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Research Article

Comparison of Various Reference Current Generation Techniques for Performance Analysis of Shunt Active Power Filter using MATLAB Simulation

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Abstract

This paper deals with mitigation of harmonics using shunt active power filter. Due to use of nonlinear load harmonics generated in the power system. To solve this problem various reference current generation techniques have been used. In this paper Synchronous Reference Frame (SRF) and Instantaneous Reactive Power Theory (IRP) Theory are discussed. This harmonics are introduced because of nonlinear load in system that causes severe damage to our system. This harmonics are mitigate using above two techniques. The performance and result is simulated on MATLAB/ Simulink platform.

Keywords: *SRF, IRP, SAPF, Non Linear Load, Power Quality, PCC, THD, TDD.*

1. Introduction

Day by day growing number of power electronic based equipment introduced an impact on the power quality. Both domestic and industrial load causes harmonics in the system. The nonlinear load may be power semiconductor device, fans, Variable speed drives, arc furnace, CFL, personal computer, fri8dge, PLC, printer, large decaying DC component, etc. generate harmonics and that effect on power quality. Disturbance occurs in voltage, current, and frequency deviation that results in failure of equipments is called as power quality. Power quality is also defined as quality of both current and voltage. Due to effect on power quality huge financial loss happen. Power quality has some problems like voltage swell, voltage sag, very long interruption, very short interruption, harmonic distortion, voltage fluctuation, noise, voltage imbalance, etc. from above mentioned power quality problems harmonics is one of the important problems that effect on power system performance. When harmonics present in system then system shows symptoms like frequent blackout, communication interference, lamp flickering, sensitive equipment frequently dropout, etc. Due to presence of harmonics in system problems occurred like tripping of circuit breaker, parallel and series resonance will occurred, blowing of fuse, fault in energy meter, damage to sensitive electronic equipment, loss of motor windings, increase of rms and peak value, excessive neutral current, electromagnetic interference with communication system, overheating of all cable and equipment. Due to all this reason power quality is main research topic in power system. Mitigation of harmonics is very important to increase power quality. To mitigate harmonics in system filter are used. There are two types of filter used to mitigate harmonics in system like passive filter and active filter. Passive filter is oldest type electronic filter. Passive filter is quite simple, cost effective and reliable. Passive filter consist of resistor, inductor and capacitor and this filter does not depend on any type of external power supply. Passive filter have some drawback like it may cause gives overcompensation of reactive power, it may cause series and load resonance in system, it is heavy and bulky, it gets overloaded when load harmonics increases. Due to this drawback of passive filter harmonics get amplified on the source side and causes serious distortion in voltage. To overcome problems in passive filter power engineers developed new filter called as active filter. Active filter is able to compensate current harmonics. The performance of shunt active power filter depends on control algorithm used for generation of reference current.

2. Shunt Active Power Filter

The basic working principle of shunt active power filter is that it generates a reference current that has equal and opposite in polarity to harmonic current drawn by the load and inject to the point of common coupling, thereby forcing the source current to be pure sinusoidal.

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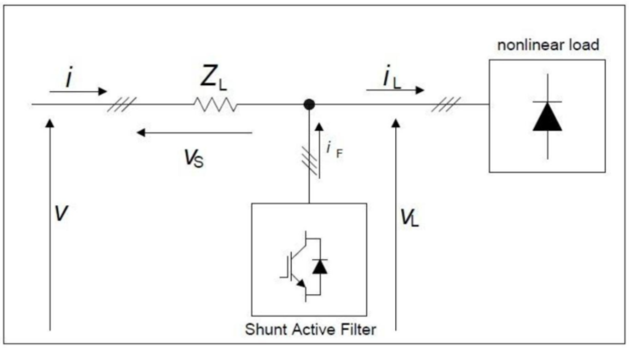

Figure 1 Basic diagram for Shunt active power filter

Harmonic and reactive current are thus cancelled at source end and the result is undistorted sinusoidal balance current such equipment shown in Figure called as shunt active power filter. Main purpose of shunt active power filter is to generate reference current. In this paper I used two techniques called Synchronous reference frame (SRF) and Instantaneous reactive power (IRP) theory for reference current generation discussed in details. The result is obtained in MATLAB/Simulink. The measure of the performance of algorithm is source current Total harmonic distortion (THD) and Total demand content (TDC) and magnitude of neutral current. The rest of paper organized as follow. In section III control algorithm is presented. In section IV Performance indices presented. In section V Simulation and result are described. In section VI comparison of SRF and IRP are done and finally in section VII conclusion are drawn.

