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A Survey of Power Quality Problem in Industry

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Abstact : *This paper present the uses of new technologically advancement controlled technique "Shunt Active Power Filter (SAPF) in three phase four wire system" for improving the power quality of network. The industry has many of non-linear loads that are the sources of harmonics in the system that creates the power quality problems. Three phase Four wire Shunt Active Power Filter is used to solve this power quality issues. In the Shunt Active Power Filter a new control algorithm is proposed for 3-phase 4-leg system based on Instantaneous real-power theory, also known as p-q theory suppress harmonic currents, compensate reactive power and neutral line current and balance load currents under unbalanced non-linear load condition. The Active Power Filter is composed from 4-leg voltage source inverter with a common DC-link capacitor and hysteresis-band current controller. The simulation results on Matlab/Simulink tool are present.*

***Keywords**: 4-leg Shunt Active Power Filter (SAPF), 4-leg Voltage Source Inverter (VSI), Instantaneous Power p-q theory, PI Controller, Hysteresis Controller.*

1. INTRODUCTION

The widespread increase of non-linear loads in industry nowadays, so amount of harmonic currents are being injected into power systems. Harmonic current flow through the power system, causing voltage distortion at the harmonic current. The distorted voltage waveform causes harmonic current to be drawn by other loads connected to the power system network. The existence of current and voltage harmonics in power system increases losses in the lines, decreases the power factor and can cause timing errors in sensitive electronic equipments.

The harmonic current and voltage produced by 3-phase non-linear lads like large uninterrupted power supplies, motor drives and silicon-controlled rectifiers are positive and negative-sequence harmonics. In addition, Harmonic current and voltage produces by single-phase non-linear loads such as switch-mode power supplies in computer equipment that are connected phase to neutral. Therefore, these loads are third order zero-sequence harmonics.

These triplen harmonic current do not cancel but add up arithmetically at the neutral bus. This can results in neutral current that can reach magnitudes as high as the phase current. In addition to the hazard of cables and transformers overheating the third harmonic can reduce energy efficiency. These power quality issues mitigate by the 4-leg SAPF not only mitigate harmonic currents but also reactive power, load current balancing and excessive neutral current simultaneously. Using SAPF into the system is to compensation harmonics and reactive power by injecting current or voltage harmonic component at 180 degree and in this paper, Instantaneous reactive power theory is used which is very efficient for designing active filer controller.

2. BASIC OPERATION OF SAPF

Fig. 1 shows the basic principle of shunt active power filter. In the APF is connect in parallel to the utility and non-linear load. Pulse width modulated Voltage Source Inverter are use in SAPF and they are acting as a current controlled voltage source. The compensation for current harmonic in SAPF is by injecting equal and opposite harmonic compensating current. As a result, the harmonic in line get cancelled out and source current becomes sinusoidal and make it in phase with source voltage.

In 3-phase 4-wire power systems has two kind of VSI are used. In the 4-leg VSI has uses 1-leg specially to compensate zero sequence current (Neutral current). While the 3-leg VSI is preferred for its lower number of switching devices. However, its DC-Link capacitors are need and the 4-leg VSI has advantage to compensation for neutral current by providing 4-leg and to need for much less DC-Link capacitance.

