e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
Volume:03/Issue:06/June-2021 Impact Factor- 5.354 www.irjmets.com

AN ENHANCED SCHEME OF HARMONIC REDUCTION USING OPTIMIZED CONTROLLER IN SHUNT ACTIVE POWER FILTER

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ABSTRACT

Now a day's Active power filters are more essential in power quality improvement by eliminating the harmonics and compensating reactive power in a three phase or single phase circuits caused due to Nonlinear loads. Under different operating conditions, the conventional controllers like hysteresis and Fuzzy based controllers are not giving better results. Hence, in our proposed system Butterfly optimization algorithm is implemented to optimize the performance of the PI controller in the control scheme. Finally, the simulations are carried out and analysis is made to validate the overall performance of the proposed optimized PI tuned SAPF. The result shows the high accuracy and stability under different operating conditions.

Keywords: Power Quality, Shunt Active Power Filter, Total Harmonic Distortion, Butterfly Optimization Algorithm.

I. INTRODUCTION

In recent years, many researches are under gone to improve the power quality by mitigating the harmonics that occurs due to Non-linear Loads like rectifiers, inverters and adaptors etc. This harmonic distortion leads to many harmful effects like damaging the electrical equipment's, causing interference in communication lines, error operation of circuit breakers, fuses etc. Anyway, the Total Harmonics Distortion (THD) must be kept within the limits of international standards like IEEE and IEC. The two types of filters used to suppress the harmonics are Passive filter and Active filter. The principle behind the passive filter is by providing a low impedance path for the harmonic current to flow thereby, the harmonics is eliminated. In this method, few drawbacks such as resonance, large size and fixed compensations are present. Therefore, now a day's harmonics are eliminated using PWM inverters. The proposed Active Power Filter (APF) will eliminate the harmonics by injecting an equal harmonic component to cancel the existing harmonics. Later PWM based Shunt Active Power Filters (SAPF) are preferred because of its better efficiency.

In this study [1], the reduction of THD using SAPF is proposed. It deals with the use of Least Mean Squares (LMS) and Recursive Least Squares (RLS) algorithms. The objective of reducing harmonics is achieved with the help of RLS algorithms and it is found to be faster and better than the LMS algorithm. Design and assessment of SAPF for harmonics elimination using intelligent fuzzy logic current controller is presented in [2]. The results shows that, this controller reduces the harmonics much better compared to conventional controller. Furthermore, a design of SAPF for grid connected Photo Voltaic Systems is introduced in [3].The aim of this study is to eliminate the harmonic currents and compensate the reactive power produced by non-linear loads. The proposed solution has achieved a low THD and a perfect compensation of reactive power that improves the power quality. Moreover in [4] a soft computing technique is introduced to compensate the reactive power. Also in this study, the compensation of harmonic current is performed using adaptive neural fuzzy interface system. A smart ANFIS system will supervise the PID controller which feemd the signal to the SAPF by hysteresis current control. The experimental result reduces the harmonic distortion in non-linear power converter model with improved power factor. According to Zhang et al. [5] a stability analysis is done through the SAPF with a capacitive load for suppressing the particular harmonics and resonance damping. To overcome the instability and to compensate the harmonic current, a control strategy is carried out in SAPF to suppress the harmonics. Moreover in [6], a novel Model Predictive control is implemented for optimal harmonic mitigation. The design and architecture based on hardware and software platform has been presented. The result shows a consistent performance to meet the real time demands.

Furthermore in [7], a control strategy for SAPF is proposed in order to improve the quality of the power distribution system by mitigating the harmonics with the help of different fuzzy systems. The performance of this method has been evaluated in terms of THD and regulation of DC link voltage under different load conditions. Furthermore, an improved hybrid approach for harmonic reduction is described in [8]. Here, the hybrid technique using Enhanced Grasshopper Optimization and ANN helps to improve the quality of power by mitigating the harmonics subject to a minimum THD less than 5%. The effectiveness is this algorithm is the less complexity. A harmonic compensating technique using 4–leg SAPF in a 3 phase 4-wire system is presented in [9]. It has the ability to mitigate the harmonics as well as absorb or generate the reactive power. Additionally, it has the feature of improving the power factor on the supply side. Validations based on THD and neutral current are reported. Xinwen Chen et al. [10] investigated a system that the harmonic compensation and resonance damping is controlled by SAPF with a closed loop system to regulate the terminal voltage. The experiment results of the proposed method could further improve the quality of both terminal voltage and grid currents effectively.

