Research Paper

Particle Swarm Optimization For Power Quality Improvement Based on Shunt Active Power Filter

A. Balakrishna	M-tech scholar Student, Department of Electrical and Electronics Engineering, Gudlavalleru Engineering College, Gudlavalleru, AP, India.
B. Mahesh Babu	Assistant Professor, Department of Electrical and Electronics Engineering, Gudlavalleru Engineering College, Gudlavalleru, AP, India.
Dr. L. Ravi Srinivas	Professor, Department of Electrical and Electronics Engineering, Gudlavalleru Engineering College, Gudlavalleru, AP, India
Dr. S. S.Tulasi Ram	Professor, Department of Electrical and Electronics Engineering, JNTU college of Engineering, Hyderabad, AP, India

ABSTRACT
In a three phase distribution system nonlinear load causes harmonics and reactive power problems, for compensating harmonics and reactive power the shunt active power filter (SAPF) controlled by (PQ-PLL) synchronization with optimized (PI-PSO) is used. The instantaneous Power Theory-Phase locked Loop (PQ_PLL) Synchronization determines reference current signals of the SAPF, the SAPF circuit is operated by the Particle Swarm Optimization (PI-PSO). This (PI-PSO) optimization is capable of controlling DC side capacitor voltage and estimating reference current. Hysteresis Current Controller (HCC) is used to generate switching signals for the VSI. The Shunt active power filter controlled by PI-PSO gives better results for harmonic minimization. The proposed shunt APF maintains the THD well within IEEE-519 standards. This proposed technique is implemented in MATLAB 7.9 / Simulink software.

1. INTRODUCTION

Ac power supply feeds different kinds of linear and nonlinear loads in commercial and industrial applications. The non-linear loads produce harmonics in the system .The current harmonics generated by, nonlinear loads causes problems in power systems particularly in consumer products like overheating, capacitor burning, and motor vibration. Dynamic and flexible solutions to the power quality problems have been examined by researchers in power system (peng, 1998). Usually, passive filters are used to compensate the reactive power and suppress the harmonic problems, but these passive filters are having some drawbacks; such as resonance, large in size, weight, and are limited too few harmonics. Recently, Active Power Filters (APF) or Active Power-Line Conditioners (APLC) developed for harmonic reduction and reactive power compensation. The active power filter topology can be connected in series for voltage harmonic compensation and in parallel for current harmonic compensation. Most of the industrial applications need current harmonic compensation, so the shunt active filter is popular than series active filter. The shunt active power filter has the ability to keep the mains current balanced and sinusoidal after compensation regardless of whether the load is non-linear or unbalanced .The controller is the heart or primary component of the APLC system. The shunt active with several topologies(jou,1995;Akagi et al., 1983; Huang and Wu 1999; Asiminoaei et al.,2006; Clerc and Kennedy, 2002; Aredes, 1996) is generally used instead of passive filters to improve the power quality by injecting compensating currents (Berbaoui et al., 2010; Peng, 1998; Gu and Xu,2003; Kennedy and Eberhart, 1995; Karsli et al., 2003) a very great for the compensation not only of current harmonics produced by distorting loads(Mattavelli,2001).

This paper describes the feasibility of PI along with PQ_PLL synchronization controller based shunt active power filter for the harmonics and reactive power compensation due to the non-linear and unbalanced loads. The fundamental component of the reference current is extracted from load current using PI-PSO and dc-side capacitor voltage of the inverter is continuously maintained constant. The voltage source inverter switching signals are generated from hysteresis band current regulation techniques. The proposed concept for shunt APLC system is validated through extensive simulation under nonlinear load conditions. A comparative assessment of without PI-PSO Controller, with PI, PI-PSO has been done.

The present work spot lights on novel control method for com-

pensating current which is known as PI_PSO optimized PI controller using particle swarm algorithm. The optimization of PI regulator's parameters is crucial (Gu and Xu, 2003). In this study, the problem of design current PI controller is formulated as an optimization problem. The problem formulation assumes in this study, two performance indexes are the integral absolute error of step response and maximum overshoot as the objective function to determine the PI control parameters for getting a well performance under a given system. We propose an optimization method for SAPF in the aim to improve the compensation performances and reduce harmonic distortion through electrical lines distribution under all voltages conditions. These objectives are obtained by minimizing the fitness function.

