

# Harmonics Reduction of 3 Phase Diode Bridge Rectifier by Implementing P-Q Theory with Active Filter

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**Abstract**— With the rapid use of power electronics devices such as rectifier, inverter etc. in power system causes serious problem with power quality. One among them is generation of current and voltage harmonics causing distortion of load waveforms, fluctuation in voltages, voltage dip, heating etc. Also presence of non-linear loads such as UPS, SMPS, drives etc. are the reason of current harmonics in power system. They draw reactive power components of current from mains causing disturbance in supply current waveform. Thus to avoid the consequences of harmonics we have to compensate the harmonics in power system. Among various methods used, one of the favourable way to compensate harmonics in power system is the effective use of Shunt Active Power Filter (SAPF). This research work gives detail performance analysis of SAPF with the help or control strategy of instantaneous active and reactive power theory i.e. “p-q theory”. Here we took 3 phase diode rectifier and simulation analysis is done to justify the method better over other. In this method a reference current is generated, which compensate harmonic current component in power system and THD of the source current is reduced. And system performance enhanced.

**Key words:** THD, P-Q Theory

## I. INTRODUCTION

Harmonic pollution is more common in low voltage side due to wide use of nonlinear loads (UPS, SMPS, Rectifier etc.), which is not desirable as it causes serious voltage fluctuation and voltage dip in power system. So it is required to eliminate these undesirable current and voltage harmonics and to compensate the reactive power, to improve the performance of the power system network. The use of traditional passive filter in removing harmonics is not that much effective because their static action and no real time action or dynamic action is taken for the removal of harmonics. But the shunt active power filter on the other hand gives promising results when compared with conventional active and passive filters. This project basically shows the current control strategy i.e instantaneous active-reactive power method which is helpful to reduce the current harmonics when used with SAPF through MATLAB simulation and modeling.

## II. THE P-Q THEORY

In 1983, Akagi have proposed the "The Generalized Theory of the Instantaneous Reactive Power in 3-Phase Circuits, which is also known as instantaneous power theory, or p-q theory. This theory is based on the instantaneous values in 3-phase power systems with or without neutral wire, and this is applicable for steady-state operation of the system or transitory operations as well as for generic voltage and current waveforms. The p-q theory consists of an algebraic transformation which is known as Clarke transformation of

the three-phase voltages and currents in the a-b-c coordinates to the  $\alpha$ - $\beta$ -0 coordinates and followed by the calculation of the p-q theory instantaneous power components:

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$p_0 = v_0 \cdot i_0$                       instantaneous zero-sequence power  
 $p = v_\alpha \cdot i_\alpha + v_\beta \cdot i_\beta$             instantaneous real power  
 $q = v_\alpha \cdot i_\beta - v_\beta \cdot i_\alpha$             instantaneous imaginary power (by definition)

The power components which are p(active power) and q(reactive power) are related to the same  $\alpha$ - $\beta$  voltages and currents, and the power component can be written as:

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

These power quantities are illustrated for an electrical system represented in a-b-c coordinates and have the following meaning:

$P_0$  = it is the mean value of the instantaneous zero-sequence power which is related to the energy per time unity. From the power supply this energy is transferred to the load through the zero-sequence components of V(voltage)and I(current).

$\sim p_0$  = it is the alternated value of the instantaneous zero-sequence power. Physical meaning of this term is the energy/time unity that is transferred between the power supply and the load through the zero-sequence components. The zero-sequence power only exists in 3-phase systems with neutral wire. Furthermore, the systems must have unbalanced V(voltages) and I (currents) and/or third order harmonics in both voltage and current of at least one phase.

$p$  = mean value of the instantaneous real power. Which corresponds to the energy/time unity. This energy is transferred from the supply to the load, in a balanced manner(it is the desired power component).

$\sim p$  = it is the alternated value of the instantaneous real power. It is the energy/time unity. This energy is exchanged between the power supply and the load via the abc coordinates.