The main objective of this paper is to implement butterfly optimization algorithm along with PI controller for tuning the SAPF inorder to mitigate the harmonic. This method pays superior to the previous includes soft computing techniques like Fuzzy logic, Artificial Neural Network (ANN), and Particle Swarm Optimization (PSO) algorithms. The simulations are carried out in Mat lab simulink environment and THD values are analyzed using Fast Fourier Transform (FFT) analyzer and results are validated. Section II describes the proposed method, control and optimization techniques and its configuration. Section III gives the simulation results. Finally, the result is concluded and reported in Section IV.

II. METHODOLOGY

The main goal of this paper is to improve the operation of Active power filter, which can eliminate the harmonics before affecting the supply system. In order to achieve it, shunt active power filter is designed using voltage source inverter, current controller and reference current generator. Shunt Active Power Filter (SAPF) consists of power electronic converters that utilize power semiconductor devices. In case, if harmonic pollution affects a consumer the controlled Shunt Active Power Filter (SAPF) will inject a compensating current by filtering the unwanted frequency components. The basic block diagram representation of shunt active power filter (SAPF) is given in fig 1.

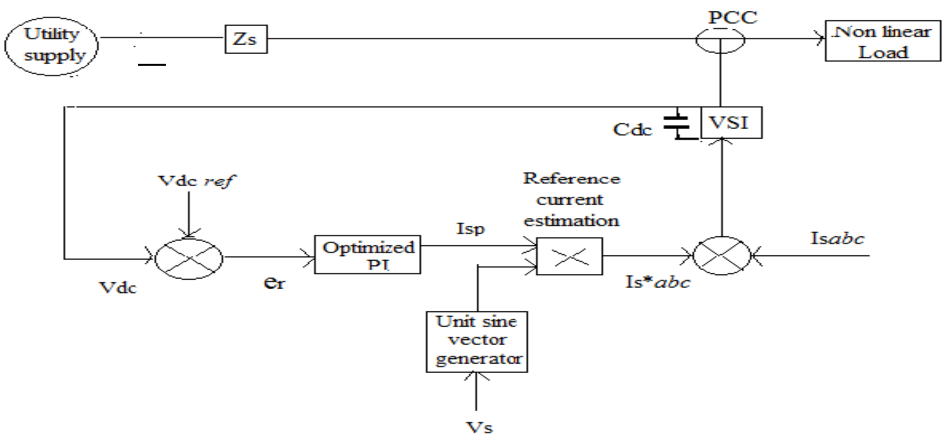

Fig. 1: Block diagram representation of SAPF

2.1 Reference current generation (Instantaneous pq theory)

In this paper, a three-phase instantaneous active and reactive Power Theory (p-q theory) is adopted for the reference current generation to the filter to compromise the harmonics in the system. In order to generate reference currents using instantaneous pq theory, the three phase voltages and currents are transformed from abc frame to αβ0 frame. This method is applicable for any three phase four wire system. The three phase voltage from abc frame to αβ0 frame is done using power invariant or Clarke transformation. The αβ0 transformation is applied in order to separate the zero-sequence components from the abc phase components. Clarke transformation maps the three-phase instantaneous voltages and current in the abc phases into the instantaneous voltages and current on the αβ0 axes as shown in the following equations.

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

The instantaneous three-phase power is given by

$$P_{3\emptyset} = V_\alpha I_\alpha + V_\beta I_\beta + V_0 I_0 = V_a I_a + V_b I_b + V_c I_c \quad (3)$$

$$P_{3\emptyset} = P + P_0 \quad (4)$$

where, P-denotes total instantaneous real power and P_0 -denotes instantaneous power in zero sequence.

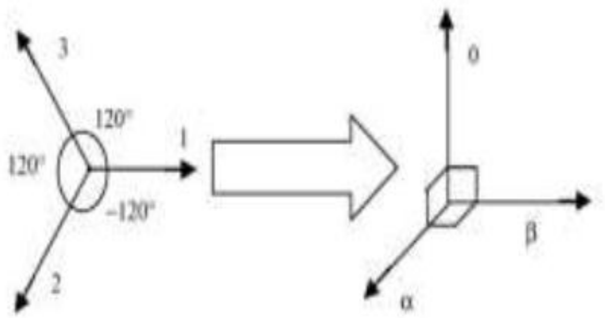

Fig. 2: Transformation of abc coordinates to αβ0 axes

Since we are considering three-phase three-wire system there is no neutral conductor, hence α and β axis contains only positive and negative sequence components. Therefore matrix equation (1) and (2) can be modified as given in the matrix (5) and (6) for threephase three-wire system.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (6)$$