The proposed solution algorithm based on Particle Swarm Optimization (PSO) technique that is based on a metaphor of social interaction. It searches a space by adjusting the trajectories of individual vectors, called 'particles', as they are conceptualized as moving as points in multidimensional space. The individual particles are drawn stochastically to words the positions of their own previous best performances and the best previous performances of their neighbors. Since its inception, two famous improvements have been introduced on the initial PSO which attempt to strike a balance between two conditions. The first one introduced by Shi and Eberhart (1998) uses an extra 'inertia weight' term which is used to scale down the velocity of each particle and this term is typically introduced by Clerc and Kennedy (2002) involves a 'constriction factor' in which the entire right side of the formula is weighted by a coefficient. Their generalized particle swarm model allows an infinite number of ways in which the balance between exploration and convergence can be controlled.

2. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling.PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called p_{best}. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called *lbest*. When a particle takes all the population as its topological neighbors, the best value is a global best and is called *gbest*.

The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its p*best* and *lbest* locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations.

In past several years, PSO has been successfully applied in many research and application areas. It is demonstrated that PSO gets better results in a faster, cheaper way compared with other methods. Another reason that PSO is attractive is that there are few parameters to adjust. One version, with slight variations, works well in a wide variety of applications. Particle swarm optimization has been used for approaches that can be used across a wide range of applications, as well as for specific applications focused on a specific requirement. For example:

The ith particle is represented as   in the d-dimensional space. The best previous position of the ith particle is recorded and represented as:

$$Pbesti = (Pbesti1, pbesti2, … Pbestid) ……….. (1)$$

The index of best particle among all of the particles in the group is gbest. The velocity for particle I is represented as .The modified velocity and position of each particle can be calculated using the current position of each particle can be calculated using the current velocity and the distance from pbest-id. To gbest-id as show in the following formulas (Gaing, 2004):

$$v_{i,m}^{(t+1)} = wv_{i,m}^{(t)} + c_1 rand(\square)(pbest_{i,m} - X_{i,m}^t) +$$
$$c_2 rand(\square)(gbest_m - X_{i,m}^{(t)}) …………………………(2)$$

$$X_{i,m}^{(t+1)} = X_{i,m}^{(t)} + V_{i,m}^{(t+1)} ………………………..……(3)$$

i=1, 2………. n

m=1, 2……………… d

Where:

n=Number of particles in the group

d=Dimension

t=pointer of iterations (generations)

$V_{i,m}^{(t)}$=Velocity of particle t at iteration t

W=Inertia weight factor

C1, c2=Acceleration constant

Rand ( ) =Random number between 0 and 1

$V_{id}^{(t)}$=Current position of particle I at iterations

P_{best}=Best previous position of the ith particle

G_{best}=Best particle among all the particles in the population

3. ESTABLISHMENT OF OBJECTIVE FUNCTION
In this study, the procedure of PSO Algorithms is used A production initial population is the first step of PSO. The popula-

tion is composed of the chromosomes that are real codes. The corresponding evaluation of a population is called the "fitness function". It is the performance index of a population (Berbaoui et al., 2010) [2]. The fitness value is bigger and the performance is better. The fitness function is defined as follow;

$$F = f_{os} + f_{ias} \quad ……………………………… (4)$$

The Optimized parameters objects are proportional gain Kp and integral gain Ki, the transfer function of PI controller is defined by:

$$G_c(s) = Kp + \frac{Ki}{s} \qquad (5)$$

The gains Kp and Ki of PI controller are generated by the PSO algorithm for a given plant. As shown in fig, the output u (t) of PI controller is

$$u(t) = Kpe(t) + Ki \int e(t)dt ……………………(6)$$

For a given plant, the problem of designing a PI controller is to adjust the parameters Kp and Ki for getting a desired performance of the considered system. Both the amplitude and time duration of the transient response must be kept within tolerable or prescribed limits, for this condition, two key indexes performance of the transient control system. These key indexes are integral absolute control error and maximum overshoot. The maximum overshoot is defined as follows

$$f_{os} = y_{max} - y_{min} \quad \text{(7)}$$

Where Y_{max} characterize the maximum value of Y and Y_{as} denotes the steady-state value. The integral of the absolute magnitude of control error is written as:

$$f_{ias} = \int_0^\infty |e(t)|dt ………………………………...…… (8)$$
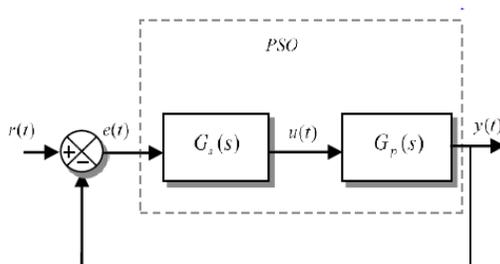
Fig 1. PI control system

