

Shunt Active Power Filter Control with Synchronous Reference Frame to Harmonic Reduction

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ABSTRACT: This paper describes about the Shunt Active Power Filter (SAPF) for the elimination of the current harmonics in the line side. The Active Power Filter is based on the Voltage Source Inverter (VSI) topology. It solves the problem of harmonic current in power system. It also compensate reactive power and balances load on three phase (if load is unbalanced). It measures load current and then transforms to dq0 coordinate system. Initial position of d axis is chosen in such a way that active part of current is given by d axis. Oscillating part of both d and q axes component of load current should be injected to remove harmonics. Non-oscillating part of q axis component should be injected to compensate reactive power. Zero sequence component should be injected to balance the loads. In this way, current that should be injected is calculated in dq0 coordinate system. It is transformed to abc coordinate system. This current is reference compensating current. The compensating current is injected to the network via three phase inverter using hysteresis band current control (HBCC) method. In this way, harmonic and reactive component of load is supplied by this shunt active power filter. The simulation of shunt active power filter is performed in MATLAB/Simulink and result shows that the current harmonics are eliminated in the system.

KEYWORDS-shunt active power filter, voltage source converters, harmonics, and synchronous d-q-0 reference frame

I. INTRODUCTION

The ever increasing use of power semiconductor switching devices in power supply for DC motors, computers and other microprocessor based equipment causes harmonics in electric power system. Harmonics may cause serious problems such as excessive heating of electric motors and malfunction of sensitive electronic gadgets. Filtering of harmonics can be effected by using either passive or active power filters. Traditionally, passive filters have been used for harmonic mitigation purposes. Active filters have been alternatively proposed as an adequate alternative to eliminate harmonic currents generated by nonlinear loads as well as for reactive power compensation. Various control methods with various control strategies as discussed in [1]-[2], [4-5] were implemented for minimizing harmonics in the electric power network. However, to date the shunt active power filter is still extensively used. Several control methods involved in generating reference signals have been discussed in [1]-[4] among them being the Synchronous Reference Frame method. Many control strategies have been proposed, for example in [4]-[5] discussed about taking care of delays which when not taken care of, 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 order to improve performance, this paper presents a method to effectively compensate the windup of the integral term of the PI controller. It is an integrator anti-windup circuit. Harmonics are the major disturbance in distribution system, the efficiency of the system reduces and cause damage to the equipment's. The elimination of harmonics is done by various methods used are using passive LC filter and Active Power Filters (APF) [3]. The APF can be connected as shunt and series configuration. The shunt connection gives better harmonics compensation than the series connection [8]. The quality of power delivering to the system to be maintained within their limits and compensation techniques also to be implemented to make the system as efficient one. The APF has the property of compensating the current and voltage related problems. The shunt active power filter is the most promising approach to compensate the current harmonics [9] in the system. The converter connected to the system which acts as the APF for the injecting the negative harmonics [1] to the system for the compensating the harmonics. The Shunt APF [2]-[3] has the converter which is based on the Voltage Source Inverter (VSI) topology using Insulated Gate Bipolar Transistor (IGBT) device. The gate

pulse for the IGBT is generated by the Synchronous Reference Frame (SRF) [4] theory for the reference signal calculation and compared using the hysteresis controller [9]. the use of shunt active power filters (APF) to eliminate harmonic currents and to compensate reactive power for linear/nonlinear loads has attracted much attention since the late 1970s [1], [2]. Fig. 1 shows the schematic diagram of a three-phase four-wire shunt APF, where the APF senses the source voltages and load currents to determine the desired compensation currents. In [3], Akagiet al. proposed the instantaneous reactive power theory (i.e.,p-q theory) for calculating the reference compensation currents required to inject into the network at the connected point of the nonlinear load. Since then, the p-q theory has inspired many works dealing with active power filter compensation strategies [3]–[4]. One of the peculiar features of a shunt APF is that it can be designed without active load.energy source units, such as batteries, or in other forms in its compensation mechanism. In other words, an ideal APF does not consume any average real power supplied by the source. To accomplish this function, it requires an effective reference compensation strategy for both reactive power and harmonic/neutral current compensation of the load.Harmonics in power supply systems have risen significantly in recent years primarily because of the increase of non-linear loads connected to the utility grid through residential, commercial and industrial customers. The power supply voltages become distorted on account of the high level of undesired harmonic currents drawn from the utility grid. In addition, drops in the fundamental voltage are caused by the interaction between the reactive current and the network impedances. To solve or minimise some power quality problems, series, shunt, and hybrid active power filters (APFs), unified power quality conditioners (UPQC) and other alternatives have been developed [1–9]. Although the series APFs are normally used to compensate utility disturbances, such as voltage sags, swells, unbalances and harmonics [22–25], shunt active power filters (SAPFs) have commonly been used for reducing harmonic currents, compensating reactive power of the load and improving power factor [1–20].

