Power quality Enhancement using Particle swarm optimization based shunt active power filter

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Abstract—The shunt active power filter is one compelling arrangement is utilized for reducing the source current harmonics distortion in nonlinear load distribution system. The synchronous reference frame control algorithm utilized to creating current controlled reference signals. The acquired reference control signals are compared with hysteresis controller for better switching of shunt active power filters. Generally SRF with PI controlled shunt active power filter are used to compensation of harmonic. But, they won't give better results to bigger variety loads. In these papers a particle swarm optimization (PSO) system is proposed for better tuning of PI values of SRF with PSO-PI controlled shunt active power filter. The simulation results without and with conventional PI and furthermore with PSO-PI is analyzed for nonlinear load distribution system.

Keywords— Shunt active power filter, PI controller, PSO-PI controller, Harmonic compensation, synchronous reference frame theory

I. INTRODUCTION

In presently, the vast number utilization of power electronic and nonlinear devices causes harmonic in distribution system [1]. The harmonic distortion may cause power quality issues such as, low productivity, poor power factor and influence the neighbouring communication lines [2-3]. These issues are repaid by using passive filters. However, these passive filters are huge in size, consistent compensation and low over loading capacity. To keep away from these disadvantages a shunt active power filters with voltage source inverter (VSI) is created for current source harmonics mitigations and for power factor correction [6]. The triggering signals for the VSI based shunt active power filter are gotten from the proposed with PI controlled synchronous reference frame control algorithm (SRF) [7-10]. The DC interface voltage of VSI is normally controlled by utilizing conventional PI control technique. In conventional technique obtained PI values are not agreeable. In this case, by utilizing PSO control program the obtained PI values are exact and keep up the constant dc bus voltage when compared with the conventional PI controller [11, 12]. PSO is an iterative based enhancement method. It is actualized dependent on the behaviour of bird's flock and fish school. In PSO, the particles have with certain velocity and position in a space is taken from the social conduct of creatures. Here population is called swarm. Swarm comprise of number of particles. Every particle in swarm looking through the best position individually encounters and speaks with their neighbouring best position in swarm insight and gets the position and updates their position and velocity. The particle is seen in the best approach to show signs of improvement and better looking position. The updating of velocity of every particle is their very own encounters and in addition involvement with their neighbours. PSO method is increasingly proficient tackling nonlinear, non differential and high dimensional issues [13].

In this paper a VSI based shunt active power filter is implemented. Here the Proportional & Integral values of the of PI controller for the DC link voltage is controlled by utilizing PSO program rather than conventional PI control for better harmonic reduction and power factor enhancement. The simulation results with PI and PSO-PI is analyzed in MATLAB/SIMULINK software.

II. SHUNT ACTIVE POWER FILTER

Fig-1. Shows the system setup of three phase, three wire non linear distribution system load with the shunt active power filter is proposed.

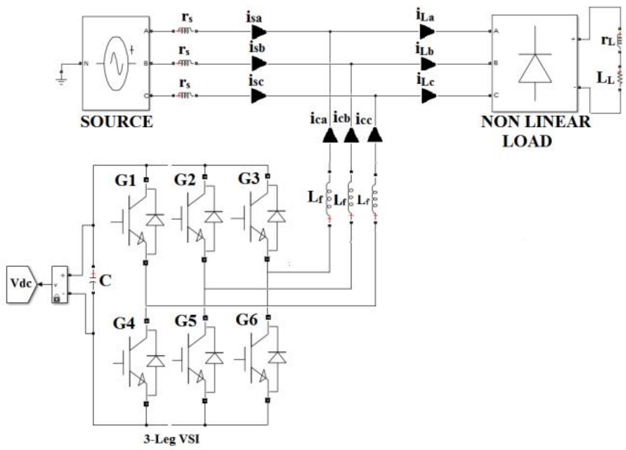

Fig-1. Shunt Active Filter

The nonlinear load introduces current harmonics disturbance at the PCC. The harmonics disturbance is eliminated by connecting shunt active power filter. The shunt active power filter comprises of 3-Leg voltage source inverter with dc link capacitor. The voltage source inverter comprises of 6 IGBT switches with anti parallel diodes. The gate signals to IGBT's are get from the proposed synchronous reference frame control circuit. The filter inductance L_f is utilized for smoothing the injected compensating currents. software.

