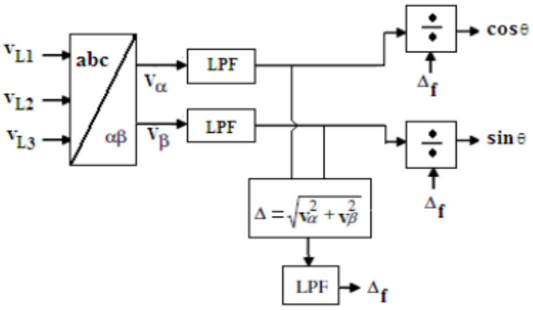


**Fig. 5:** Principal of modified (id-iq) method

The second modification consists in separating the Δ coefficient and to use a filtered Δ coefficient. This new modification is important because the system will presents better results to inverse sequence components. These concepts are presented in "fig. 5" using block diagrams. The modified synchronous reference frame method has excellent results in balanced sinusoidal and unbalanced ac mains.

In all cases studied in this paper, the load is a three phase diode bridge with an inductive circuit on its dc side. The $LPF_\alpha$, $LPF_\beta$ (cutoff frequency $f_c$) and $LPF_\Delta$ (cutoff frequency $f_d$) have different purposes. $LPF_\alpha$, $LPF_\beta$ are set to filter the ac mains and to avoid the influence of voltage harmonics presented on the network point of common coupling. The $LPF_\Delta$ is set to avoid the oscillation of the Δ parameter that is due to the inverse sequence component. The low pass filter used for $LPF_\alpha$, $LPF_\beta$, and $LPF_\Delta$, the type of LPF are of 4th order Butterworth and 1st order chebyshev type with appropriate cutoff frequencies. In this method the cutoff frequency of the Δ filter was set at 8 Hz and the cutoff frequency of the alpha and beta filters were also set to 60 Hz in Butterworth filter and passing band frequency of 20 Hz is used in chebyshev type of LPF.

## III RESULTS AND ANALYSIS

In order to evaluate the performance of all the methods simulation studies are carried out. In FMRF method it is observed that the supply current is close to sinusoidal and it remains in phase with the supply voltage, therefore, unity power factor is maintained at the output of supply system. From the figures 6 to 17 are results corresponding the three SRF Theories and Comparison is shown in the Table 1

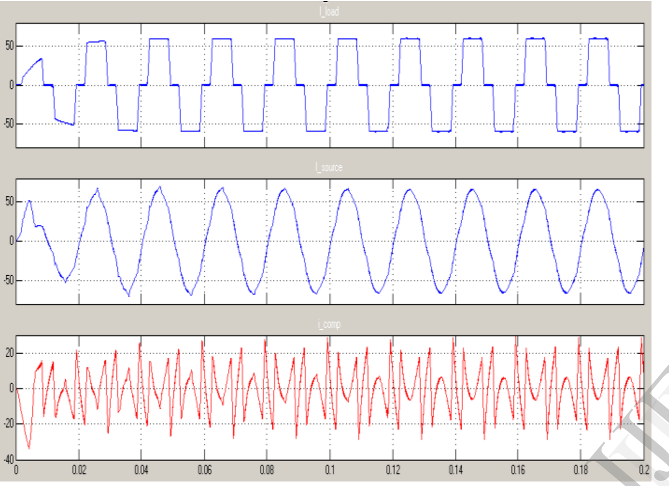
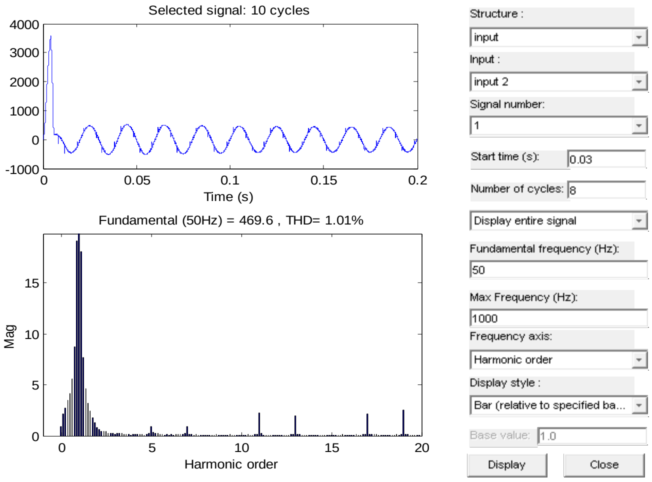


