Hysteresis Band Current Control For Harmonic Compensation of Unbalanced & Nonlinear load

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Abstract- In this paper, instantaneous reactive power theory (IRP), also known as *p–q* theory based control algorithm is proposed for 4-leg shunt active power filter (APF) to suppress harmonic line currents and neutral current and balance the load currents under unbalanced non-linear load and non-ideal mains voltage conditions. The p-q theory is composed from 4-leg voltage source inverter (VSI) with a hysteresis–band PWM current controller. Conventional p-q theory for different loading condition such as nonlinear load and unbalanced load along with Hysteresis band current control technique is simulated and harmonic disturbances has been analysed. All simulations are carried out using Matlab/Simpowersystem.

Keywords- Control strategy, harmonic compensation, hysteresis band controller, shunt active power filter, Matlab.

INTRODUCTION

In the past decades there has been continuous penetration of power electronics into so many applications. Hence there is continuous require for reliable power electronic equipment at all power levels. They play a major task in energy consumption and energy conversion. The purpose behind power electronic technologies is their high efficiency due to low loss in power semiconductor devices, high reliability, fast dynamic response compared to electromechanical converter system, flexibility in operation small size and less weight, thus low installation cost, etc.

The role of power electronics into power system introduces the major problem of nonlinearity. This nonlinearity is observed in current waveforms at the source or load end side which introduces harmonics in the system. The non linearity in power system comes in two manners:- a) Due to switching on and off of power converters. b) Due to load and source of power converter [1].

The energy conversion using power electronics converter can be of four types: The AC/AC converters are used in motors and other devices which give nonlinear characteristics. The AC/DC is normal rectification process which is highly nonlinear. The DC/AC converters are used in fluorescent lamps, lightning, etc., which again shows nonlinear behavior [2]. Hence it can be in general said that all the power converters acts as a nonlinear load. This entire nonlinear load draws harmonic current that causes lots of problems like distortion in voltage waveform, high ripple torque, voltage flickering. Several standards have been established to limit harmonics. These are IEEE std 519, IEC 1000-3-2, and IEC 1000-3-4. All this standards indicate that the power electronic converters should comply with the standards and should also deal with those nonlinear loads.

Most of the three phase systems like motor drives are balanced three phase systems but due to the nonlinear load the three phase system become unbalanced. The unbalance load/source cause heavy neutral current, distorted source, large even order harmonics, low frequency reactive power, etc.

Four leg converter is the best solution for the harmonic compensation in the line currents as well as in the neutral current of unbalanced and non linear load. Four leg converter with P-Q theory is described to generate compensating current.

I. PROPOSED BLOCK DIAGRAM.

Fig. 1 shows the basic compensation principle of the shunt active power filter. A Filter is designed to be connected in parallel with the load, to compensate its harmonic current by injecting compensating current into the system, identical with the load harmonic current [3].

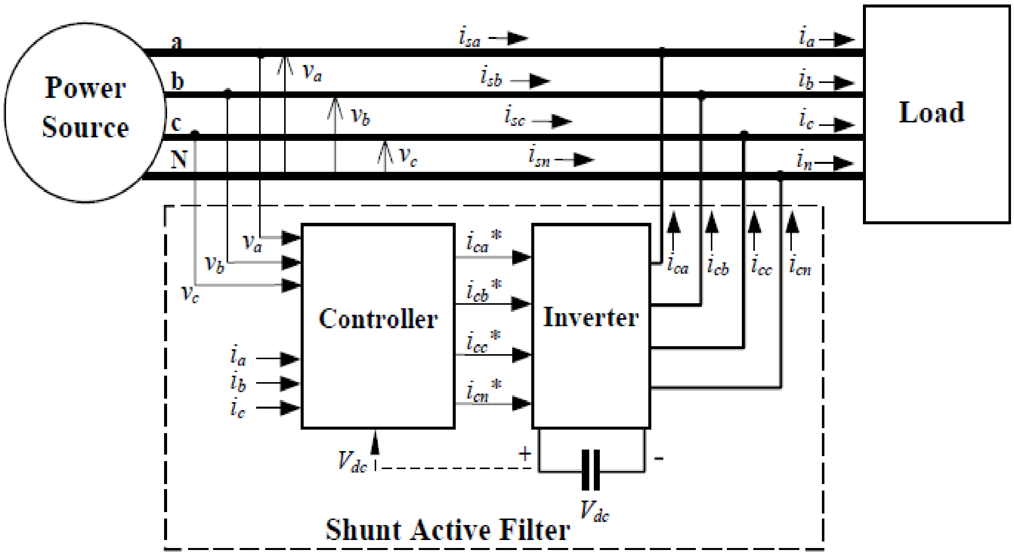

Figure.1 Proposed block diagram

Fig. 2 shows the power circuit of a 4-leg shunt APF connected in parallel with the 3-phase load as an unbalanced and non-linear load on 3-phase 4-wire electrical distribution system. The middle point of each branch is connected to the power system through a filter inductor [4].