II.SHUNT ACTIVE POWER FILTER (SAPF)

The shunt active power filter (APF) is a device that is connected in parallel to and cancels the reactive and harmonic currents from a nonlinear load. The resulting total current drawn from the ac main is sinusoidal. Ideally, the APF needs to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line. In an APF depicted in Fig. I, a current controlled voltage source inverter is used to generate the compensating current (L) and is injected into the utility power source grid. This cancels the harmonic components drawn by the non-linear load and keeps the utility line current (i,) sinusoidal. A method is used for instantaneous current harmonics detection in active power filter is synchronous-d-q reference frame theory separating successive harmonic components. SAPF consists of voltage source converter with DC link capacitor which generates compensating current with 180° phase opposition and injects at the Point of Common Coupling (PCC) in the grid, so as to cancel out the current harmonics caused by the non-linear load. SAPF compensates current harmonics by injecting equal-but opposite harmonic compensating current. The components of harmonic currents contained in the load current are cancelled by the effect of the active filter, and the source current remains sinusoidal and in phase with the respective phase to neutral voltage. With an appropriate control scheme, the active power filter can also compensate the load power factor [7].

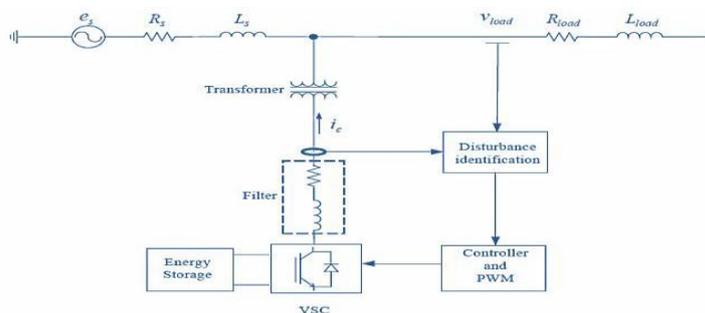


Figure 1. Shunt Active Power Filter (SAPF) Configuration

III.CONTROL STRATEGY OF SAPF

The operation of SAPF mainly depends on algorithm of controller in order to suppress the harmonics present in the source due to load. From the d-q theory the active and reactive current drawn by the load could be expressed by several components. The equations obtained after transformation consists of “ω” term coupled with current components such



as I_d, I_q . Due to this coupling term, the reference current tracking capability of controllers is not rapid enough for coupled systems. The main objective of the controller is to improve the performance and to make components as independent one, a decoupled controller is necessary [9].

SYNCHRONOUS D-Q-0 REFERENCE FRAME BASED COMPENSATION

Active Power Filter consists of Voltage Source Converter operating at relatively high frequency to give the output which is used for cancelling low order harmonics in the power system network. With Shunt Active Power Filter, crucial part involves generation of the reference signal used to generate gating signals for the VSC. The control strategy of the system is to control the converter for the injections of the negative harmonics for the compensation of the system. The converter output is controlled by the gate pulse given to the Mosfet. This is achieved by the Synchronous Reference Frame Theory [4]. The SRF [6] theory is based on the synchronous machine in which for the analysis of 3phase system is made easy. The 3phase system abc is converted to the direct and quadrature axis quantities dq0. For the shunt APF is load current is considered for the reference signal calculation and pulse is generated. the current for the three phases which is converted to dq0 for the balanced state.