**Fig 6**: Performance of SRF theory: (1) Load current (2) Source current (3) Compensating current



Selected signal: 10 cycles

Fundamental (50Hz) = 469.6 , THD= 1.01%

Structure : input
Input : input 2
Signal number: 1
Start time (s): 0.03
Number of cycles: 8
Display entire signal
Fundamental frequency (Hz): 50
Max Frequency (Hz): 1000
Frequency axis: Harmonic order
Display style : Bar (relative to specified ba...
Base value: 1.0

**Fig. 7**: SRF Theory, Butterworth type filter: (1) Source current for 10 cycles (2) FFT analysis

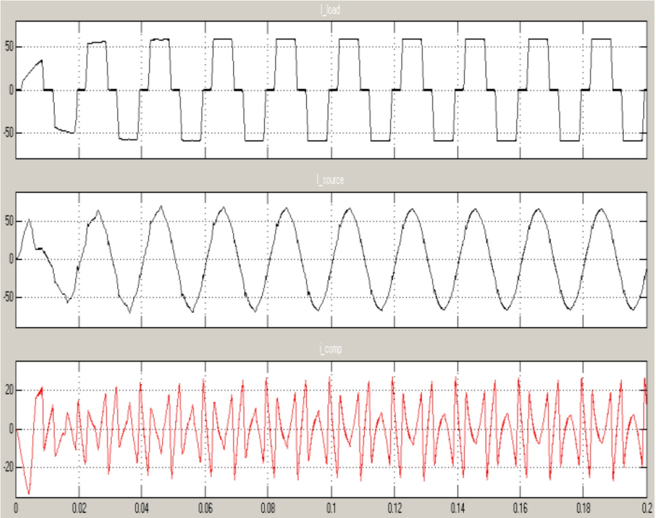
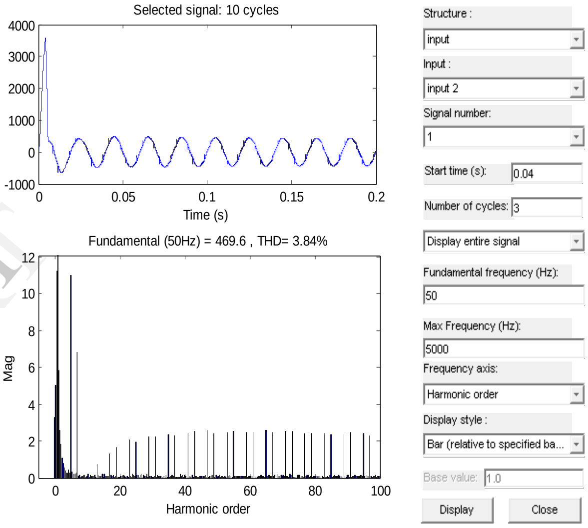


**Fig. 8**: Performance of SRF theory: (1) Load current (2) Source current (3) compensating current



Selected signal: 10 cycles

Fundamental (50Hz) = 469.6 , THD= 3.84%

Structure : input
Input : input 2
Signal number: 1
Start time (s): 0.04
Number of cycles: 3
Display entire signal
Fundamental frequency (Hz): 50
Max Frequency (Hz): 5000
Frequency axis: Harmonic order
Display style : Bar (relative to specified ba...
Base value: 1.0