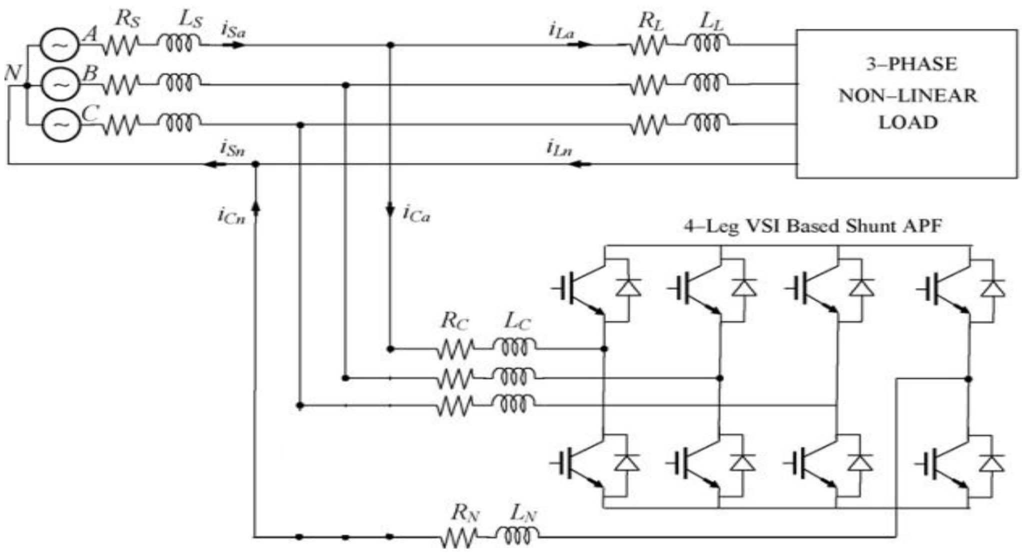

Figure.2 Four leg converter

The APF consists of 4-leg VSI, 3-legs are needed to compensate the 3-phase currents and 1-leg compensates the neutral current. The 4-leg VSI has 8 IGBT switches and an energy storage capacitor.

II. CONTROL STRATEGY

The *p–q* theory based control algorithm block diagram for the 4-leg APF is shown in Fig. 3.

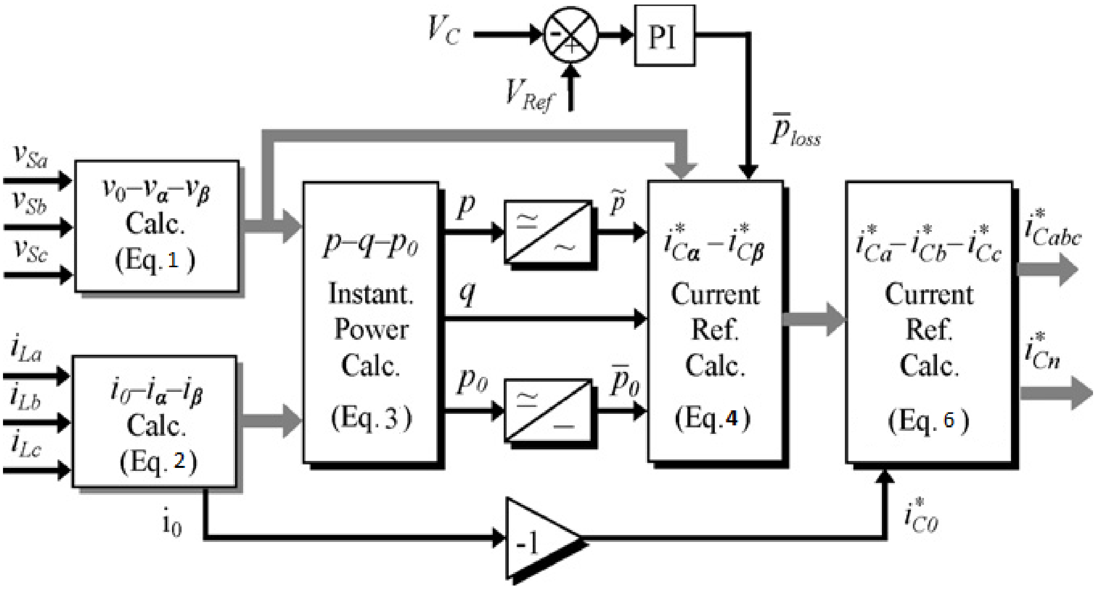

Figure.3 block diagram of p-q theory

Form the Eqs. (1) and (2), the *p–q* theory consist of an a Clarke transformation of the measured 3-phase source voltages (*Va*, *Vb*, *Vc*) and load currents (*Ia*, *Ib*, *Ic*) in the *a–b–c* coordinates to the *α–β*–0 coordinates, followed by the calculation of the instantaneous power components (*p*, *q*, *p*0) [5].