$$i_a = I_m \sin \omega_s t$$

$$i_b = I_m \sin \left(\omega_s t - \frac{2\pi}{3} \right)$$

$$i_c = I_m \sin \left(\omega_s t + \frac{2\pi}{3} \right)$$

The transformation matrix for the i_a, i_b, i_c is given by

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta & 1 \\ \cos \left(\theta - \frac{2\pi}{3} \right) & -\sin \left(\theta - \frac{2\pi}{3} \right) & 1 \\ \cos \left(\theta + \frac{2\pi}{3} \right) & -\sin \left(\theta + \frac{2\pi}{3} \right) & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix}$$

d axis current (i_{Ld}) is filtered out and applied to inverse transformation to remove DC component and to determine harmonic contents. Q axis current (i_{Lq}) is applied to inverse transformation to compensate reactive power. 0 axis current (i_{L0}) must be used when the voltages are distorted or unbalanced and sinusoidal current are desired. In this study, it is not investigated. The DC side voltage of APF should be controlled and kept at a constant value to maintain the normal operation of the inverter. Because there is energy loss due to conduction and switching power losses associated with Mosfets of the inverter in APF, which tend to reduce the value of V_{Dc} across capacitor C_{dc} . A feedback voltage control circuit needs to be incorporated into the inverter for this reason. The difference between the reference value, V_{r} and the feedback value (V_{ac}), an error function first passes a PI regulator and the output of the PI regulator is subtracted from the d axis value of the harmonic current components. Synchronous d-q-0 reference frame based compensation algorithm, described above, is depicted in Fig. 2. Reference filter currents (i_a) are determined negatives of the outputs of the inverse transformation matrix (d-q-0 to a-b-C).

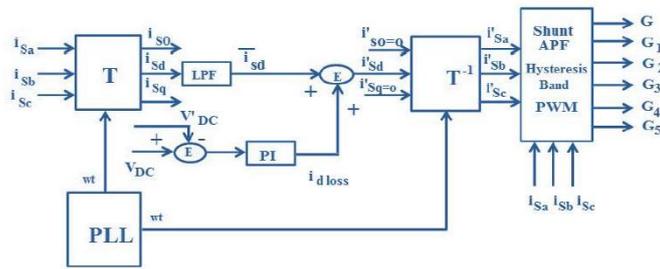


Fig 2.synchronous d-q-0 reference frame

IV.NOVEL ADAPTIVE HYSTERESIS CURRENT CONTROLLER

The hysteresis band current control can be implemented to generate the switching pattern in order to get precise and quick response. The hysteresis band current control technique has proven to be most suitable for all the applications of current controlled voltage source inverters in active power filters. The hysteresis band current control is characterized by unconditioned stability, very fast response, and good accuracy. On the other hand, the basic hysteresis technique exhibits also several undesirable features; such as uneven switching frequency that causes acoustic noise and difficulty in designing input filters. The conventional hysteresis band current control scheme used for the control of active power filter line current is shown in Fig. 3, composed of a hysteresis around the reference line current. The reference line current of the active power filter is referred to as i_c^* and actual line current of the active power filter is referred to as i_c . The hysteresis band current controller decides the switching pattern of active power filter [11]. The switching logic is formulated as follows:

- If $i_{ca} < (i_{ca} - HB)$ upper switch is OFF and lower switch is ON for leg “a” ($SA=1$).**
- If $i_{ca} > (i_{ca} + HB)$ upper switch is ON and lower switch is OFF for leg “a” ($SA=0$).**

The switching functions SB and SC for phases B and C are determined similarly, using corresponding reference and measured currents and hysteresis bandwidth (HB). The switching frequency of the hysteresis band current control method described above depends on how fast the current changes from the upper limit of the hysteresis band to the lower limit of the hysteresis band, or vice versa. The rate of change of the actual active power filter line currents vary the switching frequency, therefore the switching frequency does not remain constant throughout the switching operation, but varies along with the current waveform. Furthermore, the line inductance value of the active power filter and the dc link capacitor voltage are the main parameters determining the rate of change of active power filter line currents. The switching frequency of the active power filter system also depends on the capacitor voltage and the line inductances of the active power filter configuration.

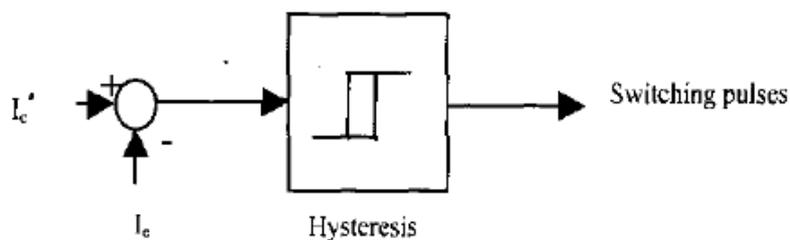


Fig. 3. Conventional hysteresis band current controller.

V.SIMULATION OF SHUNT ACTIVE POWER FILTER

The Simulink model of Shunt active power filter controller is shown in Figure 4 respectively. The figure 5, 6, 7 shows the subsystem of the SAPF controller developed using MATLAB/ SIMULINK tool. It is developed from the mathematical model of the controller.

