# HARMONICS MITIGATION USING HYBRID ACTIVE POWER FILTER FOR AN INDUCTION MOTOR

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***Abstract:*** This paper investigates compensation of harmonics problem generated in three phase squirrel cage induction motor using three phase shunt hybrid active power filter strategy along with series connected LC passive filter. The current harmonic distortion and reactive power demand were serious power quality problems occurred to distort the performance of the power system load. Traditionally, voltage source inverter (VSI) based shunt active power filter is used to address the power quality problems. The conventional shunt active power filter required high DC link voltage to compensate power quality problems. To overcome this problem, neutral point clamped (NPC) inverter based shunt active power filter strategy using instantaneous reactive power (IRP) theory is proposed in this paper. The simulation investigations were carried out using matlab/simulink and results are verified to validate the proposed system.

**Index terms - power quality, harmonic distortion, inverter, passive filter, active filter, shunt active power filter**.

## 1. INTRODUCTION

Due to the advancement of science and technology, industrial structure reforming, and the development of smart grid technology recently, people have a higher demand for improved power quality. However, with the proliferation and increased use of power electronics devices (nonlinear loads) and motor loadings, such as converters, Adjustable Speed Drives (ASDs), arc furnaces, bulk rectifiers, power supplies, computers, fluorescent lamps, elevators, escalators, large air conditioning systems, compressors, etc., it is becoming more and more difficult to achieve this goal. Although the widespread applications of power electronic devices enable the control and tuning of all power circuits for maximum performance, cost effectiveness, and enhanced energy efficiency, they will increase the distortion and disturbances on the current and voltage signals in the power network. This is because the power electronic devices draw harmonic currents from the power utility and the harmonic voltage will then be generated, as harmonic currents causes nonlinear voltage drops across the power network impedance. On the other hand, the usage of induction motor loadings will cause a phase shift between the current and the voltage in the power network. This results in lowering the power factor of the loading.

All of these current and voltage phase shift and distortion phenomena are responsible for the deterioration of power quality in the transmission and distribution power systems. Clearly, there is a need from both utilities and customers for power quality improvement. Consequently, power quality has become an issue that is of increasing importance to electricity consumers at all levels of usage. In order to provide proper power supply it is necessary to reduce/remove harmonics present in the system.

## 2. FILTERING PERFORMANCE OF HYBRID ACTIVE POWER FILTER

### 2.1 Proposed system configuration

The medium voltage variable speed squirrel cage induction motor drive acts as load The power quality issues such as current harmonic, unbalancing of current, reactive power and power factor correction were compensated by using shunt hybrid active power filter strategy. The active power filter strategy consist of two types are conventional topology and proposed topology. The hybrid filter is a combination of three phase LC tuned passive filter and a small rated conventional or proposed topology based voltage source inverter (VSI) act as an active power filter (APF) which is connected in series without transformer.

The configuration of three phase, three wire shunt hybrid active power filter (HAPF) strategy for compensating the power quality problems in a distribution system is illustrated below in fig 2.1.

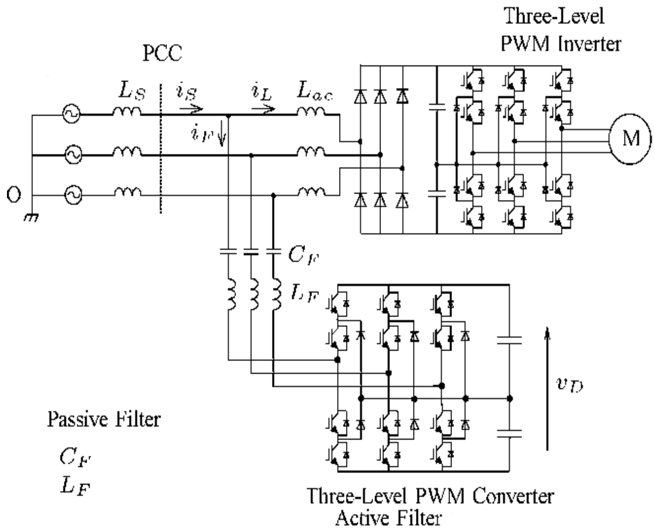


**Fig 2.1 the configuration of three phase 400volts, 50Hz AC supply, three wire shunt hybrid active power filter for a 400V, 15KW squirrel cage induction motor**

In this proposed topology consist of the three-level neutral-point-clamped voltage source inverter (NPC VSI) was introduced by Nabae in 1981 and is regarding as the most popular among the multilevel converter topologies for high voltage, high power applications. The neutral point clamped voltage source inverter shown in Fig.2.2. It has twelve active switches and eighteen diodes. It consists of twelve power diode and six freewheeling diode. The inverter circuit of three legs, each leg have four active switches and four power diode.