3. Control Algorithm

A) Synchronous Reference Frame Theory

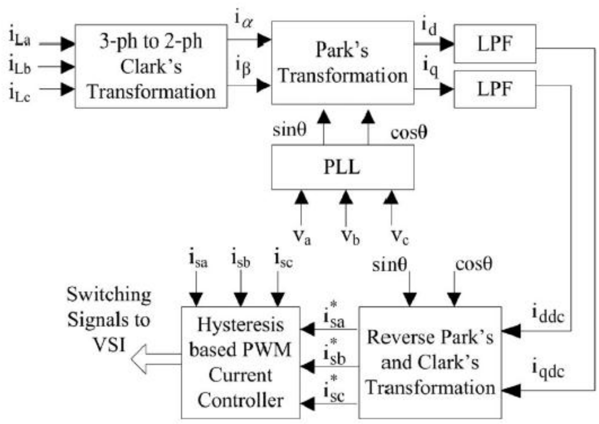

Figure 2 Block diagram of the reference current generation using SRF theory

This technique is also known as Id–Iq method or d-q. This technique is widely applied in three phase system and it is considered as one of the simple and most preferred techniques. The SRF theory can achieve fast and accurate extraction of the harmonic content and of the reactive component of a distorted current, but the application has only been focused in three-phase APFs. One of important characteristics of this algorithm is to obtain reference currents starting directly from the nonlinear load currents, regardless of grid voltage. This theory based on transformation of current in synchronously rotating d-q frame. Fig 2 shows the basic block diagram of this theory. From block diagram it is clear that sensed inputs v_a,v_b,and v_c and iLa, iLb and iLc are fed to controller. Voltage singal are processed by phase-locked loop to generate sine and cosine signal. Current signal transformed to d-q frame and these signals are filtered and transformed back to abc frame then which fed to hysteresis based pulse width modulated signal generator to generate final switching signal. During implementation of this method we have taken care of delays, if we cannot do this is may cause the controller to be unstable hence the whole system becoming unstable. However, where control is concerned, the integral component of the PI controller can lead to integrator windup resulting into instability of the controller and hence poor performance of the shunt active power filter. In synchronous reference frame theory, Clark's and Park's transformation is used to change the harmonic frequency, and to eliminate this frequency LPF is used. To generate the reference currents reverse Park's and Clark's transformation is used. PLL block is used to generate the angle θ which is used in reference current generation. This transformation done in two step.

First step

The transformation from a-b-c frame to α-β-0 frame which is also known α-β transformation or Clarke transformation and is given by

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1 & -1/2 & 1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} iLa \\ iLb \\ iLc \end{bmatrix} \quad (1)$$

Second Step

The transformation from α-β-0 frame to d–q–0 frame which is also known as park's transformation or dq transformation and is given by

$$\begin{bmatrix} id \\ iq \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \quad (2)$$

Output of this equation contains AC component or Oscillating component value as well as DC component or average value. To eliminate AC component which contain harmonic component low pass filter is used. So that DC component which is output of above equation is harmonic free.

$$\begin{bmatrix} id \\ iq \end{bmatrix} = \begin{bmatrix} \overline{\imath d} & \tilde{\imath q} \\ \overline{\imath q} & \tilde{\imath q} \end{bmatrix} \quad (3)$$

The algorithm is further carried a step forward, where the current reference signal in 0-d-q rotating frame is converted back into a -b-c stationery frame, the reference signal for the Pulse Width Modulation (PWM). The reverse transformation from 0 -d-q rotating frame to a-b-c stationery frame is achieved with two steps 0-d-q to 0-α-β and again 0-α-β to a-b-c.