III. Control Strategy

Fig -2 shows the control diagram of SRF theory. The switching signals for VSI obtained from the control algorithm for harmonic compensation under nonlinear load condition.

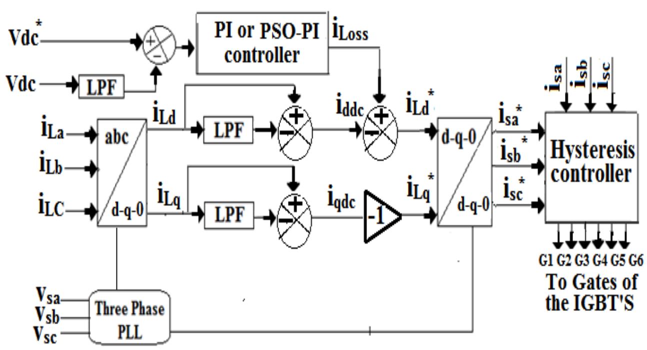

Fig-2.Control Strategy

The non linear load currents (i_{La}, i_{Lb}, i_{Lc}) comprise of active, reactive and harmonic currents. The harmonic and reactive currents are divided, for mitigation of harmonics [16, 17]. It incorporates changing over the prompt into two phase stationary d-q-0 frame from three phase load current utilizing park's equation (1).

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \cos wt & \sin wt \\ -\sin wt & \cos wt \end{bmatrix} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (1)$$

Where, wt is referred as the transformation angle, *coswt* and *sinwt* is acquired from the PLL block for synchronization of current and voltage.

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} i_{ddc} & i_{dac} \\ i_{qdc} & i_{qac} \end{bmatrix} \quad (2)$$

The i_{Ld} and i_{Lq} are active and reactive current instantaneous values of current. Each components value consists of average and oscillating valves of load current. as in eq (3) and (4).

$$i_{Ld} = i_{ddc} + i_{dac} \quad (3)$$
$$i_{Lq} = i_{qdc} + i_{qac} \quad (4)$$

i_{Ld} consists average component of $i_{d\,dc}$ and $i_{q\,dc}$ values. iLq are consist of oscillating values $i_{d\,ac}$ and $i_{q\,ac}$.
By utilizing filter, the oscillatory current separate, the reactive current and average active component given in the eq (5) and (6).

$$i_{Lq} = i_{qdc} \quad (5)$$
$$i_{Ld} = i_{ddc} \quad (6)$$

From, Fig-2. the PI or PSO-PI controller output current is i_{Loss} is applied to average of active reference current of i_{ddc} component in the d-q frame of d-axis, to keep up the DC interface constant voltage. Then, resultant active reference current component is given in eq (7).

$$i_{Ld}^{*} = i_{ddc} + i_{Loss} \quad (7)$$

The direct (Active) and quadrature (Reactive) active reference current segment (i_{Ld}^{*}), (i_{Lq}^{*}) is utilized for mitigation of harmonics.

By using inverse park's Equation, the direct and quadrature component of current (i_{Ld}^{*}, i_{Lq}^{*}) which are changed into a-b-c frame (8).

$$\begin{bmatrix} i_{sa}^{*} \\ i_{sb}^{*} \\ i_{sc}^{*} \end{bmatrix} = \begin{bmatrix} \sin wt & \cos wt & 1 \\ \sin\left[wt - 2\pi/3\right] & \cos\left[wt - 2\pi/3\right] & 1 \\ \sin\left[wt + 2\pi/3\right] & \cos\left[wt + 2\pi/3\right] & 1 \end{bmatrix} \begin{bmatrix} i_{Ld}^{*} \\ i_{Lq}^{*} \\ i_{Lo}^{*} \end{bmatrix} \quad (8)$$

The acquired three phase reference currents (i_{sa}*, i_{sb}*, i_{sc}*) are contrast with the original mitigating filter current in the band controller of hysteresis, for accurate turn of IGBT's of VSI.