PQ Theory can be applied in three phase four wire systems with a neutral conductor or three-phase three wire systems. The three instantaneous powers are (1) Instantaneous zero-sequence power P_o, (2) Instantaneous real power P, and (3) Instantaneous imaginary power q. Instantaneous powers are obtained from the instantaneous phase voltages and line currents on the αβ0 axes. The values of P, P_o and q can be calculated using equation (7) In this case, we are not considering the neutral terminal therefore P_0 is neglected during the calculation of compensation current in equation (9).

$$\begin{bmatrix} P_0 \\ P \\ q \end{bmatrix} = \begin{bmatrix} V_0 & 0 & 0 \\ 0 & V & V_\beta \\ 0 & V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (7)$$

$$P = \bar{P} + \tilde{P} \quad (8)$$

$$q = \bar{q} + \tilde{q} \quad (9)$$

where, $\bar{P}$ represents the mean value of instantaneous real power in αβ0 frame. $\tilde{P}$ represents the oscillating value of the instantaneous real power in αβ0 frame, $\bar{q}$ denotes the instantaneous imaginary power in αβ0 frame and $\tilde{q}$ represent the oscillating value of instantaneous imaginary power in αβ0 frame.

$$\begin{bmatrix} is\alpha \\ is\beta \end{bmatrix} = \frac{1}{\alpha^2+\beta^2} \begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix} \begin{bmatrix} P \\ q \end{bmatrix} \quad (10)$$

The compensating current of each phase can be derived by using the inverse Clarke transformations as shown below in equation (10).

$$\begin{bmatrix} ica \\ icb \\ icc \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} is\alpha \\ is\beta \end{bmatrix} \quad (11)$$

The compensation current can be derived from above equation and it is used as the reference current in the current controller to generate the gate pulses.

2.2 Design of SAPF

The basic components of SAPF is given below,

- Three phase supply
- Three phase non-linear load
- Reference current generator
- Current Controller
- Voltage source inverter
- Proportional Integral controller

When nonlinear load draws non-sinusoidal current, it consists of fundamental component, reactive component and harmonic components. It is sufficient to estimate the fundamental component as reference current for compensation of harmonic and reactive components. Here, the reference current is computed by controlling the DC capacitor voltage (V_{dc}) in voltage source inverter. After compensation, the load current should become sinusoidal and in phase with the supply voltage. The DC voltage 'V_{dc}' across the capacitor 'C_{dc}' is compared with the reference voltage 'V_{dcref}', and the error signal is processed by optimally tuned PI controller. Now, the response of PI gives the preferred source current 'I_{sp}'. Similarly, the reference current '$I_{sabc(ref)}$'is obtained by multiplying amplitude of 'I_{sp}' with phase angle of three phase unit sine vectors. Finally, the reference current '$I_{sabcref}$' is compared with the actual source current 'I_{sabc}', and the difference is given to generate switching pulses of PWM-based Voltage Source Inverter.

2.3 PI Controller

Normally, the PI controller operate as a feedback control loop to calculate the error signal by measuring the difference between the reference and the output of a system. In this case, the power output of battery is fixed as the set point. The tuning parameters of a PI controller are the Controller gain Kc and Proportional gain Kp. PI controller is used in such applications to avoid the noise and large disturbances during the operation process.

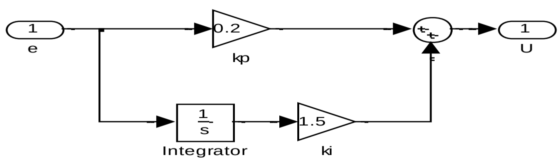

Fig. 3: PI Controller

2.4. Butterfly Optimization Algorithm

Butterfly optimization algorithm (BOA) is a recently introduced algorithm which is inspired the natural foraging and mating behavior of butterflies. BOA performs both global search as well as local search operations to achieve the optimal solution for the problem. The movement of butterflies is based on two search (1) Global search and (2) Local search. Under global search, the movement of a butterfly is towards the fragrance of another butterfly. And if any butterfly fails to sense the fragrance, it moves randomly to a new position in the search space and this process is called local search. The optimization procedure takes place in all the three phases such as (1) Global search phase (2) Local search phase and (3) Solution evaluation phase. The BOA framework is based on the emitted fragrance from the butterflies, this fragrance helps the butterflies in searching the food as well as searching the mating partner.