4. PROPOSED CONTROL STRATEGIES
PI-Controller:
The proposed PI control scheme for the active power filter is the DC side capacitor voltage is sensed and compared with a reference voltage. This error   at the *nth* sampling instant is used as input for PI controller. The error signal is passed through Butterworth design based Low Pass Filter (LPF). The LPF filter has cut off frequency at 50 Hz that can suppress the higher order components and allows only fundamental components. The PI controller is estimate the magnitude of peak reference current *I*max and control the dc-side capacitor voltage of voltage source inverter. Its transfer function is represented as

Where,

$$(H) \frac{\displaystyle \int}{\displaystyle f} = k_p + \frac{Ki}{s} ………………………………………………… (9)$$

is the proportional constant that determines the dynamic response of the Dc-side voltage control and K_i is the integration constant that determines it's settling time. The proportional integral controller is eliminating steady state error in the DC-side voltage

4.1 OPTIMIZED PI CONTROLLER
In this study, we are present the SAPF as controlled plant; the SAPF diagram is shown in fig 1[2].The inconvenience of the conventional PI controller is its incapability to improve the tran-

sient response of the system. The conventional PI controller form as follow

Where:

$$y(t) = k_p * e(t) + k_i \int_0^t e(t)dt \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Y=the control out put
Kp= Proportional gain
Ki=Integral gain

The control output is fed to inverter HCC signal generator. The difference between the injected current and the reference current, Kennedy and Eberhart (1995) are known by error signal. The design of the conventional PI controller dependent on the knowledge of the expert, in this study the trail and error method has been used to determine the parameters Kp and Ki.

The key contribution in this study is the proposed approach to find the optimal PI parameters fig 2. In order to ensure that the study-state error of the system is reduced to minimum. The objective of an optimal design of currents PI controller for given plant is to find a best parameters Kp and Ki of PI control system such that the performance indexes on the transient response is minimum.

Fig.2: Control of injected current using optimized PI controller
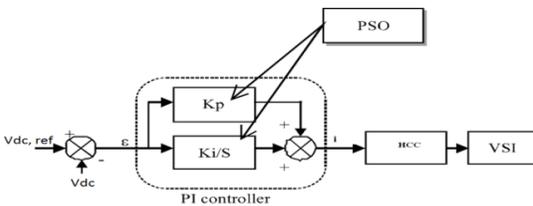
4.2 THE EVOLUTION PROCEDURE OF PSO FLOWCHART

First, the swarm is initialized; i.e., the position and velocity of particles are randomly initialized within the search space. After that, the objective values of particles are calculated. The first objective values and positions are automatically the personal best values and the personal best positions. The global best value and the global best position are set to the objective value and position of the particle with the best objective value in the entire swarm. After the initial step, all particles are moved to their new positions using Equation (2) all objective values are evaluated again. Personal best positions are updated for particles that have a new objective value that is better than the old personal best value. The global best position is updated if there is any particle with an objective value that is better than the old global best value. Again, all particles are moved to their new positions using Equation (2). The algorithm continues with evaluating the objective values and updating the positions, the personal best values, the personal best positions, the global best value, and the global best position. The algorithm stops if a termination criterion, such as a limit on the number of iterations, is reached.
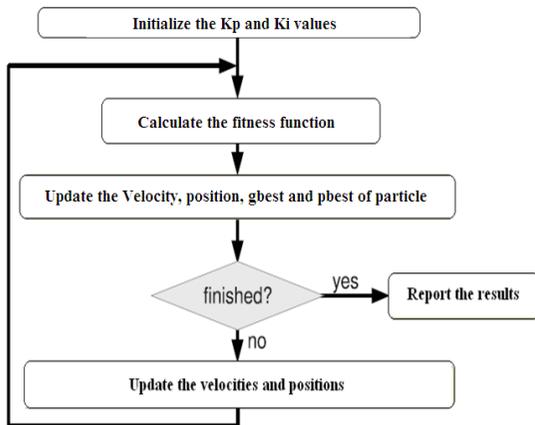