Third Step

This transformation is called as Reverse Park's transformation, in which 0-d-q to 0-α-β transformation is done and given by

$$\begin{bmatrix} i^* \alpha \\ i^* \beta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}^{-1} \begin{bmatrix} id \\ iq \end{bmatrix} \quad (4)$$

Fourth Step

This transformation is called as Reverse Clark's transformation, in which 0-α-β to a-b-c transformation is done and given by

$$\begin{bmatrix} i^* a \\ i^* b \\ i^* c \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ 1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i^* \alpha \\ i^* \beta \end{bmatrix} \quad (5)$$

These reference currents are used for the generation of the PWM pulses by using the HCC i.e. hysteresis current controller. In the HCC we compare reference current with the load current and filter current to get the pulses for the inverter.

Table:1 Parameters used for simulation For SRF Theory

Name	Parameter		Value
Source	Voltage	V_{sabc}	$400V_{p\text{-}prms}$
	Frequency	F	50Hz
	Source Resistance	R_{sabc}	0.0287Ω
	Source Inductance	L_{Sabc}	0.00001mH
Load (Diode Bridge Rectifier)	3-phase AC line inductance	L_{Labc}	2.5mH
	3-phase DC inductance	L_{dc}	5mH
	3-phase DC Resistance	R_{dc}	100Ω
DC-link	Voltage	V_{DC}	700V
	Capacitor	C_{DC}	2600Mf
SAPF	Ac Line coupling Inductance	L_{Cabc}	30mH
Settling Time			0.3sec

B) Instantaneous Reactive Power Theory

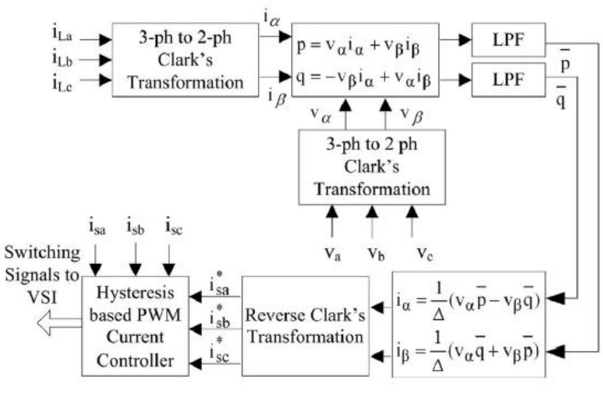

Figure 3 Block diagram of the reference current geneartion using IRP theory

Akagi in 1984 have presented new Instantaneous reactive power theory comprising switching devices without energy storage elements. This techniques based on αβ0 transformation which transforms three phase voltage and current into two phase α-β stationary reference frame. Basic block diagram of this theory is shown in figure 2.From block diagram it is clear that sensed input v_a,v_b *and* ,v_c and iLa,iLb, and iLc are fed to the controller and these quantities are processed to generate reference current commands, which are fed to hysteresis based pulse width modulation signal generator as shown in figure 3 to generate final switching signal. From transformed quantities instantaneous real and reactive power of load is calculated which consist of DC component and oscillating component. Oscillating component extracted using low pass filter and taking inverse α-β transformation compensating command signal in terms of either current or voltage are derived. To deal with instantaneous voltage and current in three phase circuit it is adequate to express their quantities as space vector. In a-b-c co-ordinate a,b and c axes are fixed on same plane apart from each other by 120 ^{0}.In this method three phase voltage and current are transformed into 0-α-β by using Clark's transformation as follow

$$\begin{bmatrix} v0 \\ v\alpha \\ v\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -11/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} * \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} * \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad (7)$$

Where α and β are orthogonal co-ordinate shown in Figure

Later on active and reactive power for three phase system can be obtained. For three phase circuit conventional instantaneous power can be given by