Algorithm of BOA

Step 1: Initialize the population of butterflies as X = (x_1, x_2...x_n) for n number and dimension d.

Step 2: Define the values for the parameters a, c, and p

Step 3: Estimate the intensity of stimulus (I_i) at x_i

Step 4: While: Final result is not met

do: For each b in X ; Evaluate fragrance f for b

End for: Identify the best b from each b in X

do: Generate the random number.

Step 5: If random number < p, then perform global search by moving towards the butterfly with most fragrance.

Else: Local search using random search is performed.

End if

End for: Update the a value

End While: Optimal results are achieved.

III. RESULTS AND DISCUSSION

3.1 System Configuration

A 3 phase, 100V, 50Hz supply with nonlinear load including diode rectifier parallel to RL load and Shunt Active Filter are developed in MATLAB/SIMULINK using SIM power System toolbox.

Table.1: Specification of Design Parameters

Parameters	Values
Source Voltage	100V
Source Resistance	0.1Ω
Source Inductance	0.15mH
Line Resistance	0.4Ω
Line Inductance	3.55mH
Load Resistance	60Ω
Load Inductance	20mH
DC Capacitance	25μF
Reference DC Voltage	220V
Filter Inductance	15mH
K_p	0.2
K_i	1.5

3.2 Output Results

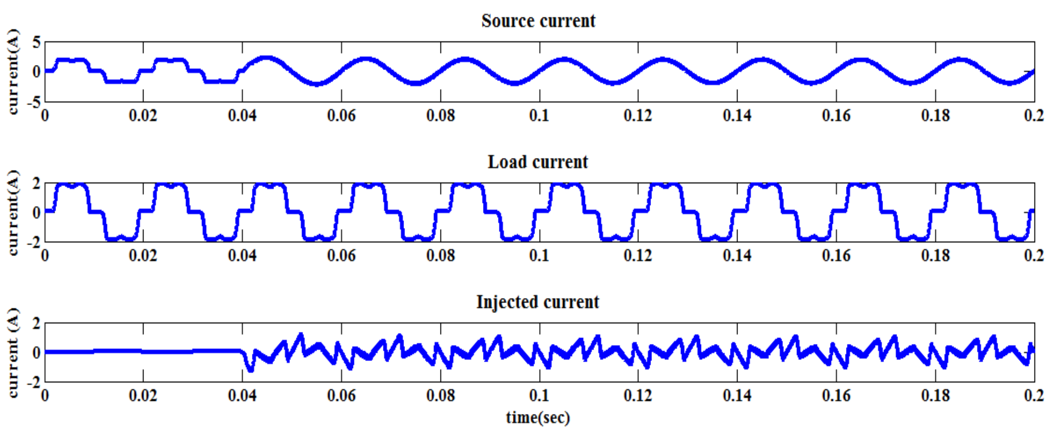

Fig. 4: Output of SAPF using PI+BOA controller I_S, I_L and I_J

e-ISSN: 2582-5208
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Table 2: Performance assessment of SAPF for PI, PI+BOA, TS-fuzzy and PI+ANN

Performance indices	Type of controller				
	Without SAPF	PI controller	BOA+PI	TS-Fuzzy	PI+ANN
K_P	-	0.2	0.0189	0.2	-
Ki	-	1.5	6.7661	9.32	
V_{dc-Ts} (ms)	-	40	35	-	-
M_P (%)	-	50	36	-	-
THD (%)	26.25	2.15	1.95	2.9	2.34

Case 1: Dynamic performance of SAPF

In order to analyze the dynamic performance of SAPF, the load resistance R_L is varied, by keeping the other parameter unvaried. Settling time at each R_L values is reported. Also it is noticed that for all change in R_L conditions, the THD is maintained within the International standards.