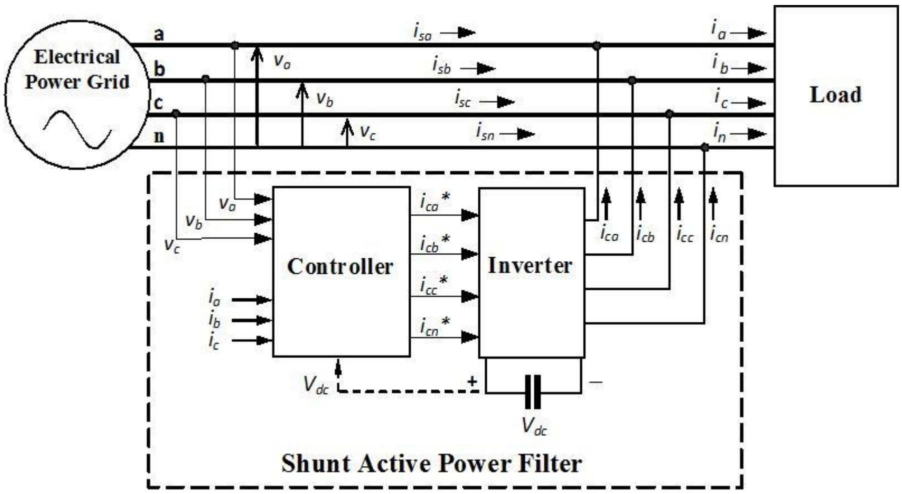

Fig. 1 Basic Principle of the SAPF

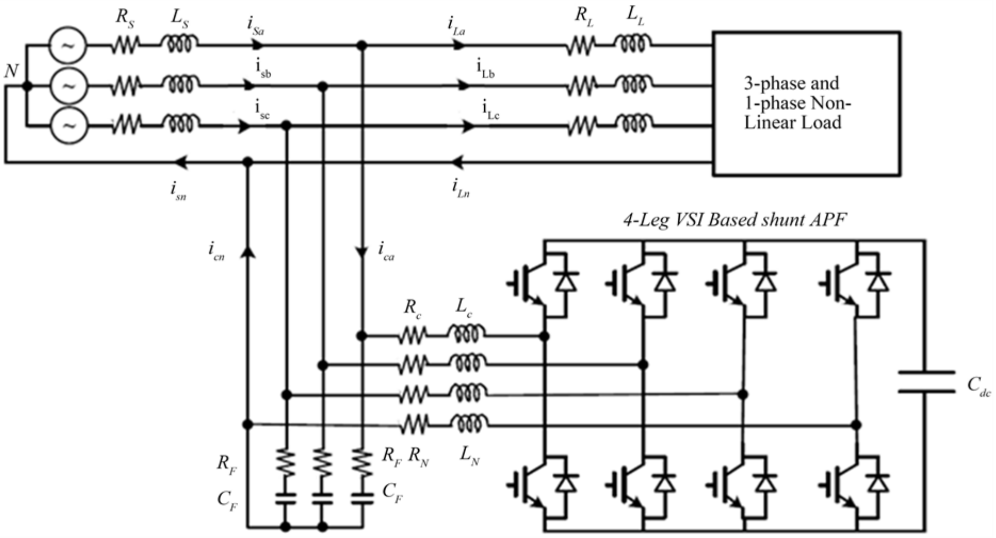

Fig. 2 Power Circuit of a SAPF

Fig.2 shows the power circuit of a SAPF. The middle point of each branch is connect to the power system through a filter inductor. The SAPF consists of 4-leg VSI, 3-legs are needed to compensate the 3-phase current 1-leg compensate neutral current. The 4-leg VSI has eight IGBT switches. High order harmonic current generated by the switching of the power semiconductor devices is filter by using a small RC high-pass filter as shown in Fig. 2.

3. INSTANTANEOUS REACTIVE POWER THEORY

This reactive power theory is propose by Akagi et al in 1983. The theory of the instantaneous reactive power is also known as p-q theory. It has no restriction are imposed on the voltage and current waveform and it can be applied to 3-phase system with or without a neutral wire for generic voltage and current waveforms.

This theory is used to calculate the real and reactive power requirements of the load instantaneously. The method is mostly applied to calculate the reference current of the shunt and series active filter. The p-q theory consists of an algebraic transformation (Clarke transformation) of the three-phase Source voltages and Load currents in the a-b-c coordinates to the α-β-0 coordinates, followed by the calculation of the p-q theory instantaneous power components.

And end of this current transform from p-q into a-b-c system such that shown in Fig. 3. This reference signal is compare with actual signal than after that signal is given to the hysteresis current controller to generate the gating signal for switching. In addition, it is given to the IGBT in VSI.