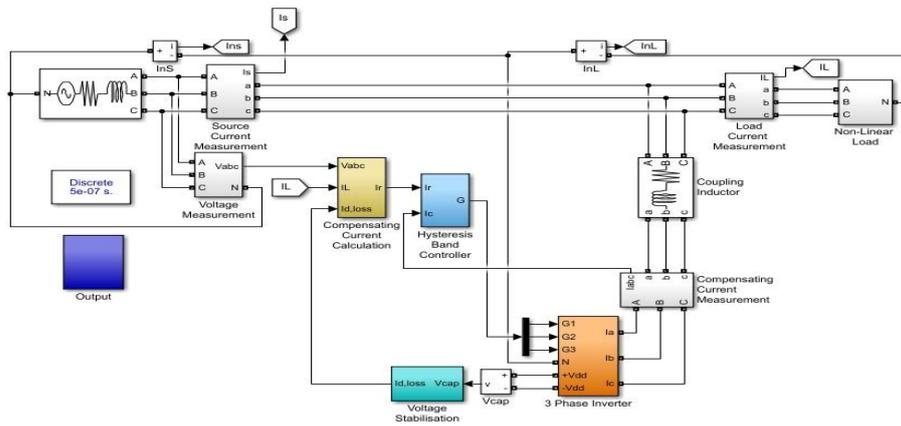


Fig 4. Simulink model of shunt active power filter

COMPENSATING CURRENT CALCULATION

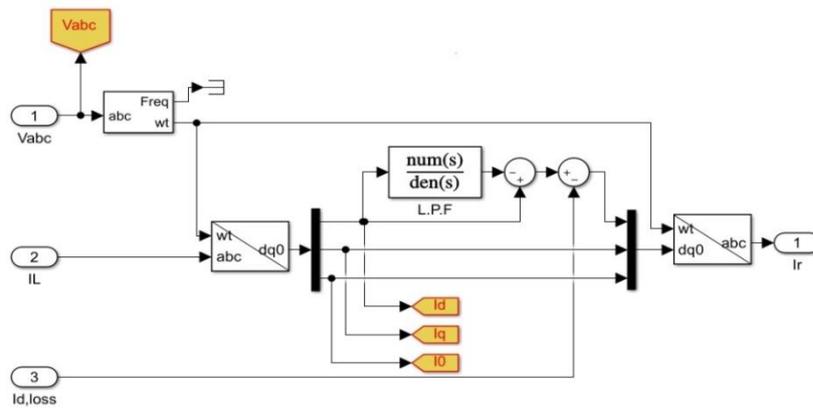


Fig 5. Simulink model of compensating current controller

HYSTERESIS BAND CONTROLLER

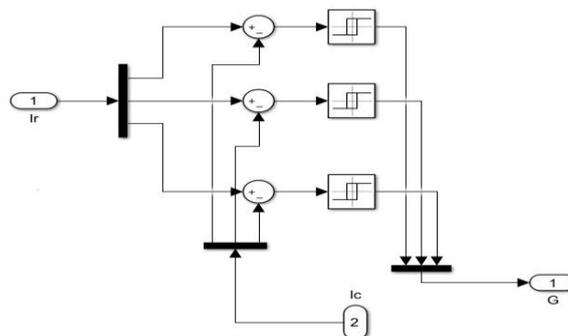


Fig 6. Simulink model of hysteresis band controller

3 PHASE INVERTER