$q$  = it is the instantaneous imaginary power – corresponds to the power that is transferred between the phases of the load. This component doesn't imply any transference or exchange of energy between the power supply and the load, but this is responsible for the existence of undesirable currents which circulate between the system phases. In the case of a balanced voltage supply and a balanced load, with or without harmonics, q (it is the mean value of the instantaneous imaginary power) is equal to the conventional reactive power ( $q = 3 \cdot V \cdot I_1 \cdot \sin \phi_1$ ).

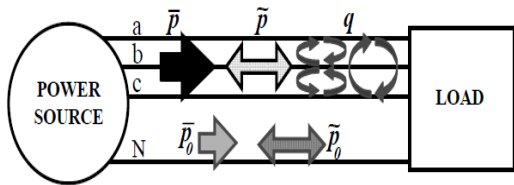


Fig. 1: Power components of the p-q theory in a-b-c coordinates.

A. The P-Q Theory Applied To Shunt Active Filters:

The p-q theory is one of the various methods that can be used in the control active filters. It has some interesting features, namely:

- It is inherently a 3-phase system theory,
- It can be applied to any 3-phase system (balanced or unbalanced with or without the harmonics in voltages and currents),
- It is based on instantaneous values, allowing tremendous dynamic response,
- Its calculations are relatively easy (it only includes algebraic expressions which can be implemented using by std. processors),
- It allows two control strategies:- one is constant instantaneous supply power and other is sinusoidal supply current.

As seen before,  $\bar{p}$  is the only desirable p-q theory power component. The other various quantities can be compensated using a shunt active filter.  $\bar{p}_0$  can be compensated without the any power supply need in the shunt active filter.

This quantity is transferred from the power supply to the load via the active filter (see Fig.2.2 ). This means that the energy previously transferred from the source to the load via the zero-sequence components of voltage and current, is now transferred in a balanced way through the source phases.

It is also possible to conclude from Fig. that the active filter capacitor is only needs to compensate  $\sim p$  and  $\sim p_0$ , since these quantities need to be stored in this component at one moment to be later transferred to the load and The instantaneous imaginary power [ q]which also includes the conventional reactive power is compensated without the needs of the capacitor. This means that the capacitor size does not depend on the amount of reactive power to be compensated.

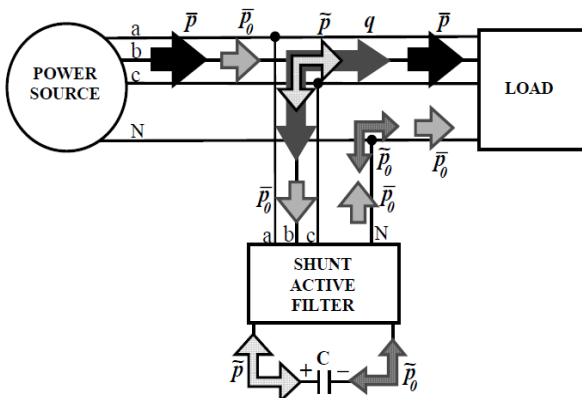


Fig 2: Compensation of power components in a,b,c coordinates.

To determine the reference compensation currents in the  $\alpha$ - $\beta$  coordinates, the expression (5) is inverted, and the powers to be compensated ( $\sim p - \bar{p}_0$  and  $q$ ) are used:

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \cdot \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} \tilde{p} - \bar{p}_0 \\ q \end{bmatrix}$$

Since the zero-sequence current must be compensated, the reference compensation current in the 0 coordinate is  $i_0$  itself:

$$i_{c0}^* = i_0$$

In order to calculate the reference compensation currents in the a-b-c coordinates the inverse of the transformation given in expression (1) is applied.

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_{c0}^* \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix}$$

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

The calculation given so far are synthesized in Fig.2.3 and similar to a shunt active filter control strategy for constant instantaneous power supply. This approach when applied to a 3-phase system with balanced sinusoidal voltages, produces following results (Fig.):

- The phase supply currents become in phase with the voltages, sinusoidal, balanced (in other words the supply “sees” the load as a purely resistive symmetrical load),
- The neutral current is become equal to zero (even third order current harmonics are compensated);
- The total instantaneous power supplied is made constant.