Table 2: Parameters used for simulation For IRP Theory

Name	Parameter		Value
Source	Voltage	V_{sabc}	$400V_{p\text{-}prms}$
	Frequency	F	50Hz
	Source Resistance	R_{sabc}	0.0287Ω
	Source Inductance	L_{Sabc}	0.00001mH
Load (Diode Bridge Rectifier)	3-phase AC line inductance	L_{Labc}	2.5mH
	3-phase DC inductance	L_{dc}	5mH
	3-phase DC Resistance	R_{dc}	25Ω
DC-link	Voltage	V_{DC}	700V
	Capacitor	C_{DC}	2000μF
SAPF	Ac Line coupling Inductance	L_{Cabc}	8mH
Settling Time			0.3sec

$$p = (v\alpha * i\alpha) + (v\beta * i\beta) \tag{8}$$

$$q = (v\alpha * i\beta) - (v\beta * i\alpha) \tag{9}$$

Matrix form of above equation can be given by

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v\alpha & v\beta \\ -v\beta & v\alpha \end{bmatrix} * \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \tag{10}$$

This active and reactive power can be expressed in two parts i.e. AC and DC as given by following equation

$$p = \tilde{p} + \bar{p} \tag{11}$$
$$q = \tilde{q} + \bar{q} \tag{12}$$

In order to get DC part of active and reactive power p and q signal need to be passed through low pass filter. Low pass filter will filter out high frequency component and will give expected signal i.e. Fundamental part. As per this theory active power is given by DC part of α-β reference current and it can be given by following equation. From this real and reactive power the reference current for 0-α-β is given by

$$\begin{bmatrix} i^*\alpha \\ i^*\beta \end{bmatrix} = \frac{1}{v\alpha^2 + v\beta^2} \begin{bmatrix} v\alpha & -v\beta \\ v\beta & v\alpha \end{bmatrix} * \begin{bmatrix} p \\ q \end{bmatrix} \tag{13}$$

Further three phase reference current can be obtained by transforming these two phase reference current to three phase using following equation and that is known as reverse Clark's transformation.

$$\begin{bmatrix} i^*a \\ i^*b \\ i^*c \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 & 1/\sqrt{2} \\ -1/2 & \sqrt{3}/2 & 1/\sqrt{2} \\ -1/2 & -\sqrt{3}/2 & 1/\sqrt{2} \end{bmatrix} * \begin{bmatrix} i^*0 \\ i^*\alpha \\ i^*\beta \end{bmatrix} \tag{14}$$

where $i*0$ is the zero sequence component, which is zero in three- phase three-wire system. These current are compared with source current and obtained error is processed through PI to generate reference current for APF. IRP theory has advantage that obtained fundamental components of active and reactive power are DC quantities. As these signals are DC quantities, αβ reference frame is unaffected by any phase shift introduced by low pass filter.

4. Simulation Results

The shunt active power filter is analyzed by using three phase source and the three phase non-linear load. In MATLAB simulation the source voltage is 400Vatfrequency 50Hz. The load used is three phase rectifier with RL. Following figures shows the MATLAB simulation diagram.