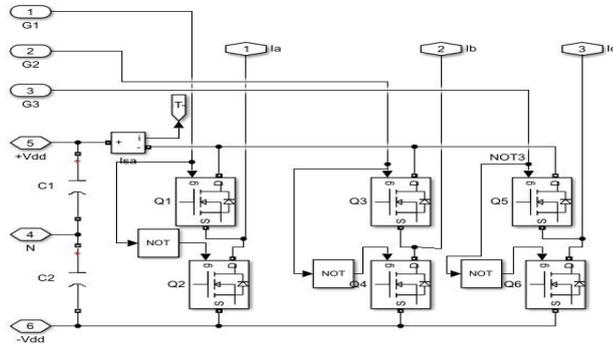


Fig 7. Simulink model of 3 Phase inverter

VOLTAGE STABILISATION

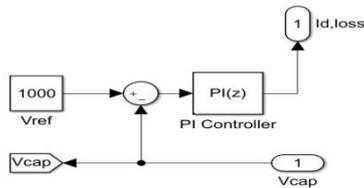


Figure 5. Simulink model of Voltage stabilisation

VI. SIMULATION RESULTS

- Without Shunt Active Power Filter with Unbalanced Load

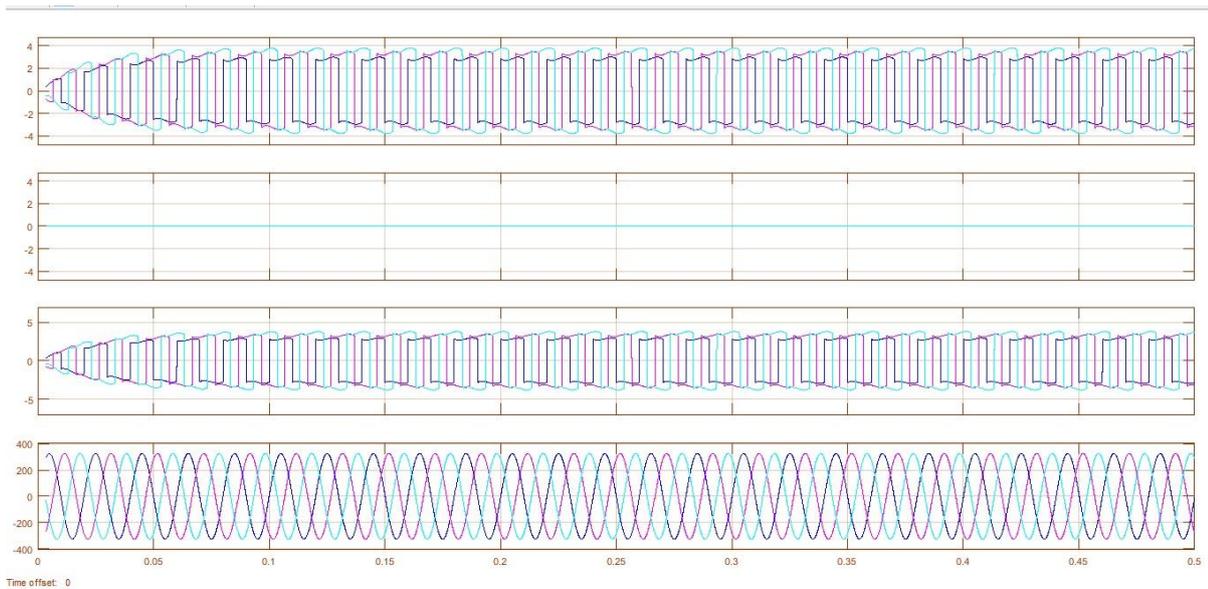


Fig 6. Load Current, Inverter Capacitor Current, Source Current and source voltage