Fig 3 Flowchart of PSO

5.1 PQ-PLL SYNCHRONIZATION

The identification theory that we have used on Shunt APF is known as instantaneous power theory or PQ theory. It is based on instantaneous values in three-phase power systems with or without neutral wire and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms. The PQ theory consists of an algebraic transformation (Clarke transformation) of the three phase voltages and current in the ABC coordinates to the coordinates

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \ldots\ldots\ldots (11)$$

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} ica \\ icb \\ icc \end{bmatrix} \ldots\ldots\ldots (12)$$

The instantaneous power is calculated as:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v\alpha & v\beta \\ -v\alpha & v\beta \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \ldots\ldots\ldots\ldots (13)$$

The harmonic component of the total power can be extracted as:

$$PL = \overline{P} + \hat{P}L \ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Where:

$\overline{P}$ = The DC component

$\hat{P}L$ = Harmonic component

Similarly

$$qL = \overline{q}L + \hat{q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Finally, we can calculate reference current as:

$$\begin{bmatrix} i^*_{fa} \\ i^*_{fb} \\ i^*_{fc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \ldots\ldots\ldots (16)$$
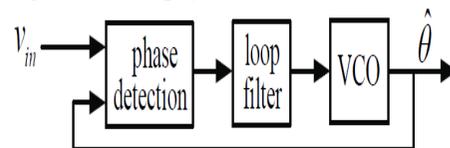
Here

$$\begin{bmatrix} p \\ q \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \hat{p} \\ \hat{q} \end{bmatrix} \ldots\ldots\ldots\ldots (17)$$

The phase locked loop circuit takes care of distorted and unbalanced voltages; it determines automatically the system frequency and the fundamental positive sequence components of three phase line voltages and *Vcb*. The outputs of the PLL synchronizing circuit are *plla*, *pllb*, *pllc* of the three phase templates. This PLL is based on the three-phase instantaneous active power expression, it's written as.

The most widely accepted synchronization solution to a time-varying signal can be described by the basic structure shown in block diagram, in Fig. 4, [13]

Fig.4 Closed-loop synchronization structure

Where the difference between phase angle of the input and that of the output signal is measured by the phase detection (PD) and passed through the loop filter (LF). The LF output signal drives the voltage-controlled synchronizing PLL based on the instantaneous real and imaginary power theory (PQ-PLL) is presented to maintain synchronization in presence of sub harmonics, harmonics, and negative sequence unbalances. Rolim etal. Point out that PLL may fail in tracking the system voltage during startup under some adverse conditions, and oscillations caused by the presence of sub harmonics can pull the stable point of operation synchronized to the sub harmonic frequency. In order to settle these problems, a robust digital synchronizing PLL based on the instantaneous real and imaginary power theory (PQ-PLL) is presented to maintain synchronization in presence of sub harmonics, harmonics, and negative sequence unbalances. The block diagram of PQ-PLL is shown in Fig 5. [13]
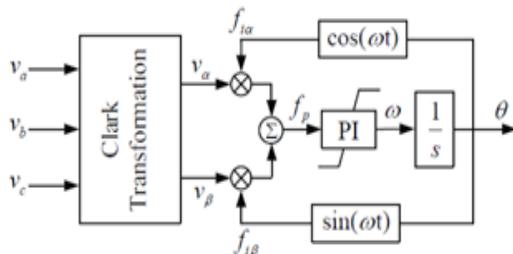
Fig 5.Block diagram of PQ-PLL

5.2 SYSTEM CONFIGURATIONS

The Principle function of the Shunt Active Power Filter (SAPF) is to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line. A multiplicity of methods is used for instantaneous current harmonics detection in active power filter such as FFT (Fast Fourier Technique) technique, instantaneous p-q theory and synchronous PQ-PLL reference frame theory. The main circuit of SAPF control is shown in fig 6. [3]

The reference current consists of the harmonic components of the load current which the active filter must supply. This reference current is fed through a controller and then the switching signal is generated to switch the power switching devices of the active filter such that the active filter will indeed produce the harmonics required by the load (huang and Wu, 1999). Finally, the AC supply will only need to provide the fundamental component for the load, resulting in a low harmonic sinusoidal supply.