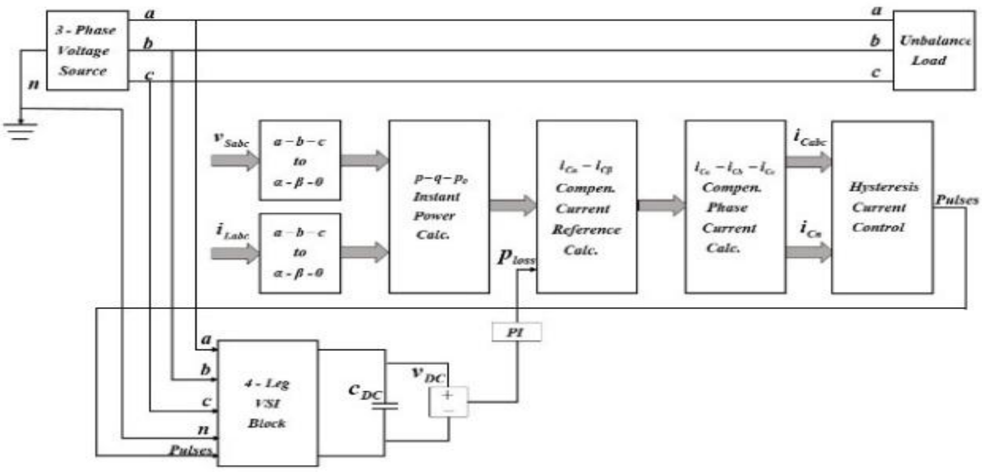

Fig. 3 Block Diagram of SAPF

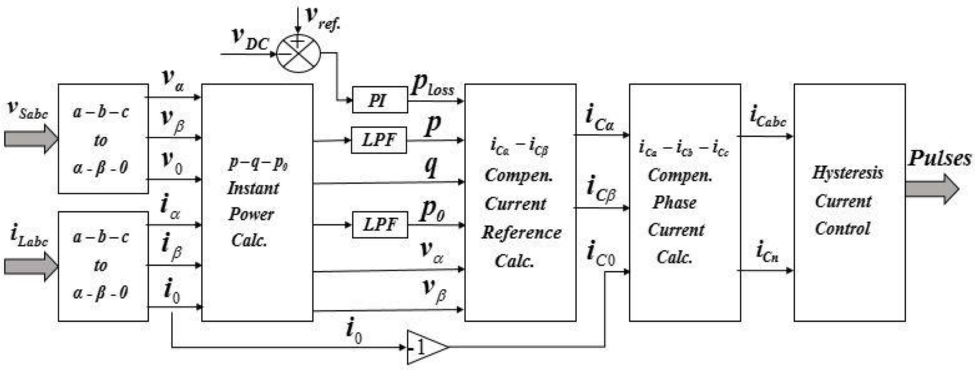

Fig. 4 Block Diagram of Control Strategy of SAPF

Three-phase source voltages and load currents in the *a-b-c* coordinates to the α-β-*0* coordinates.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{Sa} \\ v_{Sb} \\ v_{Sc} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{2}$$

Instantaneous real power (*p*), imaginary power (*q*) and zero sequence power (p_0) are calculated.

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \tag{3}$$

To calculate the reference compensation currents in the α-β coordinates.

$$\begin{bmatrix} i^*_{C\alpha} \\ i^*_{C\beta} \end{bmatrix} = \frac{1}{v_\alpha{}^2 + v_\beta{}^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \bar{p}_0 + \bar{p}_{loss} \\ -q \end{bmatrix} \tag{4}$$

Below is valid to obtain the compensating phase currents (i^*_{Ca}, i^*_{Cb}, i^*_{Cc}) in the *a–b–c* axis in terms of the compensating currents in the *α–β–*0 coordinates.

$$\begin{bmatrix} i^*_{Ca} \\ i^*_{Cb} \\ i^*_{Cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i^*_{C0} \\ i^*_{C\alpha} \\ i^*_{C\beta} \end{bmatrix} \tag{5}$$

Finally, neutral reference current is calculated as follows.

$$i^*_{Cn} = i^*_{Ca} + i^*_{Cb} + i^*_{Cc} \tag{6}$$

4. HYSTERESIS WITH PI CONTROLLER

The reference current, which we get by the comparing actual voltage and dc voltage, and it is fed to PI Controller. Therefore, PI Controller has an output is considered as peak value of the reference current. Moreover, this reference current is goes to the hysteresis current controller.