In the case of a non-sinusoidal or unbalanced supply voltage, the only difference is that the supply current will also includes harmonics (Fig2.3), but in practical cases the distortion is negligible.

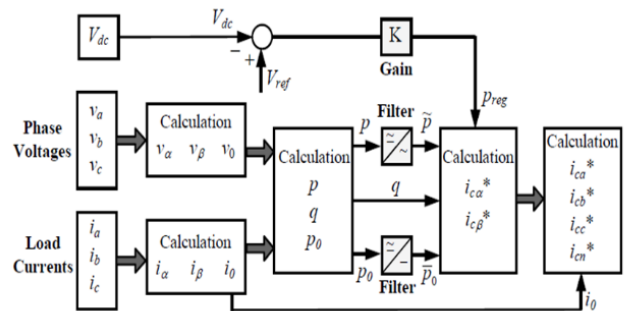


Fig. 3: Calculation for the constant instantaneous power supply control strategy.

The sinusoidal supply current control technique must be used when the voltages are distorted or sinusoidal and unbalanced currents are desired. The block diagram of Fig.2.3 presents the calculations required in this case. When this strategy is used the results, illustrated in Fig.2.4 , are:

- The Phase Supply Currents Will Become Sinusoidal, Balanced, And Become In Phase With The Fundamental Voltages,
- And The Neutral Current Is Made Nearly Equal To Zero (Even Third Order Current Harmonics Are Compensated);

- The Total Instantaneous Power Supplied (P3s) Isn't Made Constant, But It Gives Only A Small Ripple (Much Smaller Than Before Compensation).

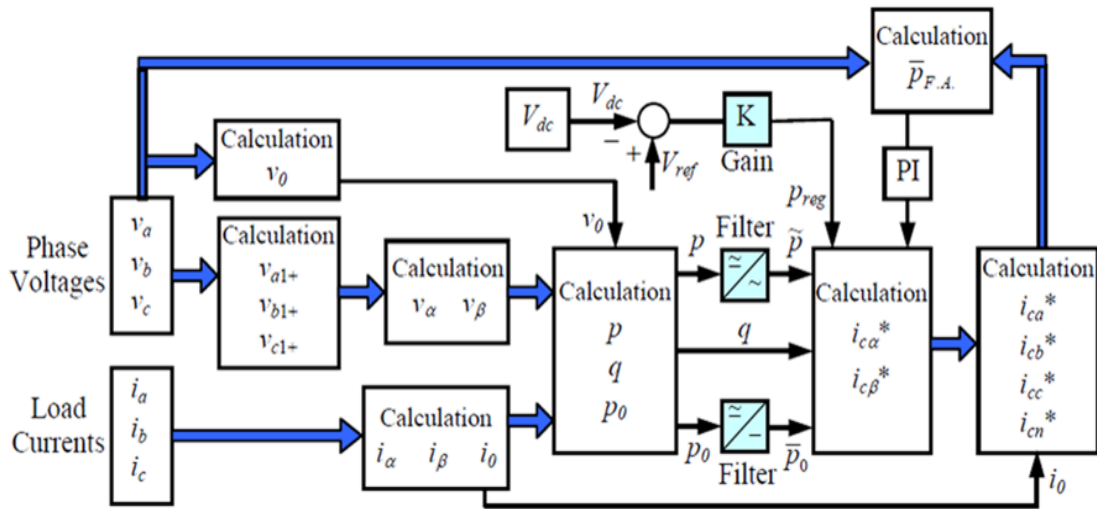


Fig. 4: Calculations for the sinusoidal supply current control strategy.