IV. Voltage Regulation of DC Link

The quality and execution of shunt active power filter depends on the compensating reference current, where in voltage control of dc link is an important factor. According to the compensating current, the voltage of dc-link (Vdc) is both either decrease or increase. For appropriate operation of VSI at specific reference value, the dc side of the inverter should be kept constant. So as to managing or keeping up dc-interface controller voltage constant is connected to the direct axis component of current (i_{ddc}) in the rotating frame theory. These are the following two controllers have been compared and added.

- PI controller
- PSO-PI controller

A. PI Controller

Fig-3(a). indicates the block diagram of PI Controller. The source supply want to deliver the current loss reference component (i_{LOSS}) along with the current active reference component (i_{Ld}). At the nth sampling instant, i_{LOSS} current is obtained by correlate the dc bus voltage V_{dc}* reference with the actual dc bus voltage V_{dc} of VSI.

$$V_{de(n)}=V_{dc*(n)}-V_{dc(n)} \qquad (9)$$

The obtained error signal $V_{de(n)}$ is applied to a PI controller for find out the loss reference component(i_{Loss}) at nth sampling instant is expressed as

$$i_{Loss(n)}=i_{Loss(n-1)}+k_{pd}(V_{de(n)}-V_{de(n-1)})+k_{id}V_{de(n)} \qquad (10)$$

Here the k_{pd} and K_{id} are the proportional and integral gains of PI controller. The qualities are given k_{pd} = 0.2, k_{id} = 10.4. The i_{Loss} current component is summed to the direct axis active reference component (i_{Ld}) for controlling the active reference component of current (i_{Ld}*). The evaluated reference current component is correlateing with the original mitigating filter current in hysteresis controller for accurate turn on VSI of IGBT's.

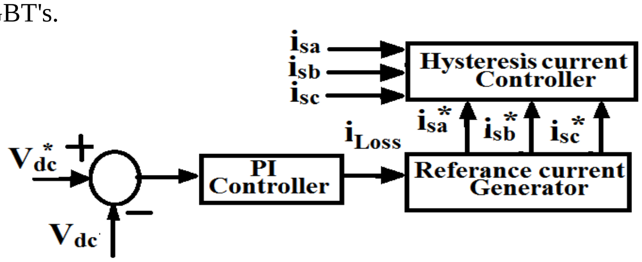

Fig-3(a). Block diagram of PI controller..

B. PSO-PI controller

Fig-3(b). Shows the proposed PSO-PI controller. The actual voltage of dc link capacitor is equal with the dc voltage reference. The error signals are processed through the PSO-PI controller. For keep up the dc-link voltage constant, the output of PSO-PI controller is summed to the resultant compensating current fundamental active current component which are compared in hysteresis band with the actual sensed compensating filter current, which results in error signal. The error signal decides the activity of VSI. The PSO method is increasingly straightforward, better understating, ease computational calculation and get exact neighbourhood and overall best qualities [13]. The PSO iterative method is understands by using following steps

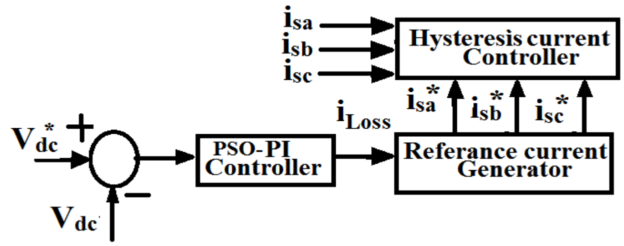

Fig -3(b). Block diagram of PSO-PI controller.

Iterative algorithm

Step-1: Set the population size, number of iterations, constants of w, c1, c2 and random numbers r1, r2. Check the current position of each particle in population.

Step-2: Initialize the each particle in population with position (x), and velocity (v).Set iteration count=0

Step-3: evaluate the fitness function of each particle and select the local best position (PLbest) of each particle is in its own current position.