The system parameter values are; line to line voltage is 440V; system frequency (f) is 50 Hz; Source impedance of RS, LS is 1Ω; 0.1 mH; filter impedance of Rc, Lc is 1Ω; 1mH; Diode rectifier RL, LL load: 20Ω; 100mH; Dc side capacitance (cdc) is 1200µf; Reference voltage (VDC, ref) is 400 V Power devices used are IGBTs with diodes [1].
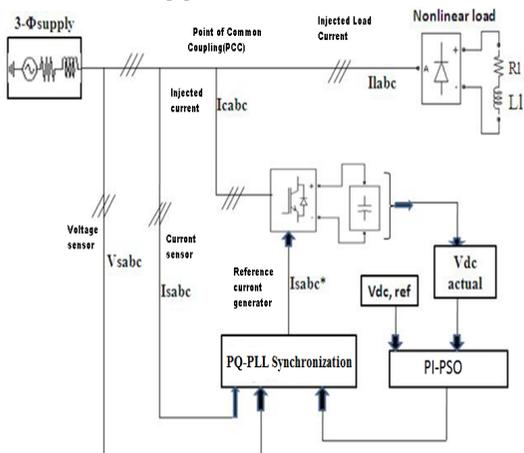
Fig 6: Basic circuit
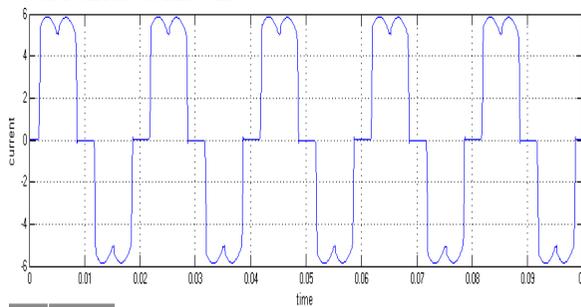
6. SIMULATION RESULTS

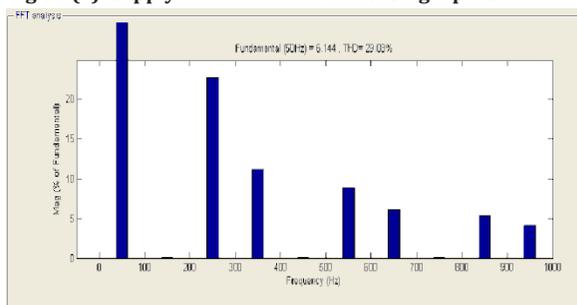**Fig 6.1(a). Supply current wave form of single phase-A**
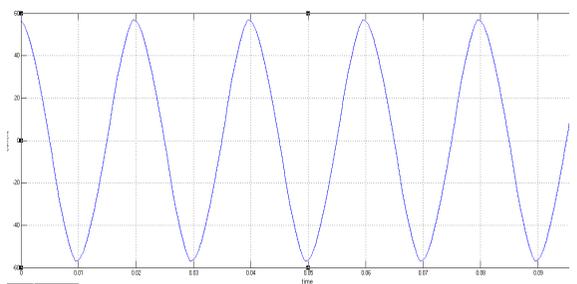
Fig6.1(b).THD for Supply current

Fig 6.2(a).Supply current using SAPF with PI controller for phase-A
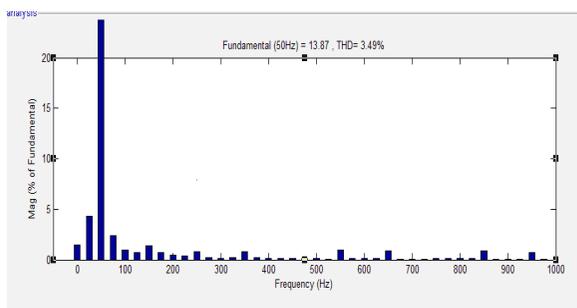
Fig 6.2(b).THD for supply current using SAPF with PI controller
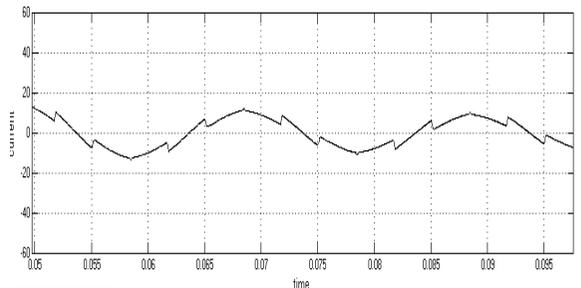
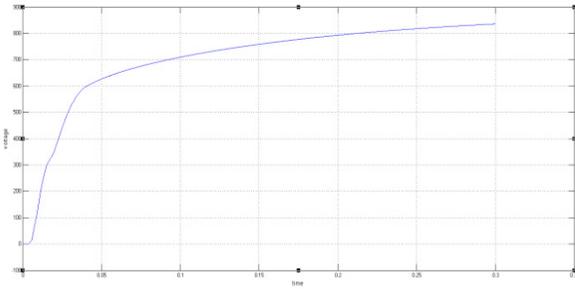**Fig6.2(c).Compensated current for SAPF with PI controller**