$$\begin{pmatrix} V_0 \\ V_\alpha \\ V_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \tag{1}$$

$$\begin{pmatrix} I_0 \\ I_\alpha \\ I_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix} \tag{2}$$

Instantaneous real power (*p*), imaginary power (*q*) and zero sequence power (*p*0) are calculated.

$$\begin{pmatrix} P_o \\ P_L \\ q_L \end{pmatrix} = \begin{pmatrix} v_o & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \end{pmatrix} \begin{pmatrix} i_o \\ i_\alpha \\ i_\beta \end{pmatrix} \tag{3}$$

The compensation current reference is calculated as Eq. (4).

$$\begin{pmatrix} i_{c\alpha}{}^* \\ i_{c\beta}{}^* \end{pmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{pmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{pmatrix} \cdot \begin{pmatrix} p^{\sim} - p_0^{-} \\ q \end{pmatrix} \tag{4}$$

Since the zero-sequence current must be compensated, the reference compensation current in the 0 coordinate is i0 itself:

$$i_{c0}{}^* = i_0 \tag{5}$$

To obtain the reference compensation currents in the *a-b-c* coordinates the inverse of the transformation given in expression (6) is applied [4]:

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

$$i_{cn}^* = -(i_{ca}^* + i_{cb}^* + i_{cc}^*) \qquad (6)$$

According to this method the high order harmonics, both in the phase and the magnitude of the load's current vector, are eliminated from the load current.

III. HYSTERESIS BAND CURRENT CONTROLLER

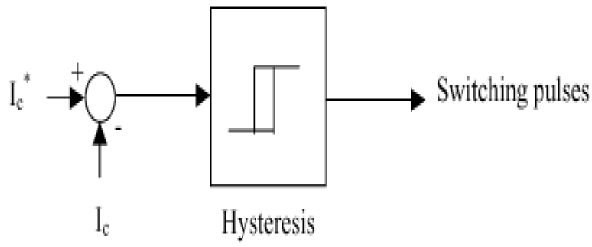

Figure 4. Conventional hysteresis band current controller.

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 [5,6].

The conventional hysteresis band current control scheme used for the control of active power filter line current is shown in Fig. 4, composed of a hysteresis around the reference line current.

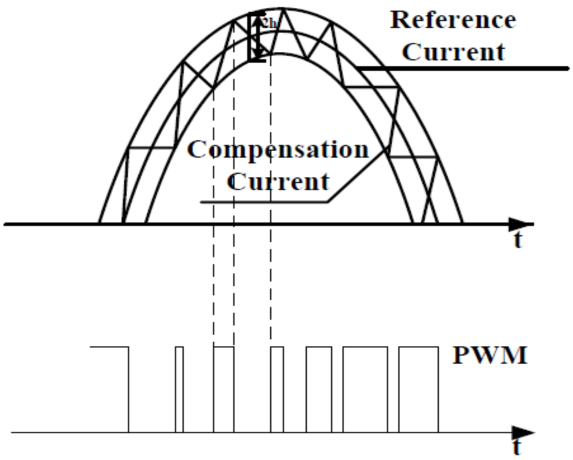

Figure 5. Current and voltage (gate) waveform with hysteresis band current control

The reference line current of the active power filter is referred to as Ic^* and actual line current of the active power filter is referred to as Ic. The hysteresis band current controller decides the switching pattern of active power filter [7]. The switching logic is formulated as follows:

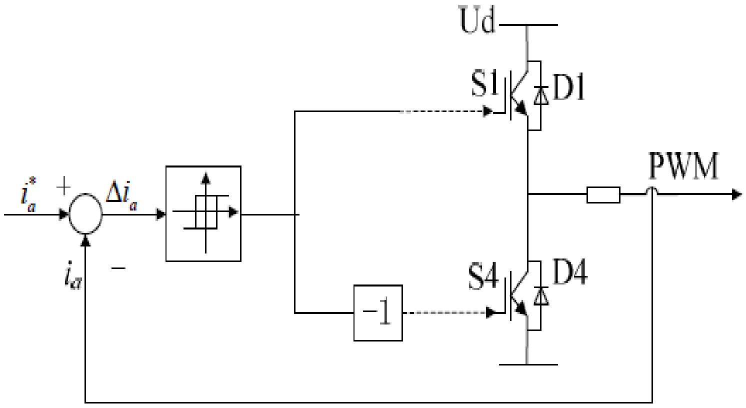

Figure 6 Circuit of current tracking control

If *i*ca < (*I*ca* − HB) upper switch is OFF, lower switch is ON.