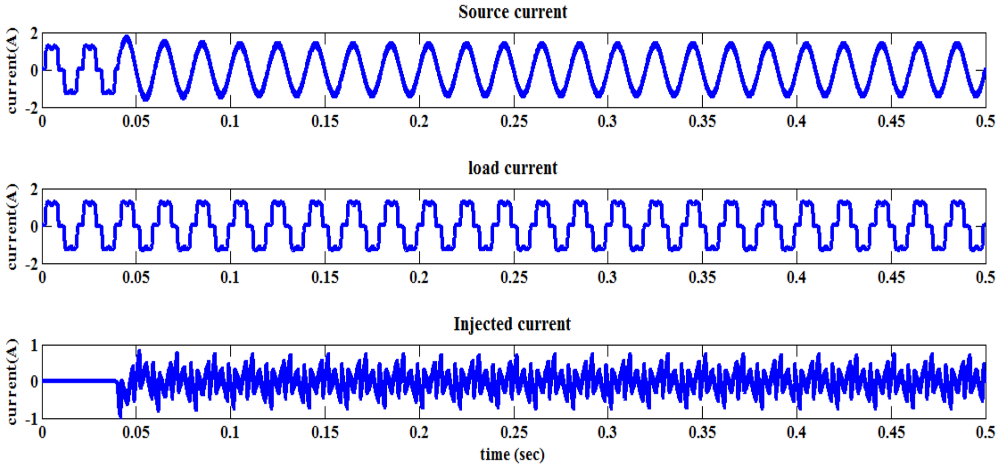

Fig. 5: Output of SAPF using PI+BOA controller for increasing R_L

Table 3: Performance comparison of PI and PI+BOA controller for variation in R_L

$R_L(\Omega)$	PI controller		PI+BOA controller	
	V_{dc}-Ts(ms)	THD (%)	V_{dc}-Ts(ms)	THD (%)
40	38	1.59	35	2.15
50	40	1.96	38	1.77
60	42	2.34	40	1.70

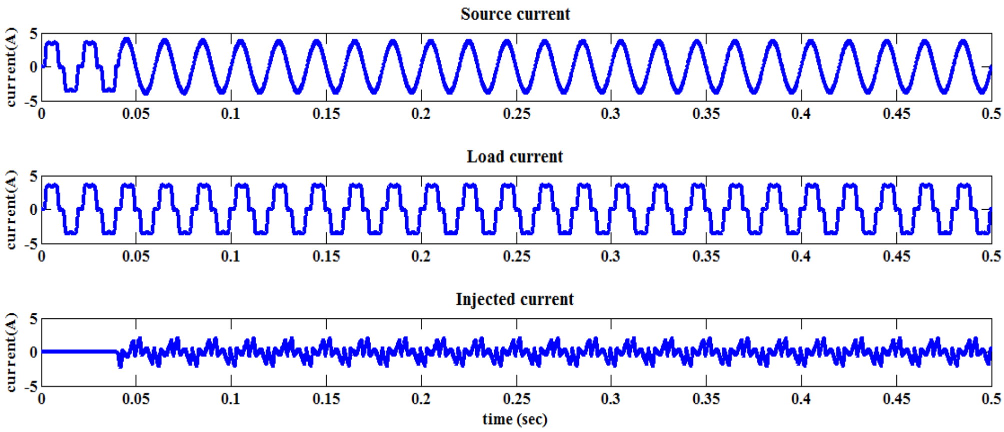

Fig. 6: Output of SAPF using PI+BOA controller for decreasing R_L

Case 2: Transient Response of SAPF

While analyzing the transient response as a sudden disturbance caused by changing load inductance L_f and capacitance Cdc. by varying L_f from 3.5mH to 15mH and C_{dc} varied from 25μF to 30μF,still the settling time remains the same. When BOA- PI is implied the settling time of $V_{dc\text{-}Ts}$ decreases from 40ms to 35ms.