**Fig. 9**: SRF Theory, Chebyshev type filter: (1) Source current for 10 cycles (2) FFT analysis

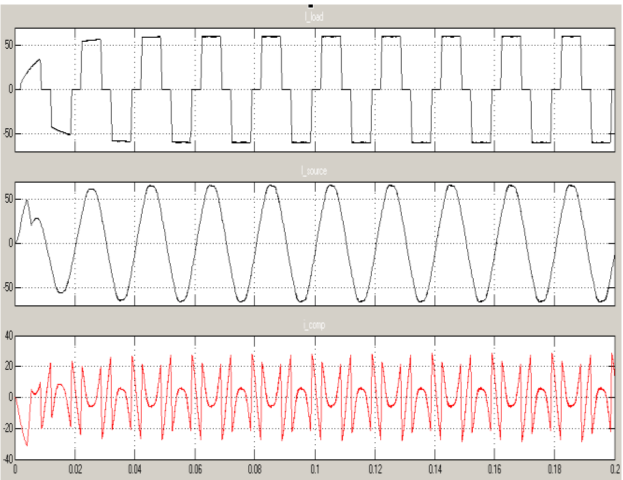
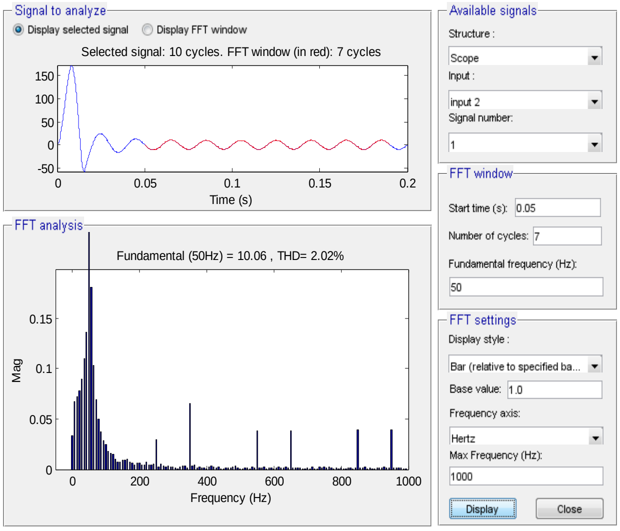


**Fig. 10**: Performance of id-iq theory: (1) Load current (2) Source current (3) Compensating current



Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 10 cycles. FFT window (in red): 7 cycles

FFT analysis
Fundamental (50Hz) = 10.06 , THD= 2.02%

Available signals
Structure : Scope
Input : input 2
Signal number: 1

FFT window
Start time (s): 0.05
Number of cycles: 7
Fundamental frequency (Hz): 50

FFT settings
Display style : Bar (relative to specified ba...
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

**Fig. 11**: id-iq Theory Butterworth type filter: (1) Source current for 5 cycles (2) FFT analysis

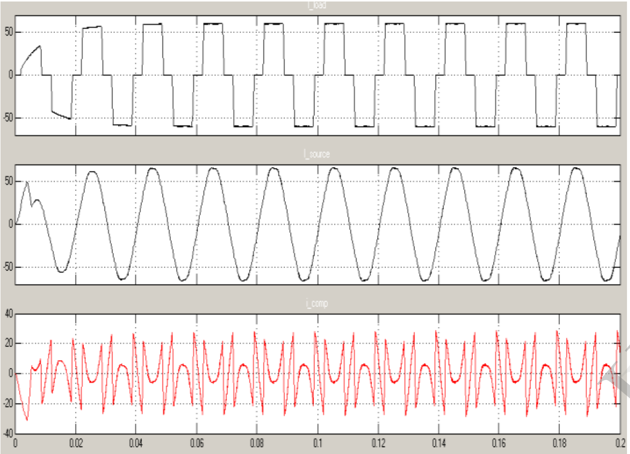
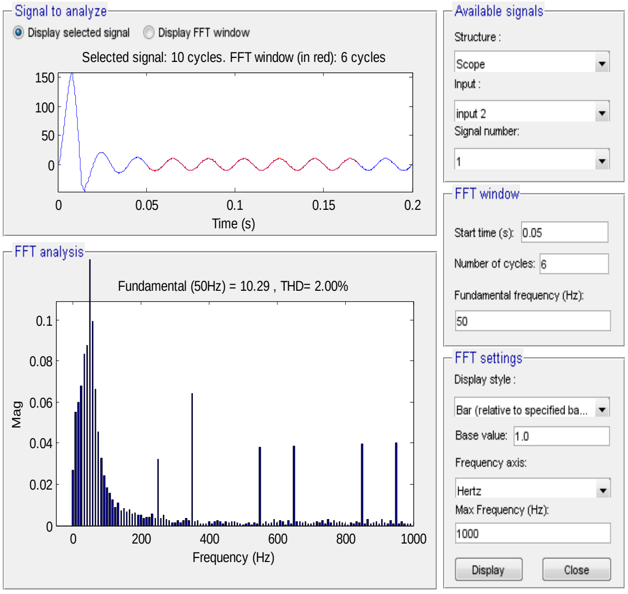