### III. SIMULINK MODEL

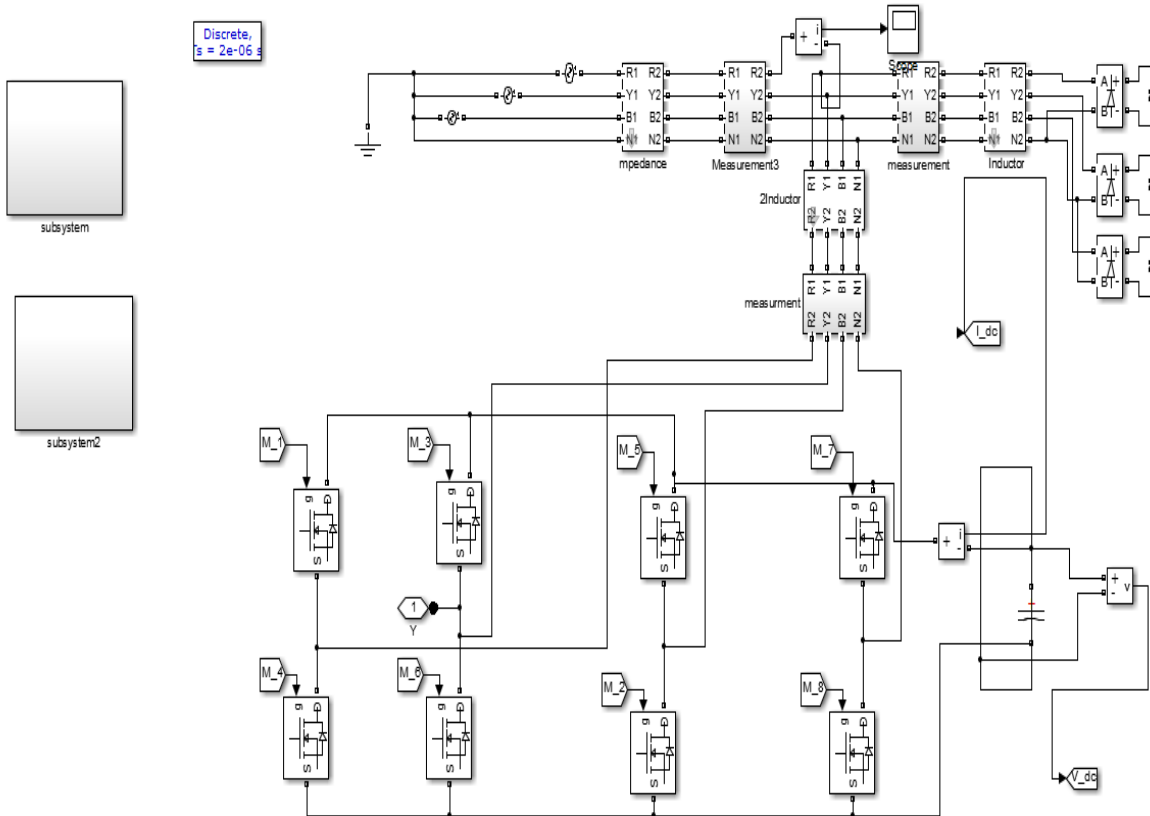


Fig. 5:

### IV. CONTROL CIRCUIT

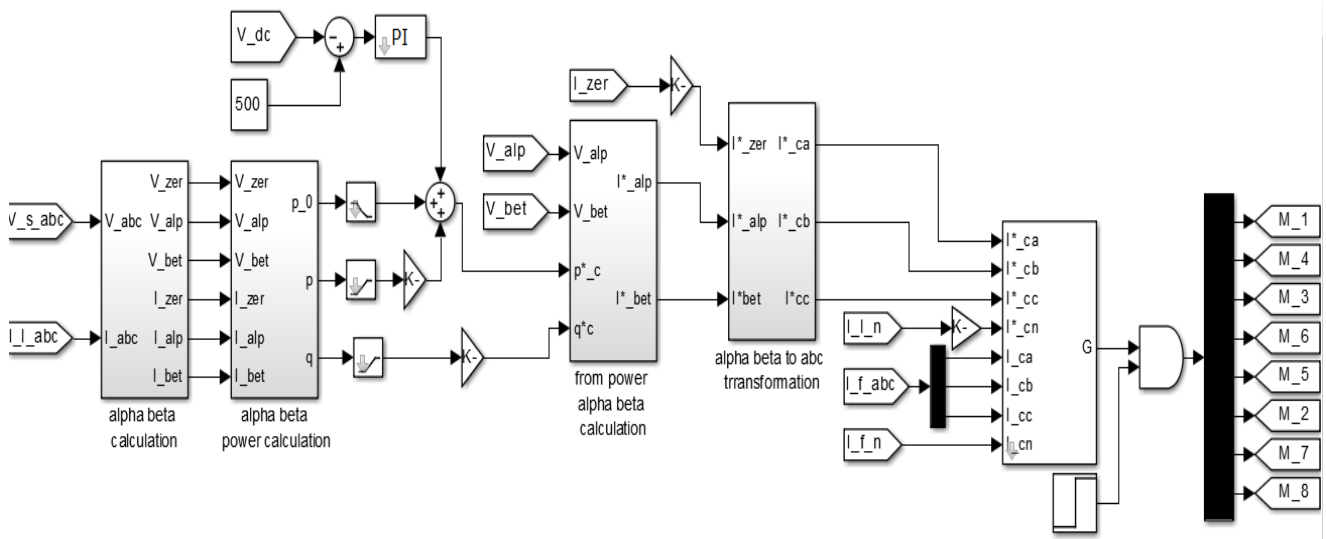


Fig. 6:

V. SIMULATION RESULT

A. 3 Phase Source Voltage And Current Waveform without SAPF:

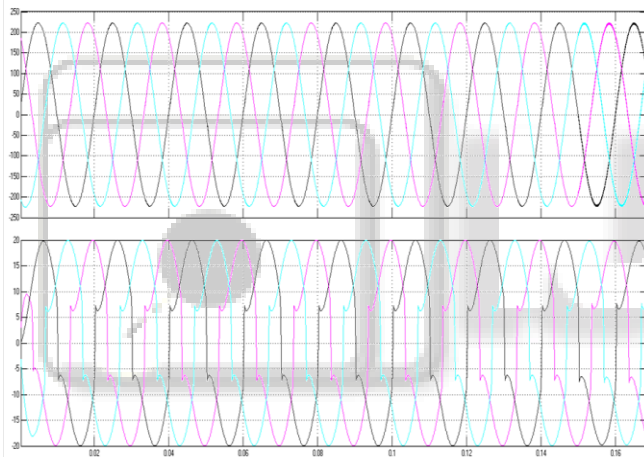


Fig. 7: 3 phase source current with harmonics.