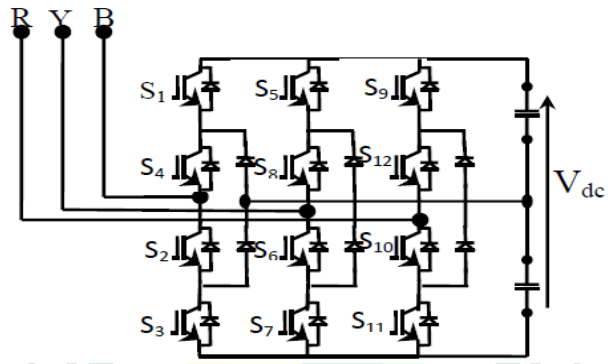


**Fig. 2.2 The neutral point clamped voltage source inverter**

The power diode coupled parallel with each active switches and two freewheeling diode were connected in parallel to the each active switching leg to freewheeling the extra circulating power in the inverter. At the end of inverter, connected parallel to the active switching inverter legs. The midpoints of two dc link capacitor are connected to the midpoint of the freewheeling diode leg. This midpoint connection expresses the neutral point clamped voltage source inverter. The two dc link capacitor act has energy storing device. It requires low voltage to save more power from the system.

**2.2 Hybrid active power filter implementation**

The shunt HAPF topology is implemented with a three phase PWM voltage-source converter connected in series to the passive filter built using inductor, $L_F$ and capacitor, $C_F$. the filter capacitor, $C_F$ is designed to offer high impedance to the line frequency and drops most of the grid voltage across it. Hence effectively no or negligible fundamental voltage appears across the AC terminals of the APF used in the shunt HAPF. This reduces the DC voltage requirement to a much lower level and allows it to connect to grid directly without transformer. This in turn reduces the VA rating of APF and makes shunt HAPF topology suitable for high power applications.
To compensate the harmonics present in the grid current the scheme will force the entire harmonic Currents present in the load current to flow into shunt HAPF, whereas it restricts the sinking of other harmonic currents present in the grid. This improves the filtering performance of the Passive filter, and prevent from overloading. Moreover, compensation characteristics of already installed passive filter can also be significantly improved by connecting an APF in series with passive filter, giving more flexibility and adding insensitivity to grid parameter variations. Once the harmonics are detected in the system the active filter inject voltage/current in the opposite direction that of harmonics produced by the source/load to nullify the harmonic components thus harmonics gets eliminated sufficiently.

**2.2.1 Passive filter design**

(a) Selection of resonant frequency ($f_r$) of the LC filter
The resonant frequency of passive LC filter present in the shunt HAPF is given by,

$$f_r = \frac{1}{2\pi\sqrt{(C_f L_f\ )}}$$

Sensibly the resonant frequency should be selected close to the predominant load current harmonic frequency which needs to be compensated. Since the passive filter selected is a single tuned filter, while selecting the resonant frequency, the focus should be to minimize the impedance offered to the load current harmonics that are being compensated. In this work the load harmonics considered for compensation are 5th, 7th, 11th and 13th order. Hence the resonant frequency is chosen as 7th harmonic order, since it offers less impedance to the 11th and 13th harmonic components, compared to that tuned for 5th harmonic frequency. Hence, if f is nominal grid frequency,

$$\frac{f_r}{f} = 7$$

(b) Design of filter inductor, Lf and filter capacitor, Cf

The selection of inductance, $L_f$ , and capacitance, $C_f$ , has many criteria that should be considered simultaneously. The passive filter should have minimum impedance at the frequencies of harmonic that are being compensated, such as 5th, 7th, 11th and 13th, which can be achieved by increasing bandwidth by reducing the characteristic impedance given by

$$Z=\sqrt{\frac{L_f}{C_f}}$$

Characteristic impedance from the above equation can be reduced by increasing $C_f$ and reducing $L_f$. But large value of $C_f$ will introduce a large capacitive reactive current to flow through the shunt HAPF, which will have more impact on source power factor and increase the current rating. On the other hand, reducing the value of $L_f$ increases the switching ripple in the shunt HAPF current.