Step-4: select the Global best position (Gbest), and its position is calculated from Global best fitness = min (Local best fitness).

Step-5: Update the velocity and position of each particle in swarm. The updated velocity and position for the next iteration is expressed as

$$v_i^{n+1} = w \cdot v_i^n + c_1 \cdot r_1 \cdot \left(xpbest_i - x_i^n\right) + c_1 \cdot r_1 \cdot \left(xgbest_i - x_i^n\right) \quad (11)$$

$$x_i^{n+1} = x_i^n + v_i^{n+1} \qquad (12)$$

Where v_i^{n+1} is the i[th] particle velocity at K[th] iteration, x_i^n is the i[th] particle position, K[th] iteration, w is the weight c_1 is the acceleration coefficient of cognitive component ,c_2 is the acceleration coefficient of social component, r_1 and r_2 random variables varied from 0 to 1,w is the inertia constant. Normally the value of w is 1. From the different empirical researches, it has been proposed that the two acceleration constants should be C1=C2=2.

Step-6: Set the iteration count by i+1. Calculate the current fitness function of each particle. Check the Current fitness function < local best fitness if yes than set local best fitness = Current fitness.

Step-7: Check the Current Global fitness function < Global best fitness if yes than set Current Global fitness function = Global best fitness.

Step-8: Repeat the procedure of step-4, 5 and 6. Up to maximum number of iteration is reached as motioned in step-1 or check the global best position through algorithm. If there is no improvement in algorithm than stop the algorithm where there is no improvement. From the both the controllers the PSO-PI controller provided the better response and improve the behaviour of shunt active power filter.

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V. Results and Discussion

The proposed shunt active power filter is implemented in MATLAB/SIMULINK software by utilizing SRF algorithm with PI and PSO-PI controller. The results are verified under nonlinear load condition. The model is utilized for harmonic mitigation and power factor enhancement at the PCC. The simulation results with PI and PSO-PI controller is additionally analyzed. The performance of shunt active power filter is analyzed for the following cases. Here the three phase wave form is followed by A, B, C phase sequence.

- Non Linear load without shunt active power filter
- Shunt active power filter with PI Controller
- PSO-PI controlled shunt active power filter
- Total harmonic distortion analysis
- Comparison of DC-link voltage (PI &PSO-PI controller).

A. Non Linear load without shunt active power filter

The Connection of three phase nonlinear load, to the distribution system introduces harmonic in source current waveforms. The harmonics not just influence the source and furthermore influence other loads connected to the same source. The source voltage wave form in per phase as shown in Fig-4(a), the source and load harmonic current wave forms in per stage as observed in Fig 4(b) and 4(c). And furthermore the source and load current harmonic current wave form in three phase as shown in Fig 4(d) and 4(e).

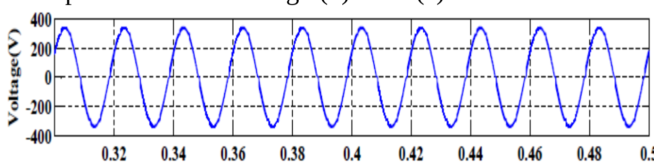


Fig-4(a)

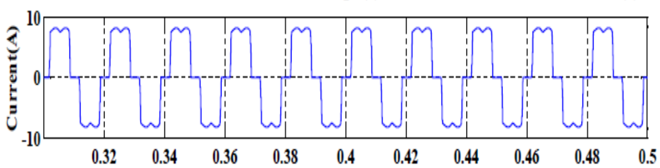


Fig-4(b).

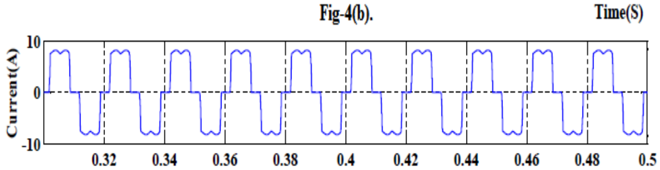


Fig-4(c)

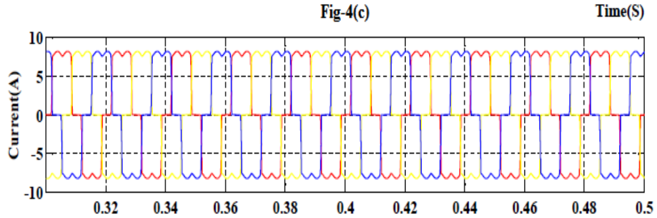


Fig-4(d).