The hysteresis current controller is compare two signal by logical operation. Therefore, it is set two defined limits such as upper limit and lower limit. Hysteresis current control operates by comparing an actual source current and reference current, which gives the switching signal for PWM current converter. For controlling a Voltage Source Inverter, the hysteresis current control method is use so that the obtained output current will follow reference current waveform.

In between limits the error is determined the status of inverter switches. When the error exceeds the upper hysteresis band, the inverter output is switches low, and when the error falls below the lower hysteresis band, the inverter output switches high. This process is shown in Fig. 5.

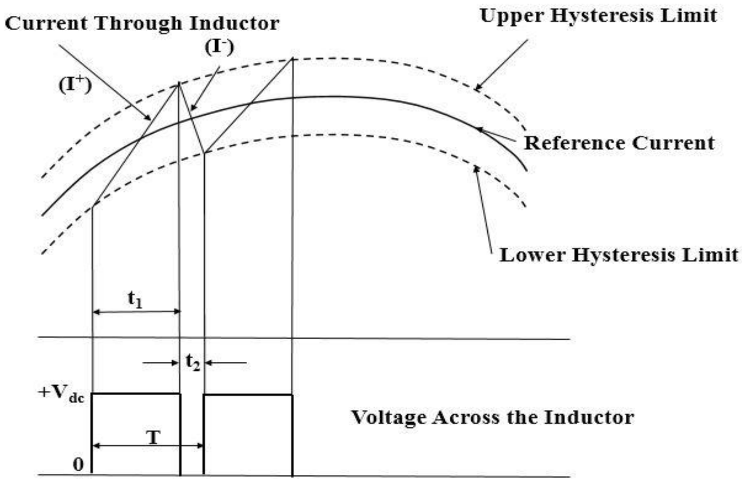

Fig. 5 Hysteresis Current Controller Band

5. SIMULATION AND RESULTS

Table-1
System Parameter

	Parameters		Value
Value	Fundamental voltage	V_{sabc}	440
	Frequency	f_s	50Hz
Load	Diode rectifier load inductance	L_{dc}	20e-03
	Diode rectifier load resistance	R_L	60 ohm
DC Link	Reference voltage	V_{dc}	750
	Capacitance	C_{dc}	3.5e-05
Shunt Active Filter	Filter inductance	L_{sh}	1.50e-02

Table-2
Comparison of With & Without SAPF

THD in source Current without SAPF	THD in source Current with SAPF
26.23%	1.73%

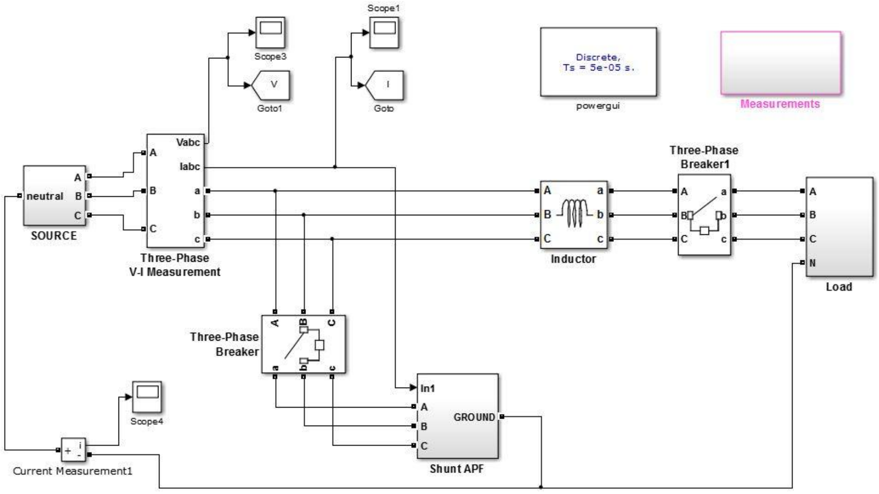

Fig. 6 Three-phase four-wire Simulation Model

A load with highly nonlinear characteristics is considered for the load compensation. The THD in the load current is 26.23% as shown in Fig. 7