Hence, selection of $L_f$ and $C_f$ is a trade-off between various conditions, which is represented in inequalities detailed below:

The upper limit of the filter capacitor value is fixed such that capacitive reactive current drawn by it is only 10% of the rated load current. In such condition, even if the load feeder power factor is unity the grid is degraded only by 0.5%, whereas for lagging load power factor it will improve the situation. If the resistance of passive filter and the relatively small fundamental pole voltage of converter are neglected, this capacitive reactive current is given by

$$I_{conv(fund)} = \frac{V_{grid}}{|(2\pi f L_f - \frac{1}{2\pi f C_f})|} \leq 0.1 I_L$$

Where, Vgrid is the rated phase to neutral grid voltage, f is the nominal grid frequency and $I_L$ is the rated load current. Rewriting the above formula

$$L_f \geq \frac{V_{grid}}{9.6\pi f I_L}$$

### 2.2.2 Active filter design

The APF part of the HAPF is composed of a dc-to-ac centre-split VSI with dc-link capacitors, which includes IGBT power switches with drivers, transducers with signal conditioning boards, and digital controller. In the following, the design of the following three components of the APF part will be presented.

(A) IGBT power switches with drivers,
(B) Transducer with signal conditioning boards,
(C) Digital controller and its software design.

**(A)IGBT Power Switches with Drivers**

For the switching frequency range from a few kHz up to 20 kHz and the allowable maximum voltage of 400 V, IGBT is chosen as the power switching devices of the APF part of the HAPF system. Moreover, IGBT has the merit of low switching losses and require very little drive power at the gate. IGBT module can cover a power range up to about 1 megawatt and is now having a major impact on the power electronic systems in the low to medium power range for industrial and consumer applications. The Mitsubishi third generation IGBT PM300DSA60 dual intelligent power module (IPM) is selected, with maximum rated current and voltage of 300 A and 600 V, respectively. The IPM provides the user with the additional benefits of equipment miniaturization and reduced time to market as they include gate drive circuit and protection circuits. This module can be used as one leg of the VSI, which provides great convenience to the hardware implementation.

**(B)Transducers with Signal Conditioning Boards**

The three-phase load voltages, load currents, compensating currents, and dc-link voltages of the HAPF are measured by transducers with signal conditioning boards. The adopted transducers are based on the Hall-Effect transducer, which provides an isolated measurement for dc and ac voltage and current. The voltage and current signal conditioning boards can transfer the large electrical signals into small analog signals in order to be adopted as the A/D converter inputs of the digital control system. The measured output signals from the signal conditioning boards are sent to the A/D converter and converted into digital signals in the digital controller. These signals are required to calculate the reference compensating currents.

**(C) Software Design of Digital Controller DSP-TMS320F2812**

The reference compensating current calculation is achieved by a digital signal processor (DSP). The high speed DSP-TMS320F2812 is chosen which has high performances in the real-time control and motor/machine control.

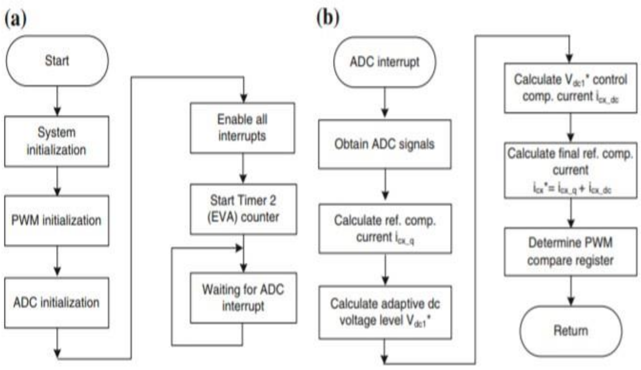


**Fig. 2.3 DSP program flowchart of the HAPF**
**a) Main program and b) interrupt service routine**

### 2.3 Active power filter control strategy

The Instantaneous Real-Reactive power theory is very attractive control theory for generation of reference current signal with the controllability of real and reactive powers. This theory is also called as instantaneous power theory or P-Q theory and its block diagram is given in fig. 2.4