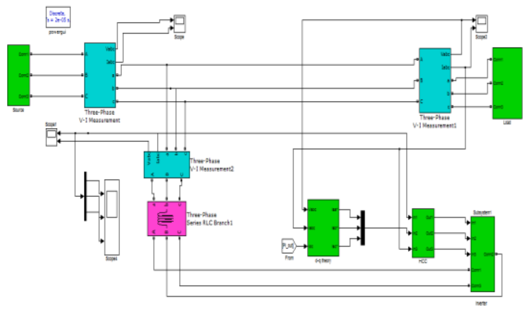

Figure 4 MATLAB simulation block diagram of SRF theory

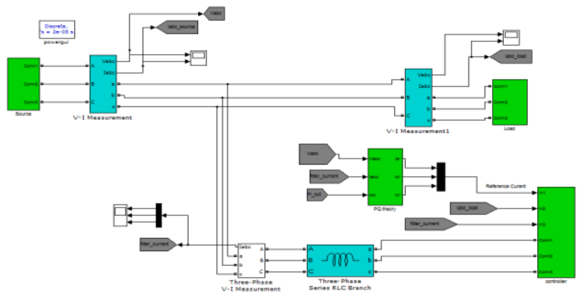

Figure 5 MATLAB simulation block diagram of IRP theory

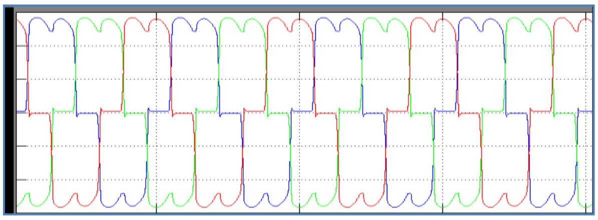

Figure 6 Source current before compensation in SRF theory

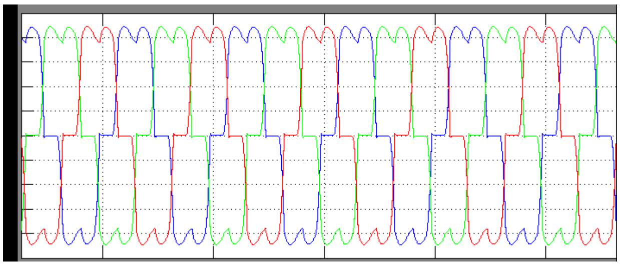

Figure7 Source current before compensation in IRP theory

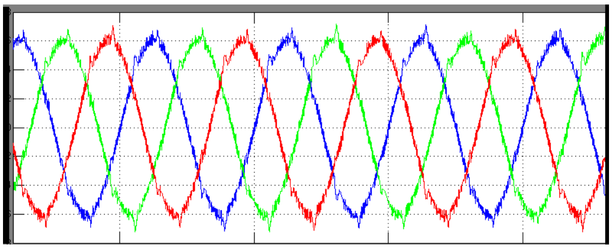

Figure 8 Source current after compensation in SRF theory

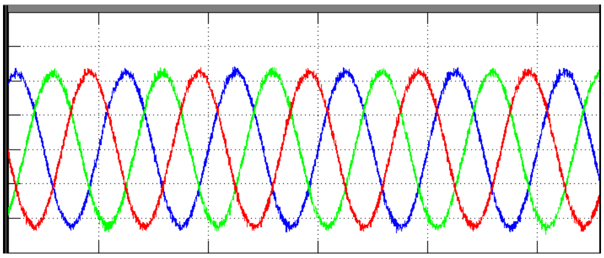

Figure 9 Source current after compensation in IRP theory

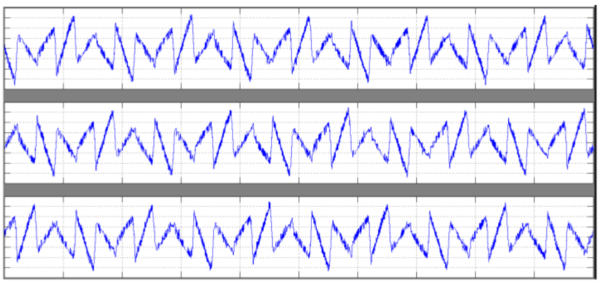

Figure10 Filter current injected at PCC by inverter in SRF theory

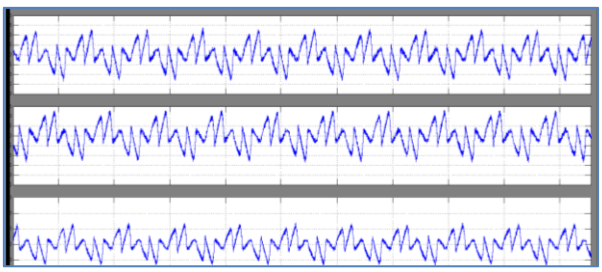

Figure11 Filter current injected at PCC by inverter in IRP theory

Before compensation the total harmonic distortion in the source current is 28.17 IN SRF theory and 25.03 % in IRP theory. But after compensation, the total harmonic distortion in SRF theory is 6.00% and in IRP theory is 3.42%. These results are shown in following figures.