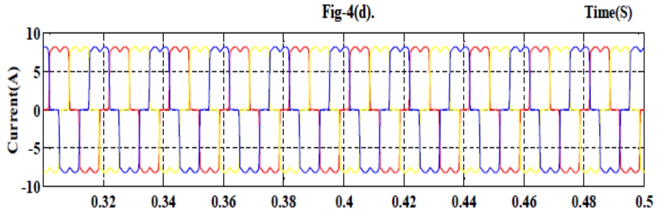


Fig-4(e).

Fig 4-(a). Source voltage wave form, (b). Source current wave form, (c). Load current wave form, (d).Three phase source current waveform, (e). Three phase load current waveform, Under Nonlinear load distribution system without shunt active filter.

B. Shunt active power filter with PI Controller

The SRF with PI controlled shunt active power is connected at the distribution system as shown in Fig-(1), the shunt active power filter is adding the necessary measurement of current for mitigation of harmonics of current source. The voltage of DC-link is controlled with the PI controller. The mitigated waveforms of current source in per phase as observed in fig-5(b). Fig 5(c) indicates the load current waveform. The injected compensating current is shown in fig-5(d). Fig-5(e). Is the compensated source current in three phase. Fig-5(f) is the three phase injected compensating current. Fig-5(f) shows the controlled DC-link voltage wave form.

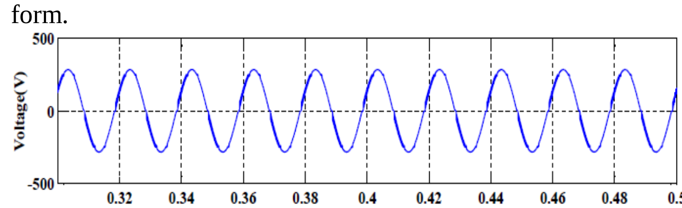


Fig-5(a).

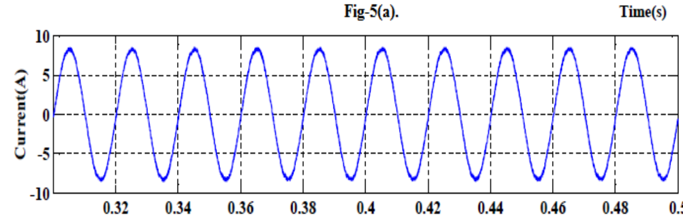


Fig-5(b).

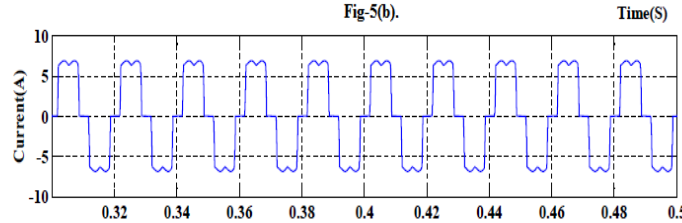


Fig-5(c)

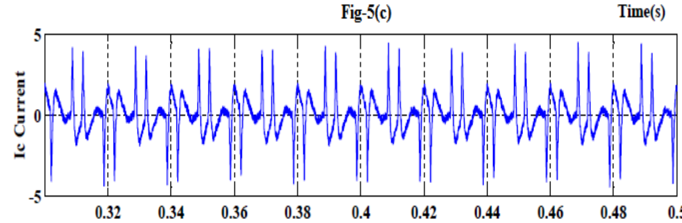


Fig-5(d).