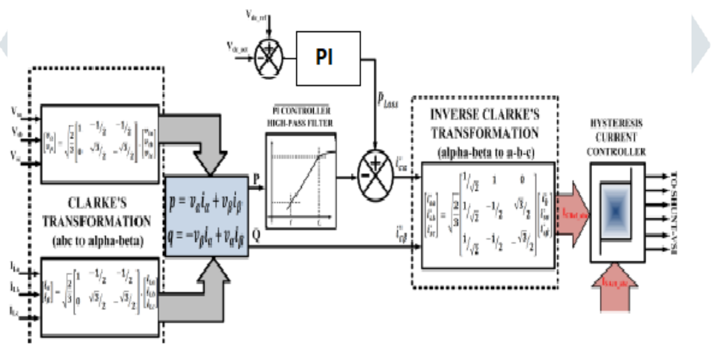


**Fig. 2.4 Block diagram of Instantaneous reactive power theory**

The operating principle of IRP theory is generally situated based on transformation process of three-phase abc quantities to two quantities as αβ sequences in a coordinated orthogonal frame. The input variables of IRP theory is load currents ($I_{Labc}$) from sensors and source voltage ($V_{Sabc}$) are fed to Park's transformation process. This scheme provides the current voltage component in coordinated orthogonal are used to represent the real and reactive powers. The instantaneous real & reactive power sequences are measured based on above transformation process by specific equations as fundamental active current sequence and voltage functions. The instantaneous vector coordinates are posed on the axis-"a" and respective magnitudes are changed with positive-negative with time. By using Park's transformation process these phases are transforming to (α-β) coordinates, follows as

$$\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix}$$

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

Where, the (α-β) are coordinated orthogonal sequences, the classical immediate power for system can be depicted as

$$p = v_{s\alpha} i_{L\alpha} + v_{s\beta} i_{L\beta}$$

The formal active power equation is defined as

$$p = v_{sa} i_{La} + v_{sb} i_{Lb} + v_{sc} i_{Lc}$$

Relatively, the formal IRP theory is defined as

$$q = -v_{s\beta} i_{L\alpha} + v_{s\alpha} i_{L\beta}$$

Although, the instantaneous real-reactive power is illustrated in matrix form as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ -v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix}$$

The (α-β) current components can be acquired as

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \frac{1}{\Delta_k} \begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ -v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix}$$

Where,

$$\Delta_k = v_{s\alpha}^2 + v_{s\beta}^2$$

The active-current sequence is by-pass to High-Pass Filter (HPF) which is used to recognize the harmonic elements from desired wave-shape. This filter eliminates the lower-order frequencies and allows high-order frequency into the system as reference current generation. The DC-link controller is used to regulate the common DC-link voltage by utilizing PI controller, which is used to control the DC-link voltage as maintained constant. The reference DC-link voltage is directly compared to measured DC-link voltage resembles the error quantities. The outcome error value from this task is fed to PI controller for minimization of dominant error quantities in $P_{Loss}$ with good stability index.

The instantaneous real and reactive power can be conveyed into a DC average & oscillatory components are,

$$p = \bar{p} + \tilde{p}$$

$$q = \bar{q} + \tilde{q}$$

The reference compensator currents can be evaluated as

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{\Delta_k} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix}$$

These reference currents are transformed to a-b-c components using inverse transformation process as the evolution of reference current component in orthogonal coordinate is extracted by summation of active fundamental current component and component is called utmost reference current. The reference current is differentiated to actual measured current from feeder-1 for producing optimal switching states to shunt-VSI compensator by Hysteresis Current Controller (HCC). The HCC is highly engaged to develop the optimal switching states to shunt VSI by using hysteresis band limits. This band limit acts as boundary conditions of compensation current which is controlled in between the upper and/or lower limits to generate the switching pulses to compensator. The switching pulses related to ON/OFF of switches in VSI are greatly depended by reference current and actual current component. When actual current is increased more than reference current then the respective switch is conducted and decreased the switch is in OFF condition. However, the actual current is continuously swinging between inside the bands limits followed by reference current component provided by $I_d$-$I_q$ synchronous detection scheme.