**Fig. 12**: Performance of id-iq theory: (1) Load current (2) Source current (3) Compensating current



Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 10 cycles. FFT window (in red): 6 cycles

FFT analysis
Fundamental (50Hz) = 10.29 , THD= 2.00%

Available signals
Structure : Scope
Input : input 2
Signal number: 1

FFT window
Start time (s): 0.05
Number of cycles: 6
Fundamental frequency (Hz): 50

FFT settings
Display style : Bar (relative to specified ba...
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

**Fig. 13**: id-iq Theory Chebyshev type filter: (1) Source current for 6 cycles (2) FFT analysis

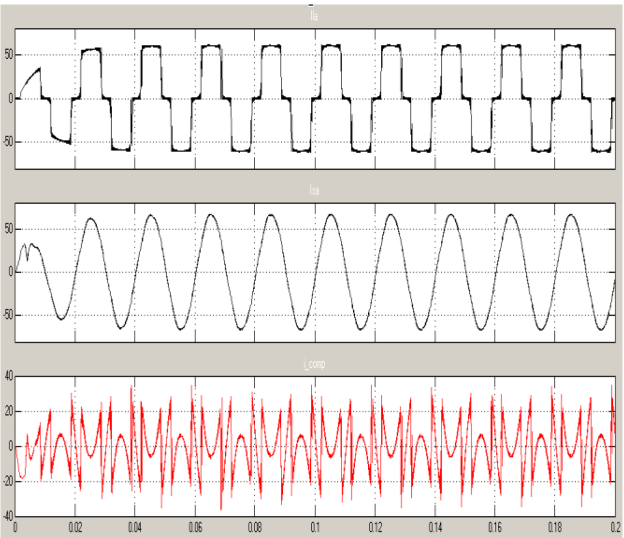
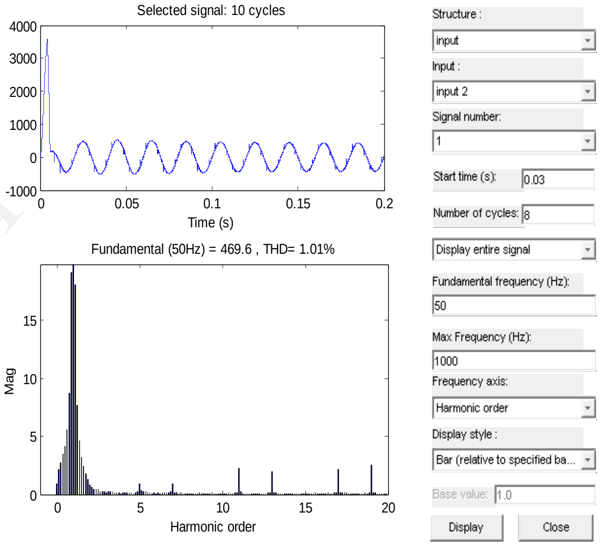


**Fig. 14**: Performance of Modified id-iq theory: (1) Load current (2) Source current (3) compensating current



Selected signal: 10 cycles

Fundamental (50Hz) = 469.6 , THD= 1.01%

Structure : input
Input : input 2
Signal number: 1
Start time (s): 0.03
Number of cycles: 8
Display entire signal
Fundamental frequency (Hz): 50
Max Frequency (Hz): 1000
Frequency axis: Harmonic order
Display style : Bar (relative to specified ba...
Base value: 1.0