If *i*ca > (ca + HB) upper switch is ON, lower switch is OFF. .

The switching functions for other two phases are determined similarly, using corresponding reference and measured currents and hysteresis bandwidth (HB) [8].

IV. FLOW CHART FOR PROPOSED SOLUTION

Flow chart of proposed solution is shown in fig. 7. Line currents I_{La}, I_{Lb}, I_{Lc} and neutral current I_{sn} are measured and %THD of individual current waveformes are formulated. If the %THD of individual current is beyond permissible level then compensation should be provided [9].

Compensatiing currents (I_{ca}, I_{cb}, I_{cc}, I_{cn}) will be calculated through instantaneous theory. By comparing this compensating current with line current corresponding gate signals will be generated by hysteresis band current controller. Hence harmonic currnts will be eliminated.

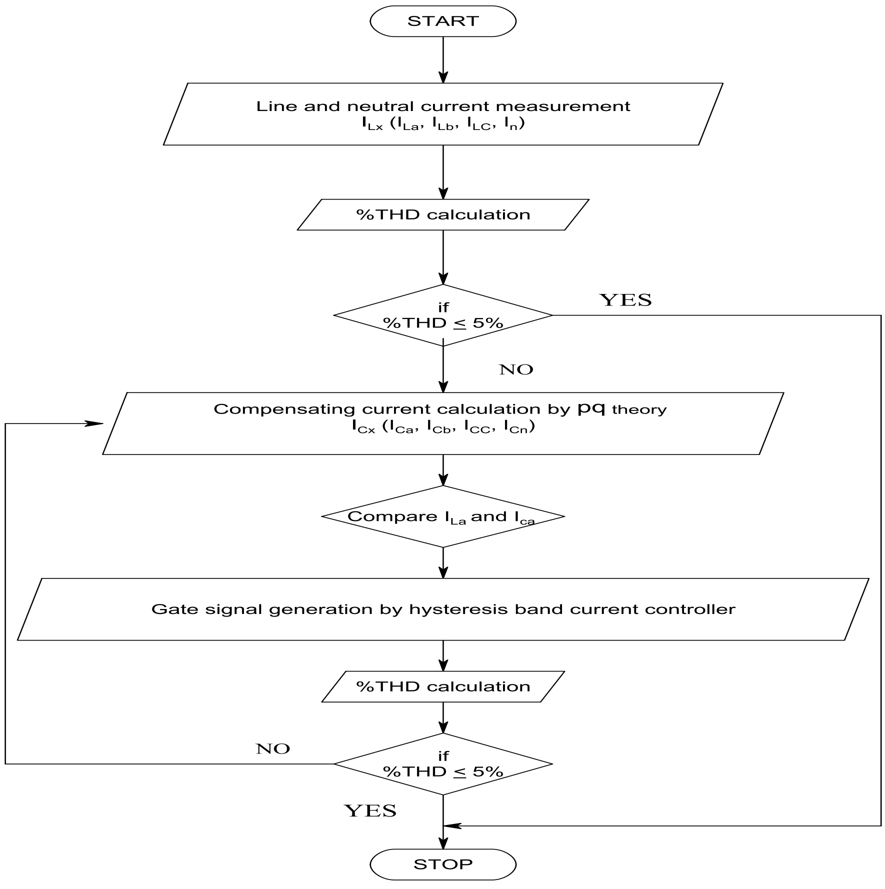

Figure 7 Flow chart of proposed solution

V. SIMULATION RESULTS

Simulations are taken for different unbalance and non linear loads. Compensating currents are formed by instantaneous p-q theory for different load conditions.Four different load conditions are considered here.

(1) *Nonlinear load:*
Two different load cases are considered as nonlinear load
Case 1: 3-ph diode bridge rectifier as load
Case 2: 3-ph AC drive as load
(2) *Nonlinear and Unbalance load:*
Case 1: 3-ph and 1-ph diode bridge rectifier load

Simulation results for different line currents and neural current are shown for different load conditions are shown.