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & 1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_0^* \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix}$$

## 3. SIMULATED RESULTS

The simulation circuit of the proposed system is given in fig 3.1.

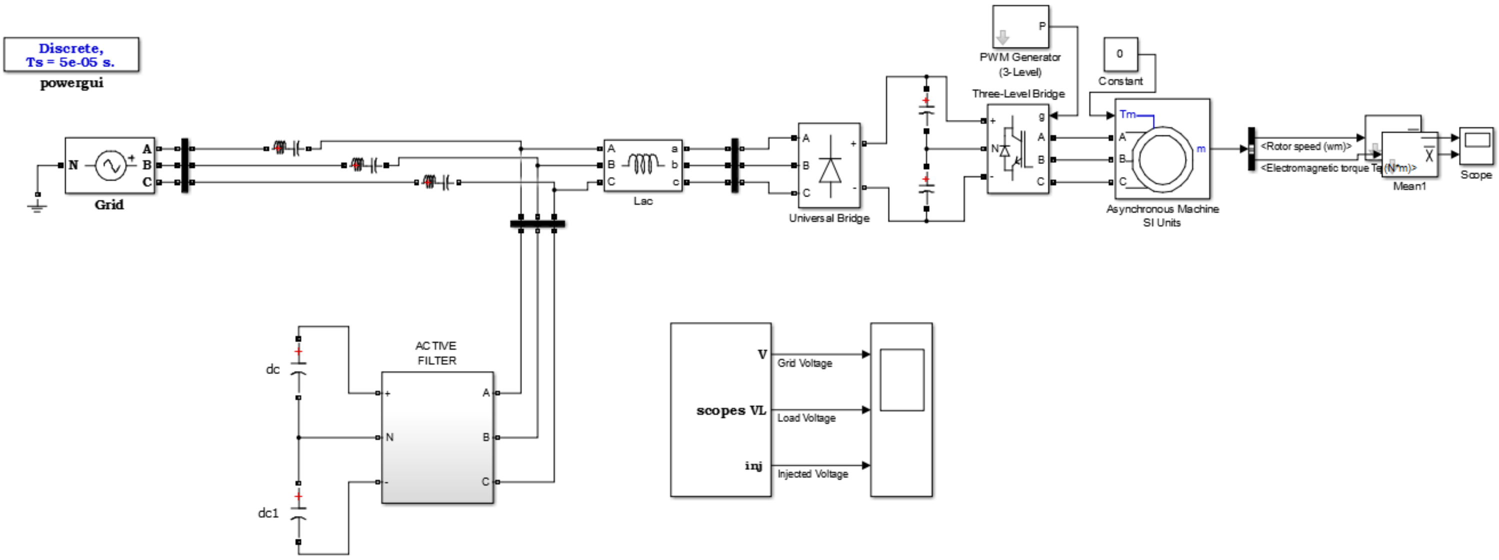


**Fig. 3.1 simulation circuit using MATLAB/SIMULINK**

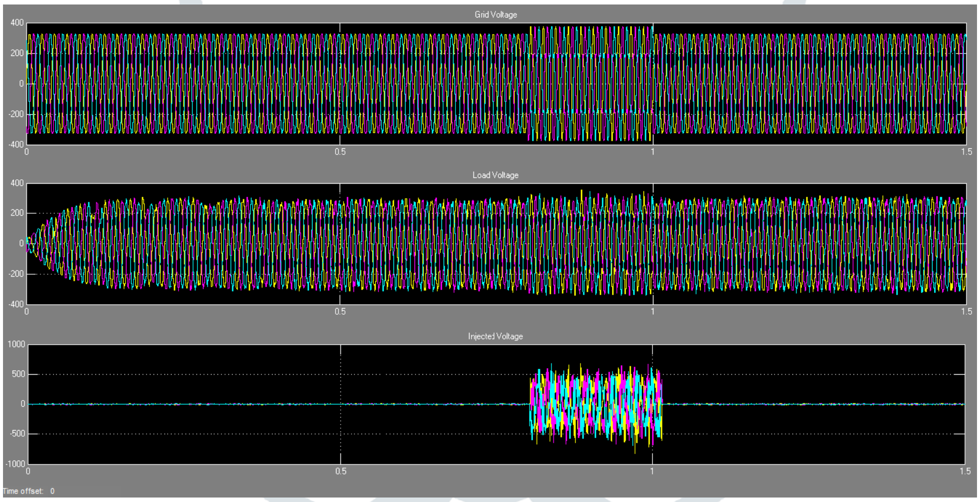


**Fig 3.2.The grid and load voltage waveforms with harmonics presented at t=0.8s to 1.0s**

From fig 3.2 it is seen that harmonics are detected from t=0.8s