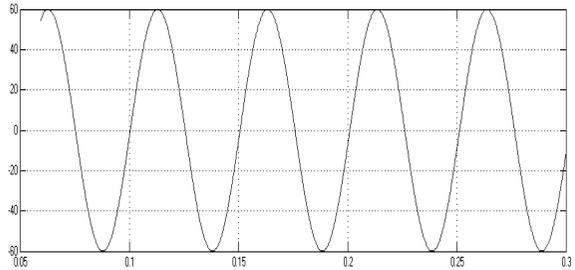**Fig6.2(d).Vdc capacitor voltage with PI controller**

Fig 6.3(a).Supply current using SAPF with PI-PSO controller for phase-A
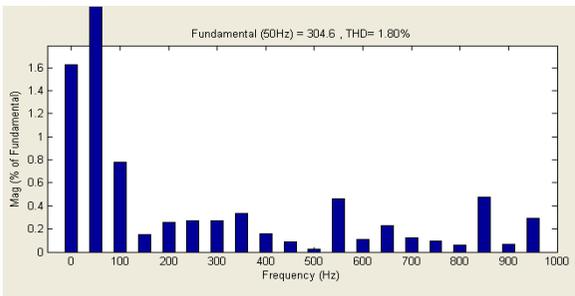

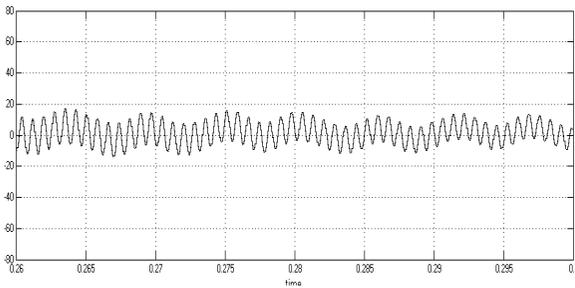**Fig 6.3(b) Supply current using SAPF with PI-PSO controller**
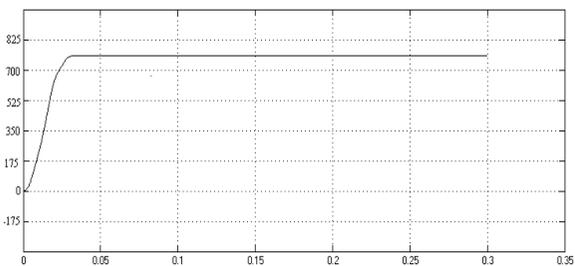

Fig6.3(c) Compensated current for SAPF with PI-PSO controller

Fig6.3(d)Vdc capacitor voltage with PI-PSO

	WITH OUT SAPF	SAPF WITH PI CONTROLLER	SAPWITHPI-PSO
THD	29.07	3.37	1.80
SETTLING TIME	-	0.25	0.03

Comparison table: 1

7. CONCLUSION
In this paper amalgamation of the new approach based on particle swarm optimization improves the power quality and system performance. The PQ-PLL synchronizing circuit is the controller for SAPF. The PI or PI-PSO ensures that the dc-side capacitor voltage is nearly constant. The PQ-PLL synchronizing circuit assists that the active filter to function even under distorted voltage or current conditions. The results presented indicate that the PSO has a good sharp for finding the optimal fitness function and has proved its effeteness in finding optimal parameters Kp and Ki for current-SAPF controller, it can be seen that after SAPF with PSO-PI controller runs, the current total harmonic distortion to 3.37 to 1.80.

According to the previous results the proposed controller (PI-PSO) has good dynamic performance and robustness. The control performance of a PI, PI-PSO optimized technique controlled. APLC system is verified and compared various Parameters that are presented graphically this approach brings down the THD of the source current.

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