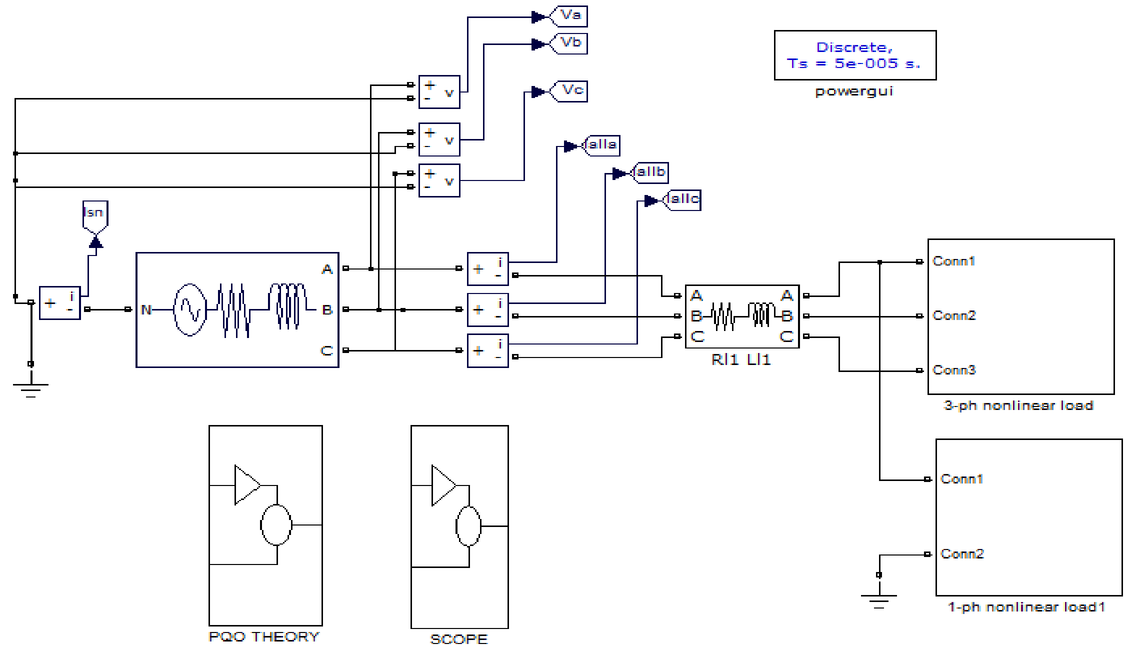

Figure 7 Matlab simulation block diagram

(1) *Nonlinear load:*
Simulation results for two types of nonlinear loads and %THD in line currents are shown. As the load is nonlinear but balanced in nature there will be no current in neutral wire, hence %THD of neutral current become zero.

Case 1: 3-ph diode bridge rectifier load
Line current, its harmonic spectrum and compensating current of phase A are shown in below fig.