to 1.0s and also at that time we have injected a desired amount of voltage to eliminate the harmonics.

Fig 3.3 shows the grid and load voltage waveforms without harmonics.

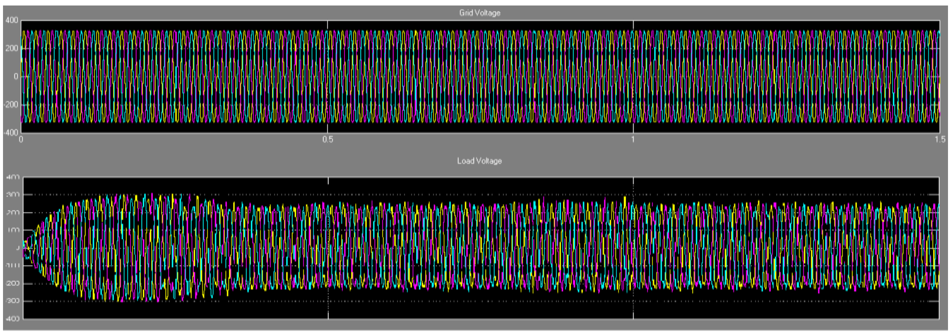

**Fig 3.3.The grid and load voltage waveforms without harmonics**

The current waveforms are provided in fig 3.4

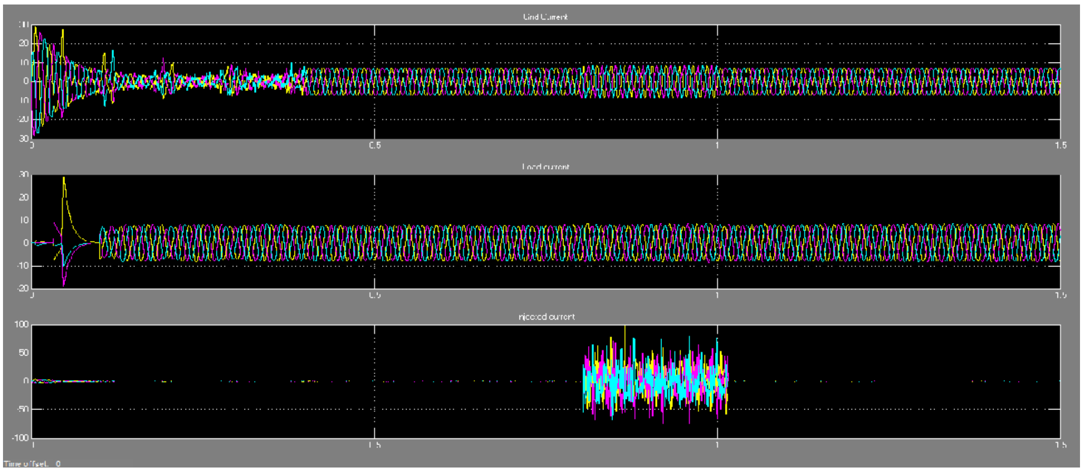

**Fig 3.4.The grid and load current waveforms along with injected current**

From fig 3.4 it is seen that the filter injects the current at t=0.8 to 1s when the harmonics are generated.