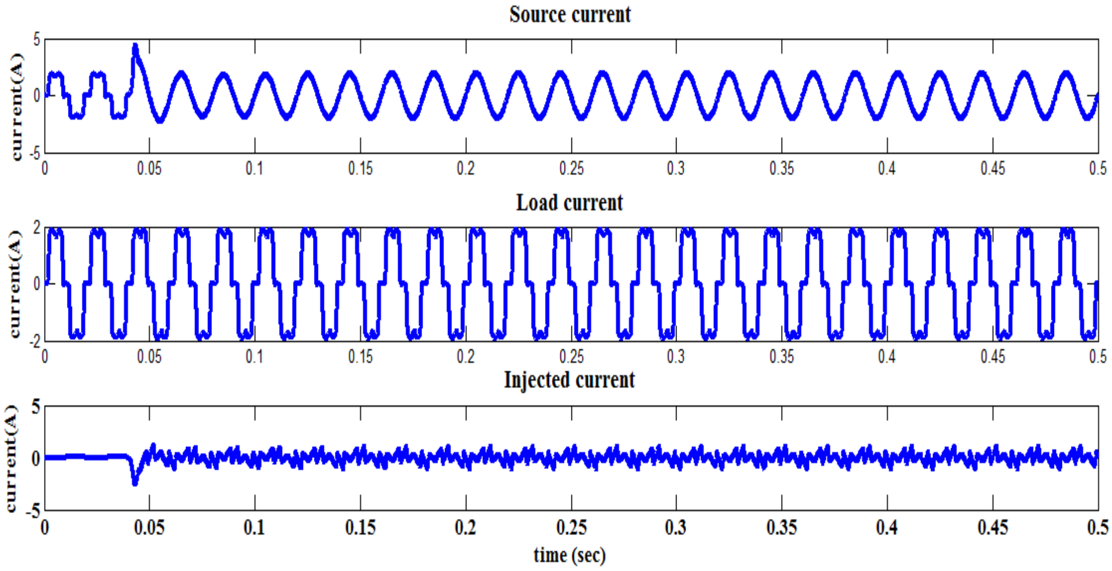

Fig. 7: Output of SAPF using PI+BOA controller for varying L_F

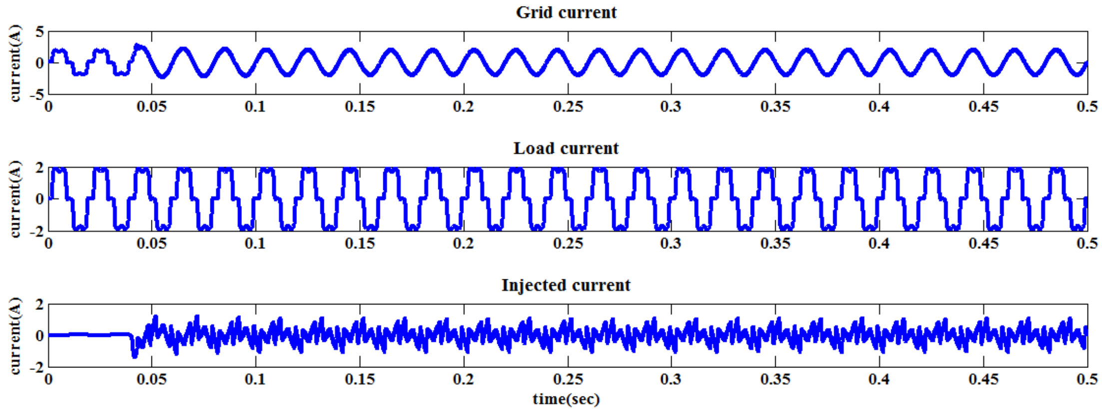

Fig. 8: Output of SAPF using PI+BOA controller for varying C_{dc}

Table 4: Performance comparison of PI and PI+BOA controller for variation in L_f

L_f (mH)	PI controller		PI+BOA controller	
	V_{dc}-Ts (ms)	THD (%)	V_{dc}-Ts (ms)	THD (%)
3.5	40	5.44	35	6.54
6.6	40	3.71	35	4.42
15	40	1.96	35	2.03

Table 5: Performance comparison of PI and PI+BOA controller for variation in C_{dc}

C_{dc} (μF)	PI controller		PI+BOA controller	
	V_{dc}-Ts (ms)	THD (%)	V_{dc}-Ts (ms)	THD (%)
25	40	1.96	35	2.00
27	40	1.84	35	1.98
29	40	1.81	35	2.03

IV. CONCLUSION

Now a day's harmonics and reactive power requirements cause a major problem in maintaining the power quality due to non-linear loads, power electronic devices, energy efficient lightings etc. In order to solve this problem shunt active power filter provides a better solution. Therefore a three-phase shunt active power filter tuned with controller is developed which is used to compensate harmonic current and reactive power. In this chapter, PQ theory is used to generate reference current to control SAPF. Comparative performance analysis between PI controller and BOA based PI are simulated experimentally and the results are reported. In addition, the dynamic response and transient response analysis using BOA+PI technique are also carried out to validate the ability of the filter in compensating under different load impedances. In the above analysis BOA based PI is proved a better response in terms of harmonic reduction of the source current. When compared to other controllers BOA based PI show a stable and robust performance.

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