B.  $\alpha\beta 0$  Reference Voltage:

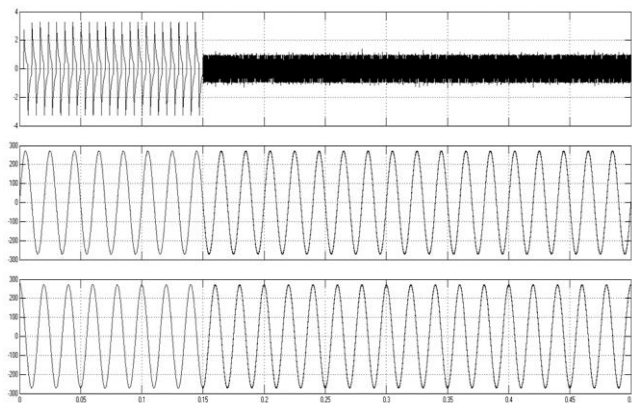


Fig. 8:  $\alpha\beta 0$  reference voltage

C.  $\alpha\beta 0$  Reference Current:

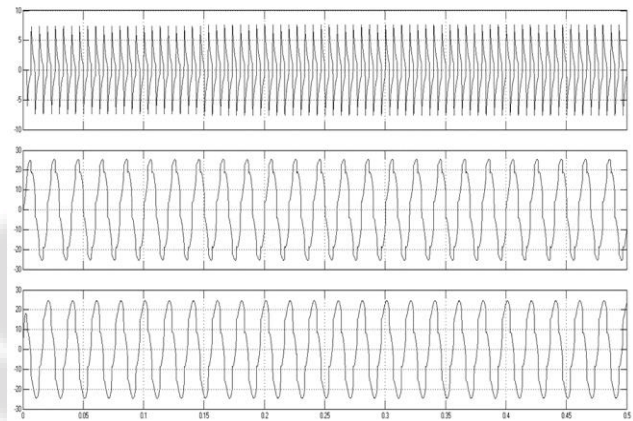


Fig. 9:  $\alpha\beta 0$  reference current.

D.  $\alpha\beta 0$  Reference Power:

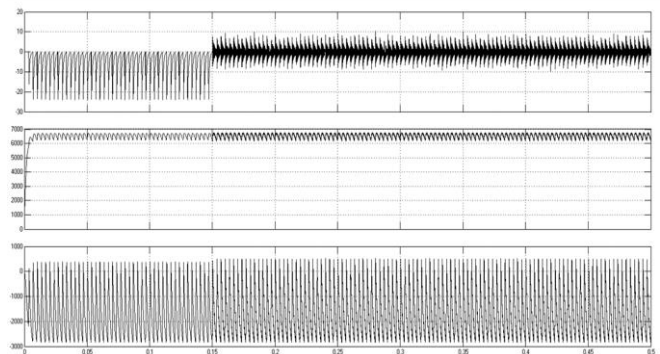


Fig. 10: (a) Zero sequence power (b) Active Power (c)Reactive Power

E. Compensating Current In  $\alpha\beta 0$  Coordinates:

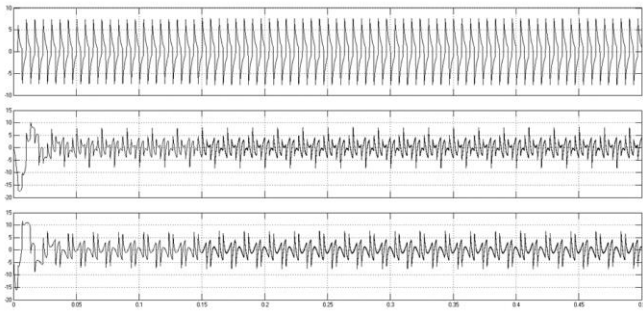


Fig. 11: (a) Zero sequence compensating current. (b)  $\alpha$  sequence compensating current. (c)  $\beta$  sequence compensating current.

F. Compensating Current in  $abc$  Coordinates from  $\alpha\beta 0$  Coordinates:

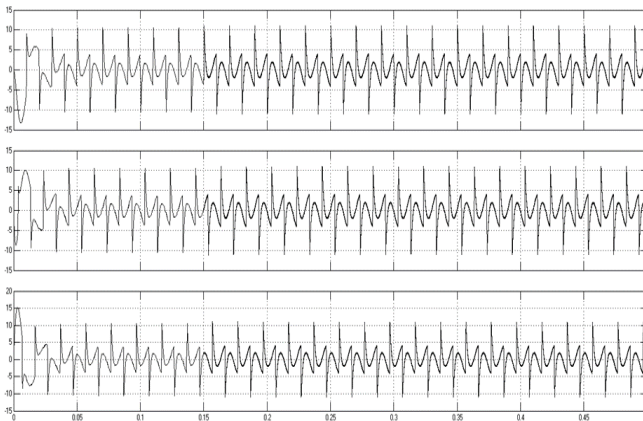


Fig. 12: compensating current in abc coordinate.