The THD of the load current is provided in fig 3.5

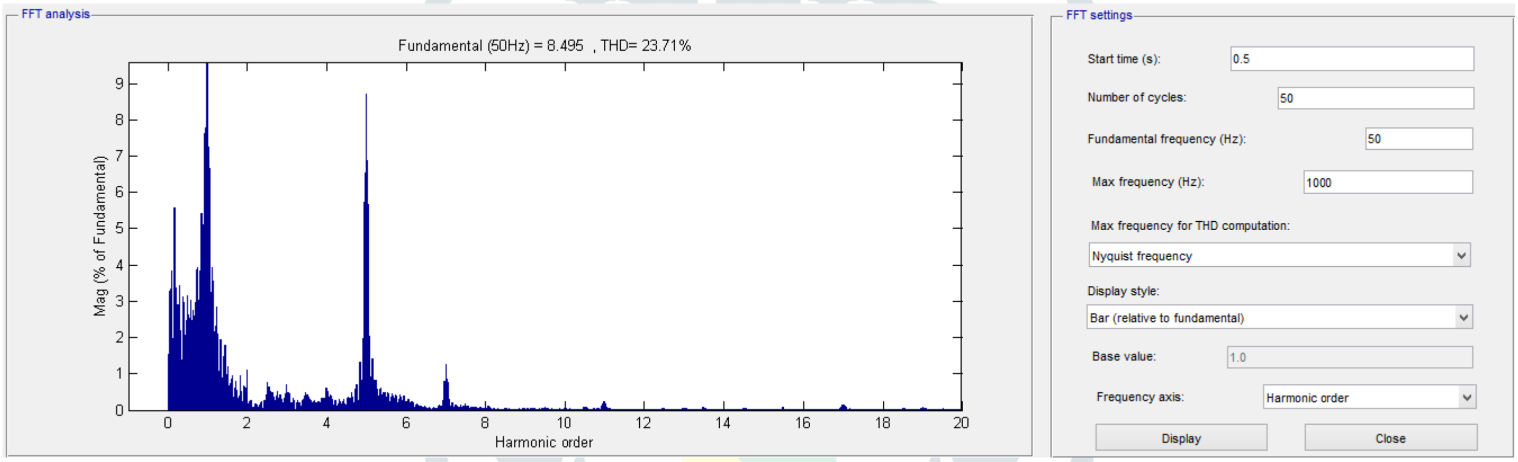


**Fig 3.5.FFT analysis of the load current without HAPF filter**

From fig 3.5 it is observed that the total harmonic distortion (THD) of the load current without filter is 23.71%.Which is much more than the IEEE standard 519-1992 and ultimately reduces the quality of the machine more.

Therefore by implementing the hybrid active power filter configuration into the system the filter reduces the %THD of the load current from 23.71% to 2.48%. Fig 3.6 shows the %THD graph of load current with filter.