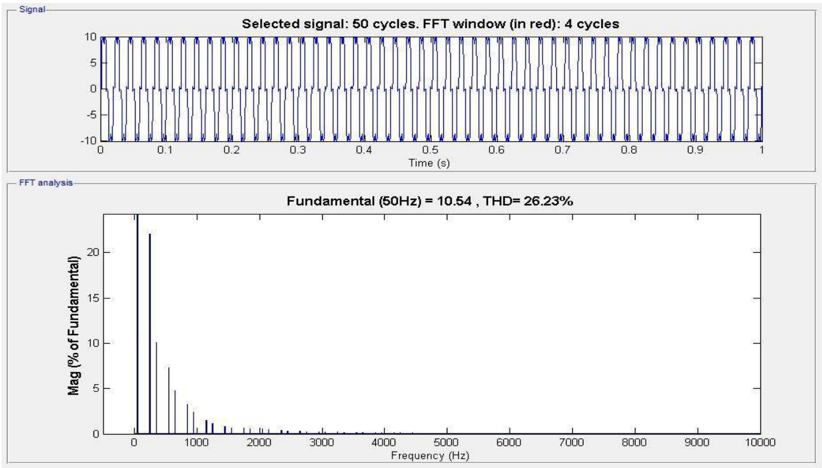

Fig. 7 THD analysis without Compensation

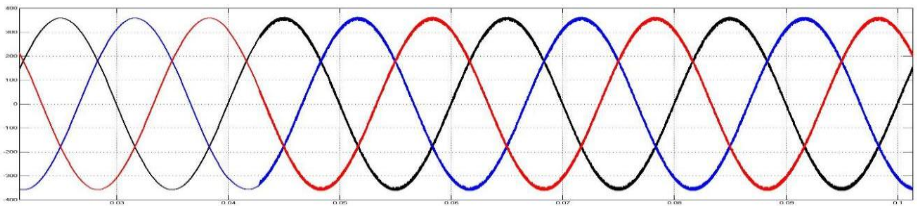

Fig. 8 Three phase Source Voltage

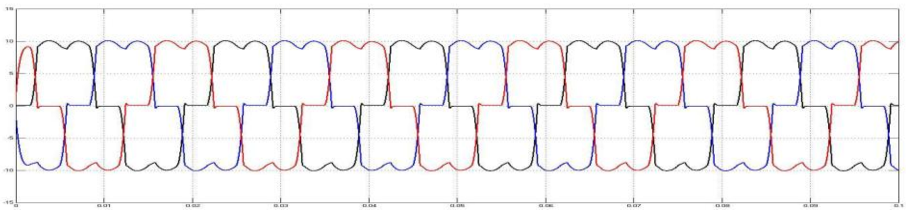

Fig. 9 Three phase Load Current

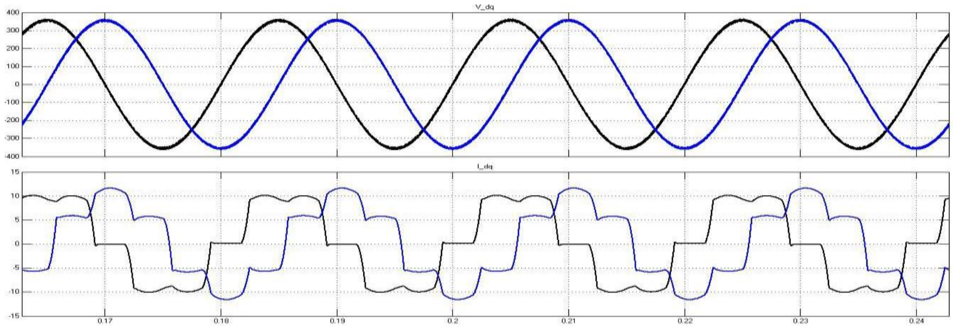

Fig. 10 α-β Voltage and Current

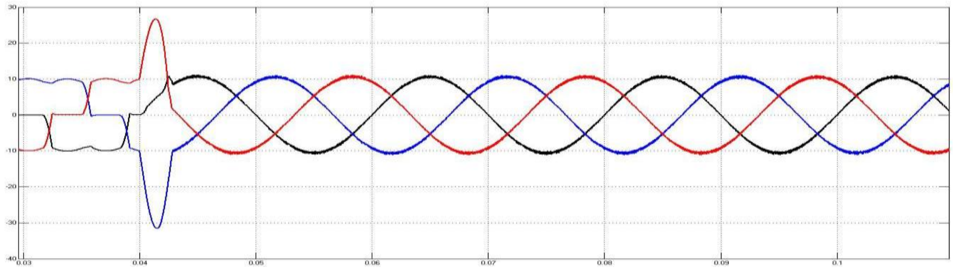

Fig. 11 Source Current after Compensation

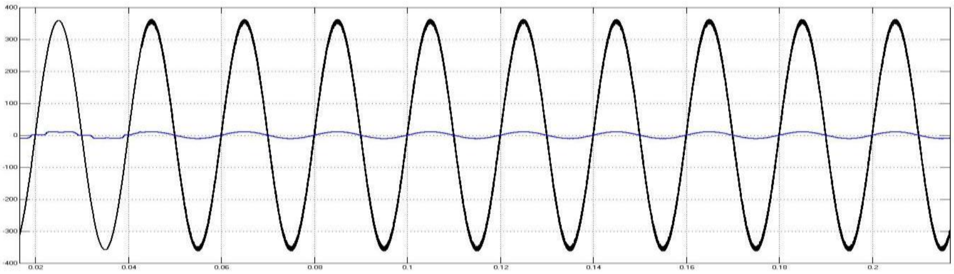

Fig. 12 Phase-A Source Voltage and Current

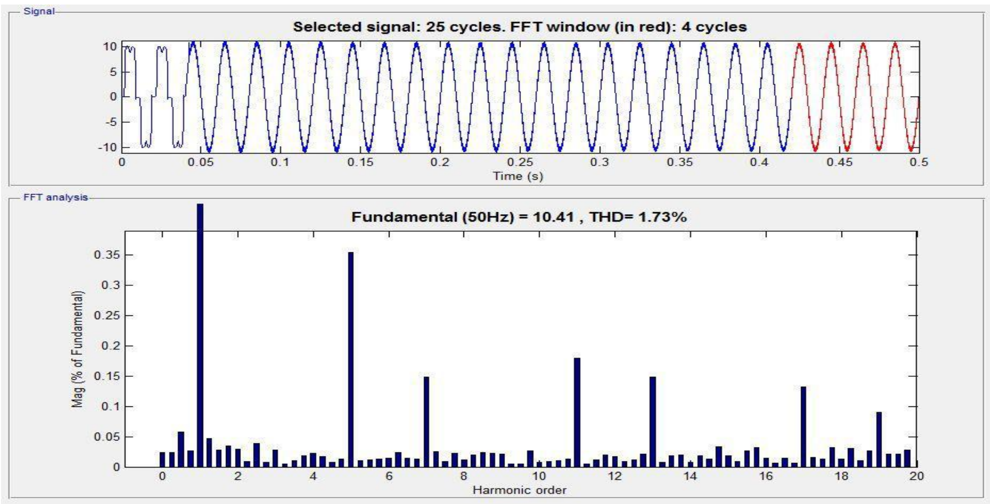

Fig. 13 THD Analysis after Compensation

6. CONCLUSION

Nowadays in Industry has the non-linear loads are used rapidly which creates a power quality issues such as Harmonics and Unbalance. So, Instantaneous reactive power theory is used for 3-phase 4-wire SAPF to reduce the Total Harmonic Distortion as well as voltage related problem and improvement of the power quality issues. This is simulated in MATLAB/SIMULINK system. So, This SAPF is able to reduced Total Harmonic Distortion in source current below as per IEEE-519.

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