G. Current Fed in System:

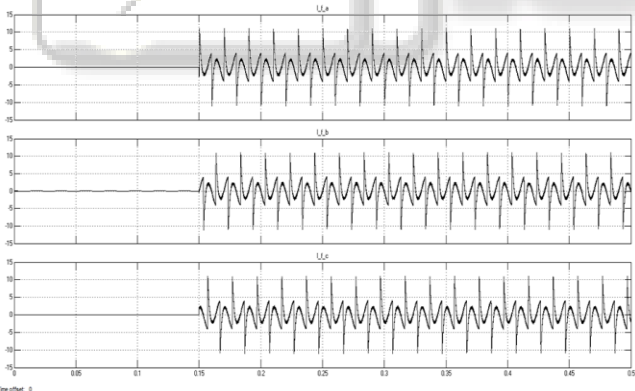


Fig. 13: Compensating Current fed in system.

H. Filtered Source Current:

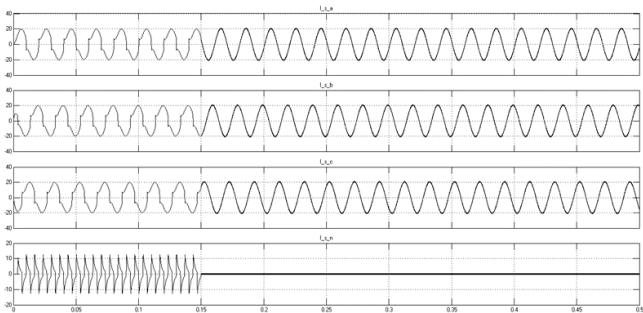


Fig. 14: Current Comparison after & before the SAPF.

I. Source Current Waveform With and Without Harmonics.

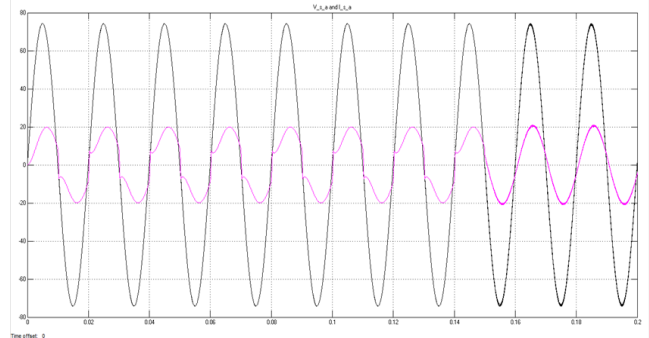


Fig. 15: Source current waveform with and without harmonics.

VI. RESULT

Three phase diode bridge rectifier is simulated in matlab/simulink. Various parameters used for simulation is given in table 6.1. the model was run for 0.5 seconds. In the waveforms it is clearly shown that the harmonics before 0.15 seconds and after 0.15 seconds when filter injects the compensation current, harmonics are eliminated from source current. FFT analysis is done for both the conditions and results are compared.

	%THD
Before SAPF	19.61%
After SAPF	1.03%

Table 1:

From above table it is clear that the harmonics are reduced/compensated to a great extent using this theory i.e. the p-q theory and THD is reduced from 19.61% to 1.04%.

VII. CONCLUSION AND FUTURE SCOPE

From MATLAB/SIMULINK simulation of hysteresis current controller based active power filter of 3 phase diode rectifier, it is found that THD of source current is reduced to 1.04 % from 19.61 % after use of filter. Reactive power required by nonlinear load is completely compensated by active power filter (APF) and power factor at source end becomes almost unity.

Active filters are an up-to-date solution to power quality problems. Shunt active filters allow the compensation of current harmonics and unbalance, together with power factor correction, and can be a much better solution than the conventional approach (capacitors for power factor correction and passive filters to compensate for current harmonics).

This paper presents the p-q theory as a suitable tool to the analysis of non-linear three-phase systems and for the control of active filters.

The implementation of active filters based on the p-q theory are cost-effective solutions, allowing the use of a large number of low-power active filters in the same facility, close to each problematic load (or group of loads), avoiding the circulation of current harmonics, reactive currents and neutral currents through the facility power lines.

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