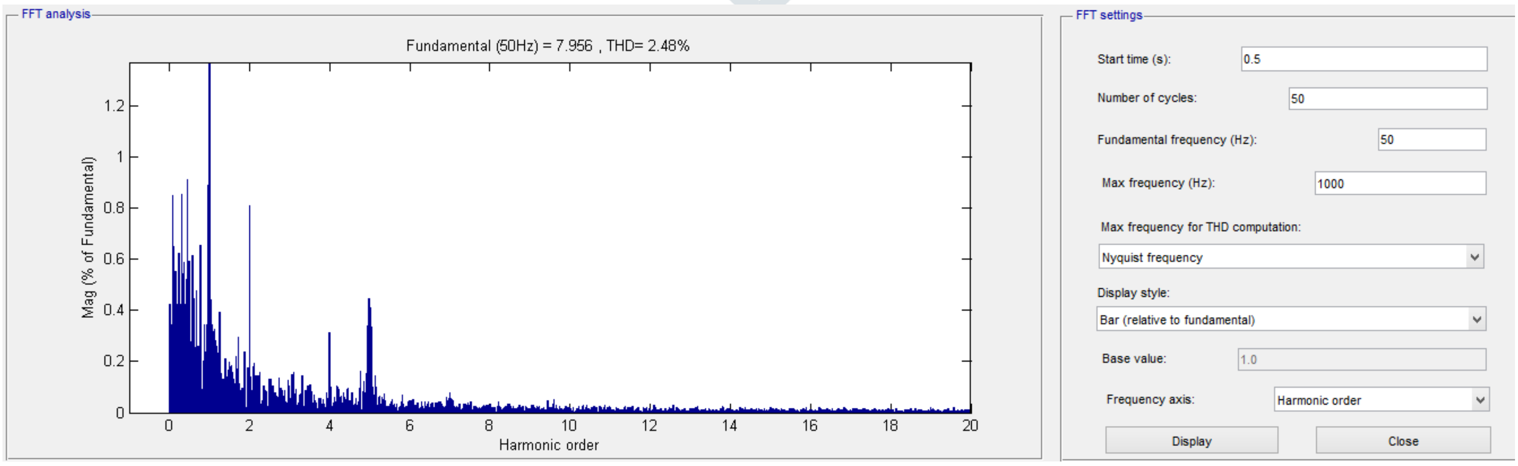


**Fig 3.6.FFT analysis of the load current with HAPF filter**

The percentage harmonics of different harmonic orders of the load current without and with filter is given in table 3.1 and from the table it is verified that the hybrid active power filter reduces both THD as well as other order harmonics effectively.

**Table 3.1 the individual odd harmonic components and THD values of Load current.**

| Harmonics order | %Harmonics Without filter (THD=23.71%) | %Harmonics With filter (THD=2.48%) |
|---|---|---|
| 1 | 100 | 100 |
| 3 | 0.71 | 0.10 |
| 5 | 8.72 | 0.36 |
| 7 | 1.27 | 0.08 |
| 9 | 0.01 | 0.01 |
| 11 | 0.24 | 0.02 |
| 13 | 0.06 | 0.01 |
| 15 | 0.02 | 0.01 |
| 17 | 0.15 | 0.02 |
| 19 | 0.07 | 0.01 |

## 4. CONCLUSION

A hybrid active power filter for harmonic current mitigation has been studied. The hybrid filter is simulated for a 12 pulse converter connected to an induction motor. The Active filter used here is based on three- level-Neutral point clamped PWM inverter. The active filter taking part in the hybrid filter is much smaller in converter capacity than the pure active filter because of the presence of $L_{AC.}$ The simple single-tuned LC filter used in the hybrid filter is much smaller in size, lower in cost and weight, than the traditional passive filter.
The control strategy for active filter is based on IRP theory which detects the harmonics and then injects current into the system in opposite direction that of harmonics produced. Sinusoidal pulse width modulation has been used for gating signal generation.
From the simulated results it is seen that the hybrid active power filter (HAPF) reduces both various individual harmonics as well as the THD of the induction motor effectively and it is compared with the harmonics results of without filter and hence it is verified that HAPF is much effective in filtering harmonics and the THD of the load current obtained here is within the limit of 5 percentage as prescribed by IEEE 519 standards.

## REFERENCES

**[1]** Hirofumi Akagi, Kousuke Isozaki, " A hybrid active filter for a three phase 12-pulse diode rectifier used as the front end of a medium voltage motor drive", IEEE Transactions on Power Electronics.

**[2]** Meera S Nair, Deepa Sankar "A Review of Hybrid filter topologies for power quality compensation", International Research Journal of Engineering and Technology.

**[3]** Aredes, M.; Monteiro, L.F.C.; Mourente, J., "Control strategies for series and shunt active filters," Power Tech Conference Proceedings, 2003 IEEE Bologna, vol.2, no., pp.6 pp. Vol.2,, 23-26 June 2003

**[4]** A. Bhattacharya, C. Chakraborty, and S. Bhattacharya, Shunt compensation: Re-viewing traditional methods of reference current generation, IEEE transaction on industrial electronics, Sep. 2009.

**[5]** Nastran J., Cajhen R., Seliger M., and Jereb P., "Active power filter for nonlinear AC loads," IEEE Trans. Power Electronics., vol. 9, (1994):pp. 92–96.

**[6]** H. Akagi, S. Ogasawara, H. Kim, The theory of instantaneous power in three-phase four-wire systems: a comprehensive approach, in Conference of Record IEEE-34th IAS Annual Meeting, vol. 1, 1999, pp. 431–439.

**[7]** Litran, S.P.; Salmeron, P.; Herrera, R.S., "Practical design of a control strategy based in current and voltage detection for hybrid power filters," Power Engineering, Energy and Electrical Drives (POWERENG), IEEE 2011 International Conference on , vol., no., pp.1,6, 11-13 May 2011.