**Fig.15**: Modified id-iq Theory Butterworth type filter: (1) Source current for 10 cycles (2) FFT analysis

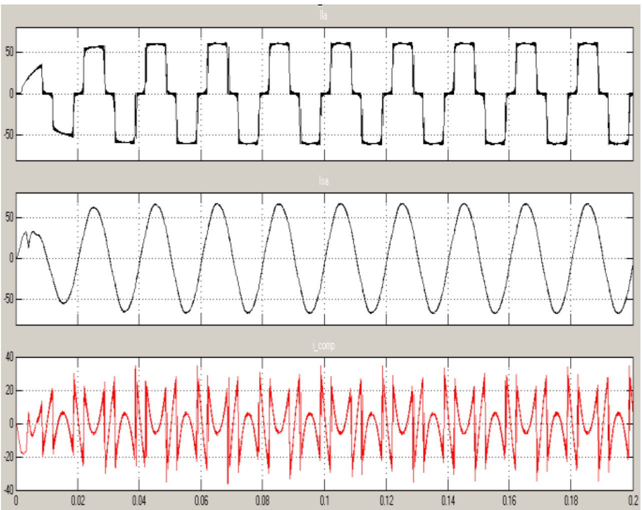
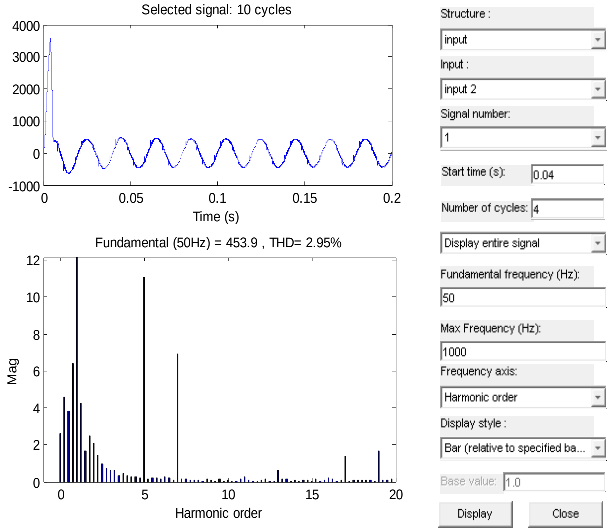


**Fig. 16**: Performance of Modified id-iq theory: (1) Load current (2) Source current (3) compensating current



Structure : input
Input : input 2
Signal number: 1
Start time (s): 0.04
Number of cycles: 4
Display entire signal
Fundamental frequency (Hz): 50
Max Frequency (Hz): 1000
Frequency axis: Harmonic order
Display style : Bar (relative to specified ba...
Base value: 1.0

**Fig. 17**: Modified $i_d$-$i_q$ Theory Chebyshev type filter: (1) Source current for 10 cycles (2) FFT analysis

In real filtering, a Butterworth type filter is normally chosen, but chebyshev filter is also equally compatible for preparing experimental prototype. This particular filter type was chosen, in order to obtain magnitude and phase characteristics as close as possible to an ideal filter since its magnitude response is maximally flat in the pass band and is monotonic in both pass band and stop bands. To minimize the influence of the HPF's phase responses, an alternative HPF (AHPF) can also be used by mean of a low-pass filter (LPF) of the same order and cutoff frequency, simply by the difference between the input signal and the filtered one, which is equivalent in performance.

TABLE 1
Comparison of the Different SRF Methods

| **parameters** | SRF Theory | | Id-Iq Theory | | Modified SRF Theory | |
|---|---|---|---|---|---|---|
| Filter type | BW | CH | BW | CH | BW | CH |
| Source Current THD(%) | 1.01 | 3.84 | 2.02 | 2.00 | 1.01 | 2.95 |
| 5th Harmonic | 2.46 | 1.6 | 1.7 | 1.89 | 2.51 | 2.44 |
| 7th Harmonic | 1.52 | 1.4 | 1.15 | 1.23 | 1.57 | 1.52 |
| 9th Harmonic | 0.03 | 0.02 | 0.28 | 0.30 | 0.01 | 0.02 |
| Load Perturbation Response | 30 ms | 40 ms | 20 ms | 25 ms | 10 ms | 10 ms |
| Requirement Of Ripple Filter | no | yes | yes | no | yes | no |

BW = Butterworth, CH = Chebyshev (Type of Filter Used)

## IV. CONCLUSION

This paper presents the mitigation of harmonics by evaluation of control algorithm. 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. The Synchronous Reference Frame method is one of the most common and performing more accurate for detection of harmonics in active filters. An enhanced Synchronous Reference Frame Method for the organize of active power filters was presented. It is called FMRF and is based on the same principle as the SRF method. So finally it concludes that the isolation of harmonics does not depend on the position of the RRF (rotating reference frame) & it's depends on the speed of the system. So, the reference frame can be detected by introducing some delay with ac power filters. Compared with other methods, this latest method presents some benefits due to its ease and its rudeness to perturbations on the ac network.