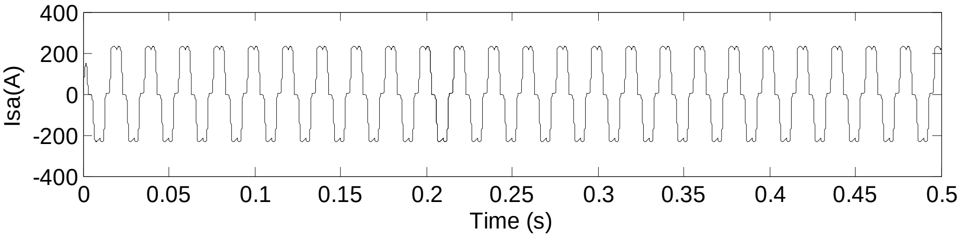

Figure 8 line current waveform for phase A without compensation

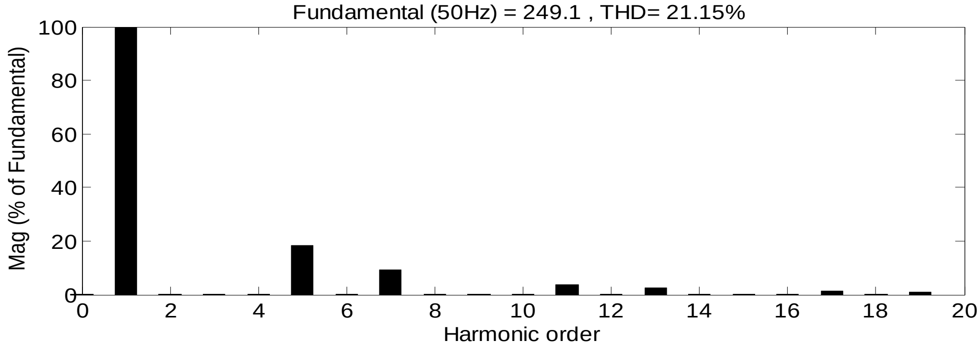

Figure 9 %THD spectrum for phase A

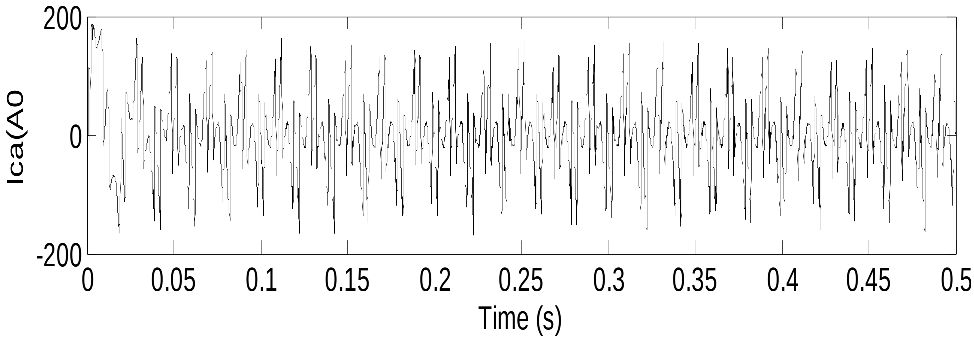

Figure 10 Compensating current waveform for phase A

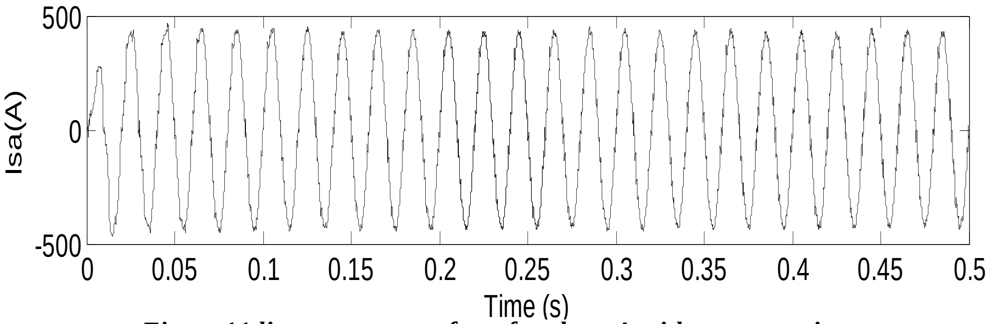

Figure 11 line current waveform for phase A with compensation

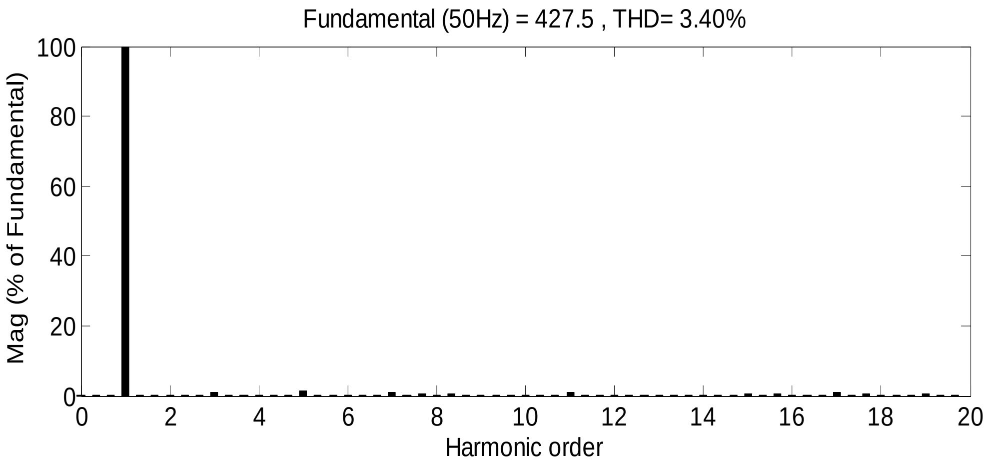

Figure 12 %THD spectrum for phase A after compensation

Case 2: 3-ph AC Drive as load

Line current,its THD and compensating current of phase A are shown in below figure.