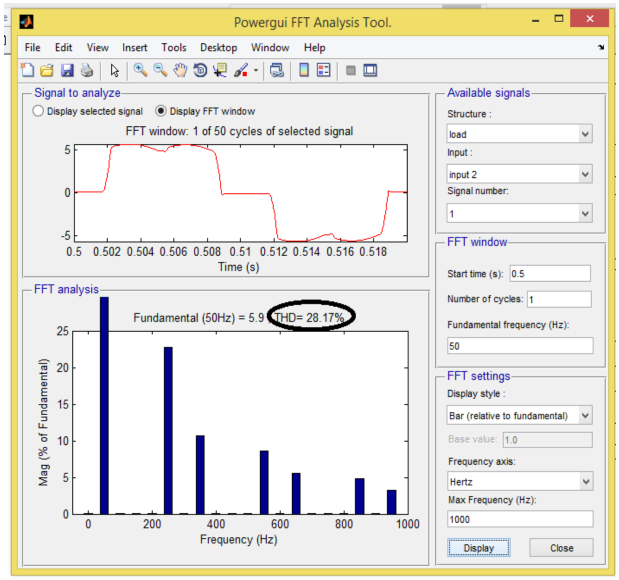

Figure12 % THD in source current before compensation in SRF theory

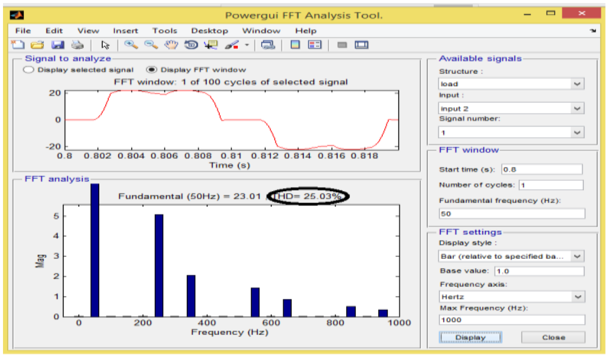

Figure 13 % THD in source current before compensation in IRP theory

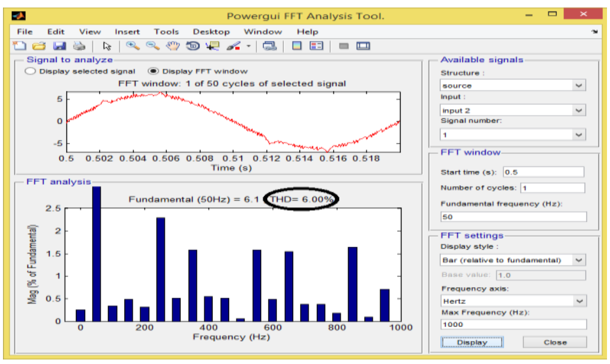

Figure 14 % THD in source current after compensation in SRF theory

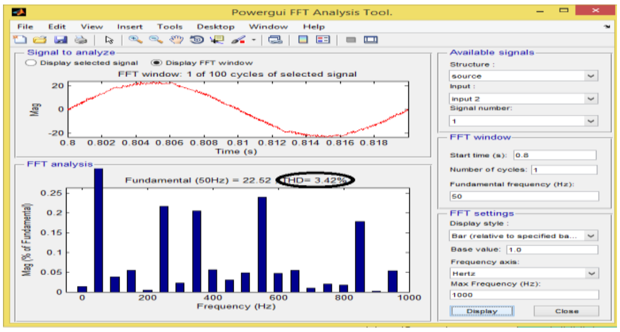

Figure 15 % THD in source current after compensation in IRP theory

5. Comparison of SRF and IRP methods

Sr.No.	Method	Before Compensation in %	After Compensation in %
1	SRF	28.17	6.00
2	IRP	25.03	3.42

Thus from above comparison it is clear that with help of SRF method more harmonics are eliminated.

Conclusion

In this paper two different reference current generation techniques are studied for performance analysis of shunt active power filter. The harmonic content in the power system are also studied before and after shunt active power filter is connected. The results are analyzed considering the %THD. In IRP theory the % THD is reduced from 25.03 % to 3.42 %. The advantage of this theory is that in this case there is no requirement of filter for elimination of ac component and this theory can be used in steady state and transient state. Similarly, in SRF theory the harmonics are reduced from 28.17 % to 6.00 %. Therefore from above analysis we can see that the instantaneous SRF theory is most efficient and can reduce more harmonic distortion from the system.

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