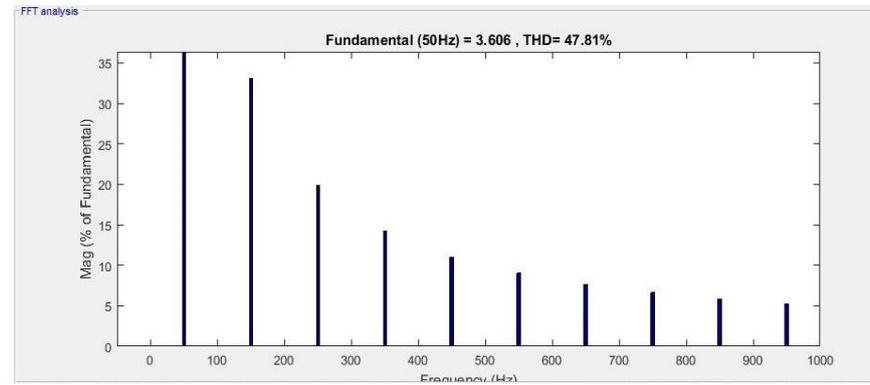


Fig.7 Harmonic spectrum of the source current

- With Shunt Active Power Filter with Unbalanced Load

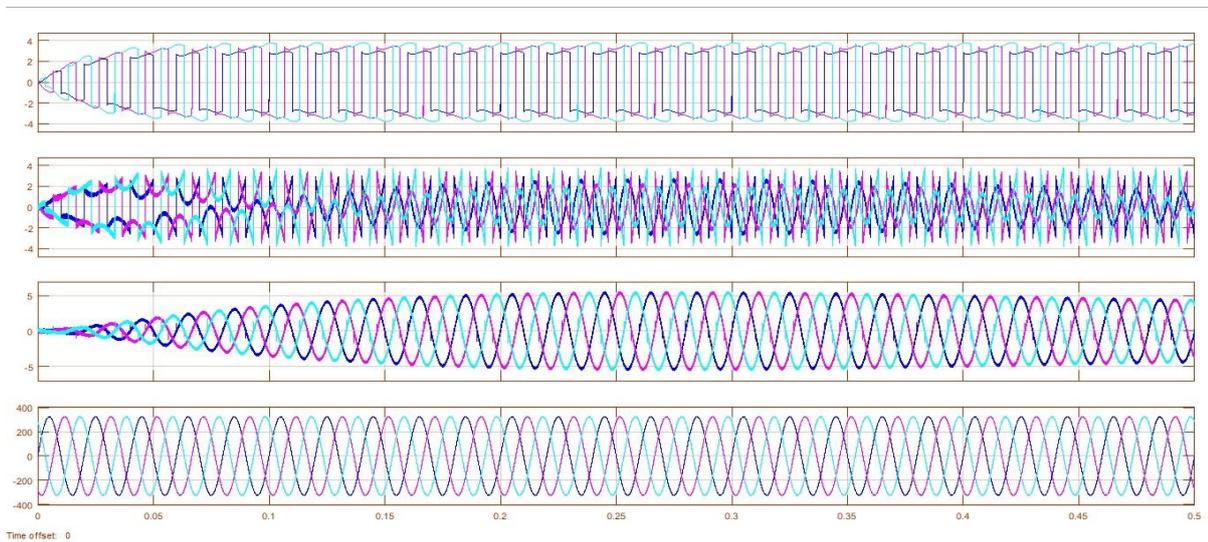


Fig 8. Load Current, Inverter Capacitor Current, Source Current and source voltage

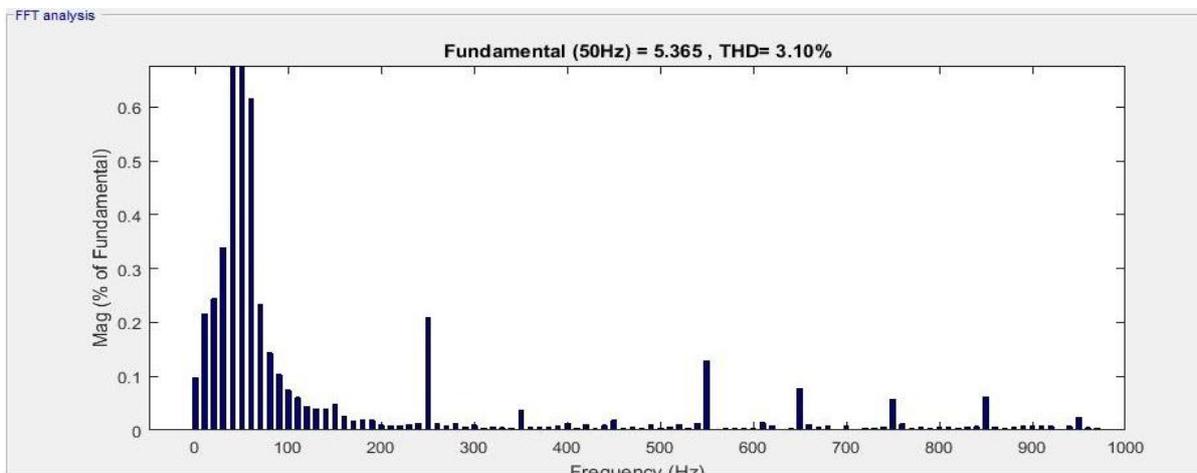


Fig.9 Harmonic spectrum of the source current

VII. CONCLUSION

This paper has discussed the control and performances of a shunt active power filter with unbalanced load under distorted voltage conditions. The above figure shows that the SAPF provides a smooth output with both compensation of reactive power and harmonic elimination. It provides information that the inverter current follows the source current according to the connected balanced as well as unbalanced loads. The THD of SAPF with unbalanced connected loads can be observed in the above figure. The shunt active power filter gives the best performance results. The design of the SAPF controller is done by using mathematical modelling and analysis. This system is simulated by using MATLAB/SIMULINK upon selecting specified parameters. The current waveforms and %THD results with and without SAPF are presented. The SAPF provides a better solution to reduce current harmonics.

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