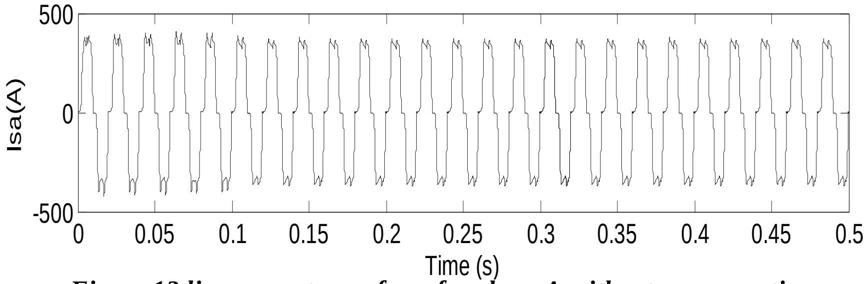

Figure 13 line current waveform for phase A without compensation

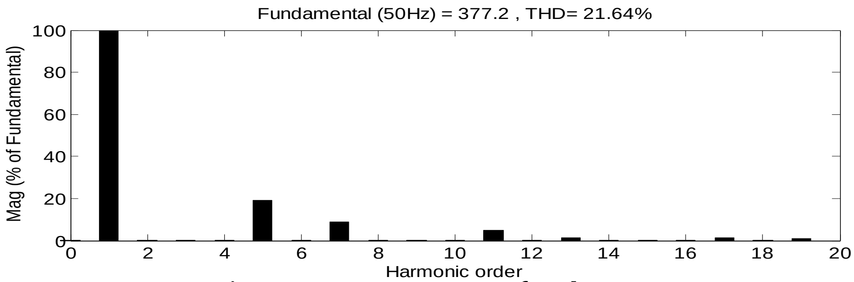

Figure 14 %THD spectrum for phase A

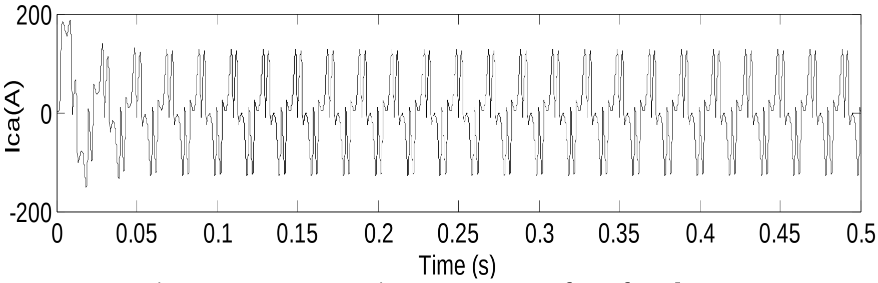

Figure 15 Compensating current waveform for phase A

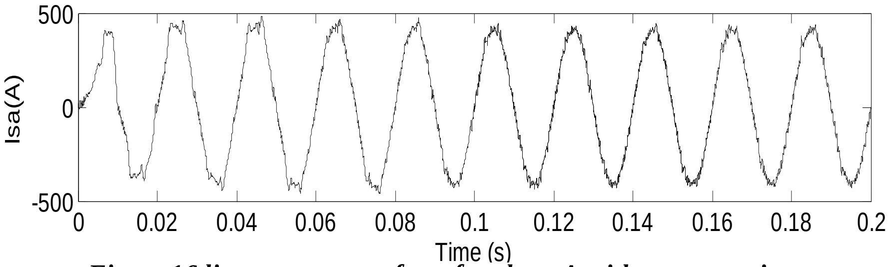

Figure 16 line current waveform for phase A with compensation

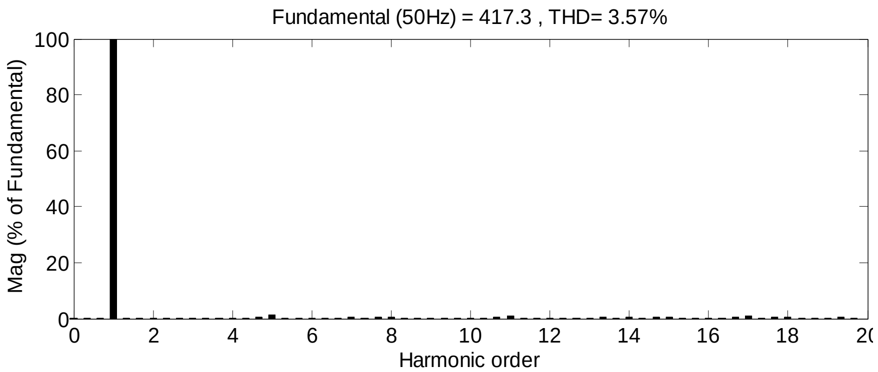

Figure 17 %THD spectrum for phase A

(2) *Nonlinear and Unbalance load:*

Simulation results for two types of nonlinear loads and %THD in line currents are shown. As the load is nonlinear and unbalanced in nature, neutral current will present in the system.

Case 3: 3-ph and 1-ph rectifier as load

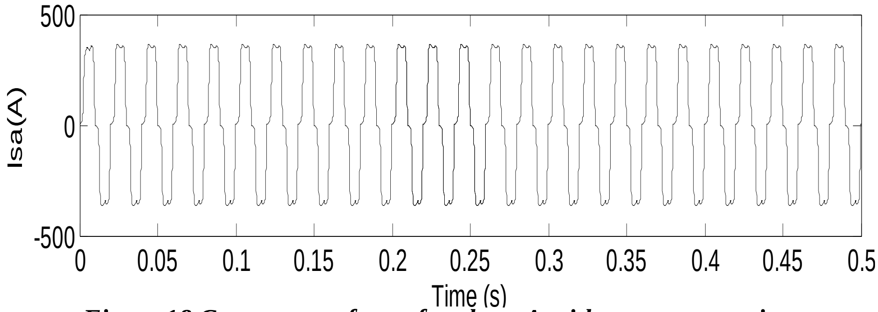

Figure 18 Current waveforms for phase A without compensation

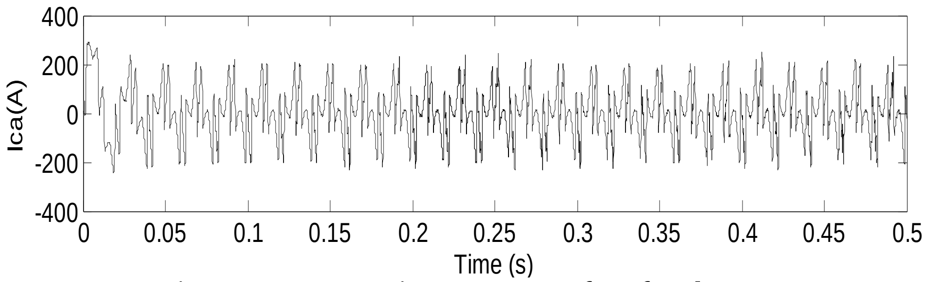

Figure 19 Compensating current waveform for phase A

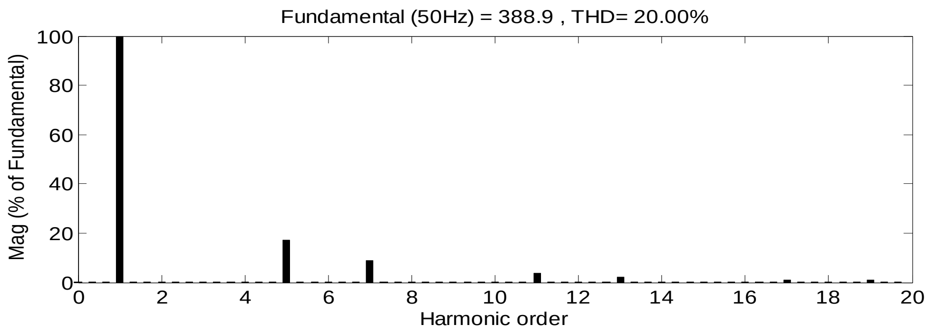

Figure 20 %THD spectrum for phase A

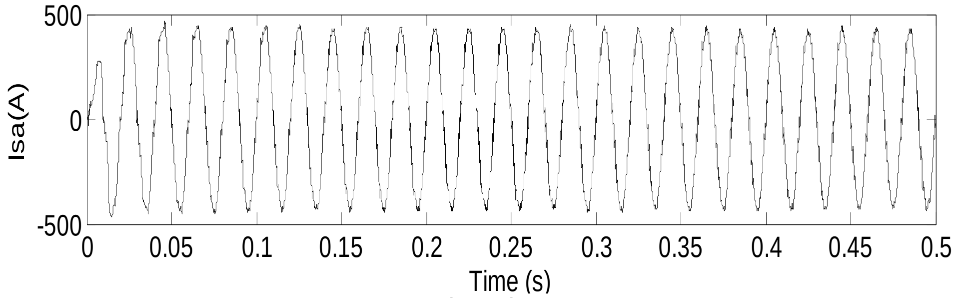

Figure 21 line current waveform for phase A with compensation

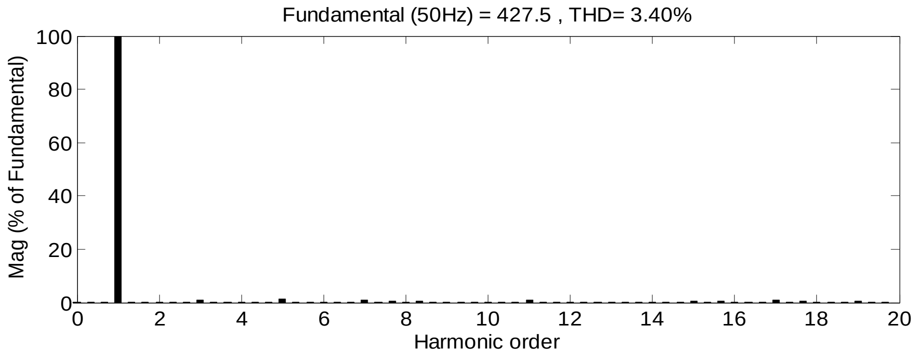

Figure 22 %THD spectrum for phase A

Table 1
%THD in line current A with and without compensation

Load	%THD Without compensation	%THD With compensation
Case 1 3-ph uncontrolled rectifier	21.15%	3.40%
Case 2 3-ph AC Drive	21.64%	3.57%
Case 3 3-ph & 1-ph rectifier	20.00%	3.40%

CONCLUSION

In this paper, harmonic evaluation for all the lines as well as neutral wire is done. An instantaneous active and reactive power theory is used to generate required compensating current for harmonic elimination. The implementation p-q theory is cost-effective solution, allowing the use of a large number of low-power active filters in the same facility, close to each problematic load (group of loads), avoiding the circulation of current harmonics. Harmonics compensation is done according to this compensating current along with Hysteresis band current control technique. Harmonic elimination is carried out as per IEEE 519 standards.

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