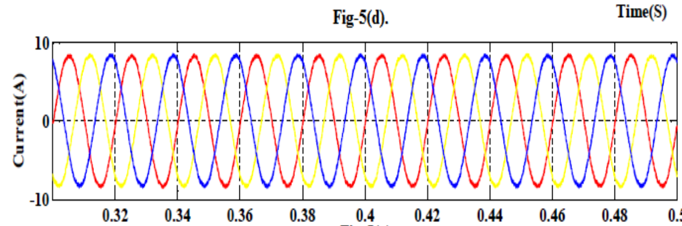
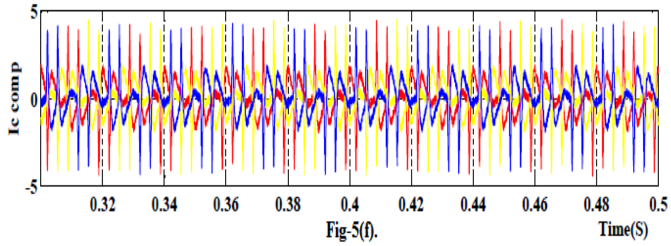


Fig-5(e)



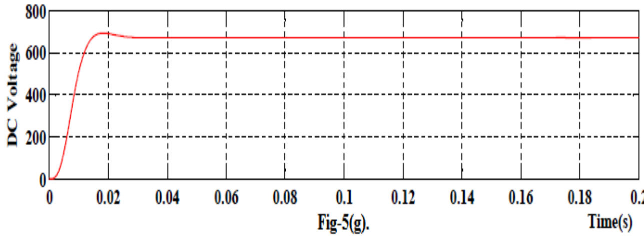
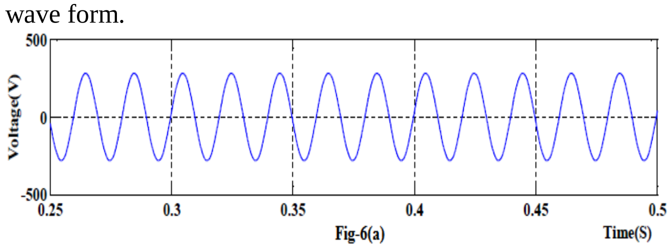
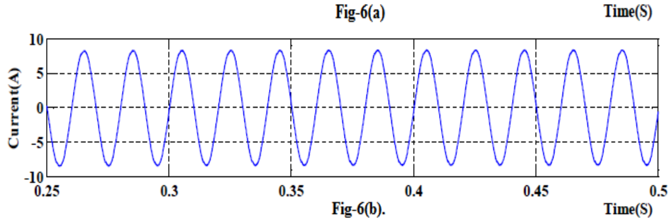


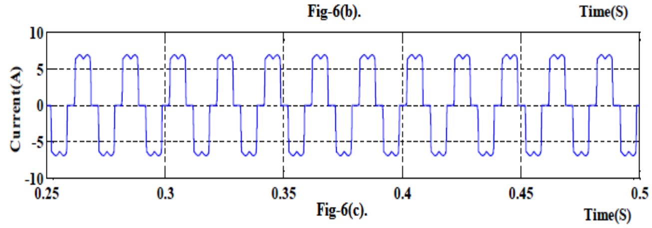
Fig 5-(a).Per phase source voltage wave form, (b). Per phase compensated source current wave form, (c). Per phase Load current wave form, (d). Per phase injected compensating current waveform, (e).Three phase source current waveform, (f). Three phase injected compensated current waveform, (g).DC-link voltage waveform, Under nonlinear load distribution system with PI controlled shunt active filter.

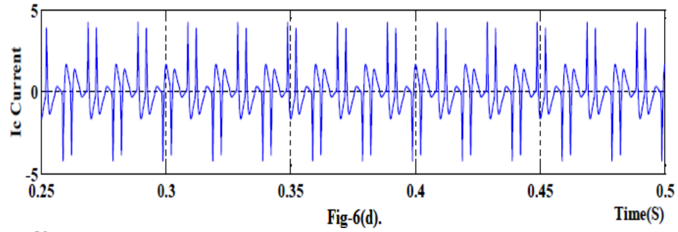
C. PSO-PI controlled shunt active power filter

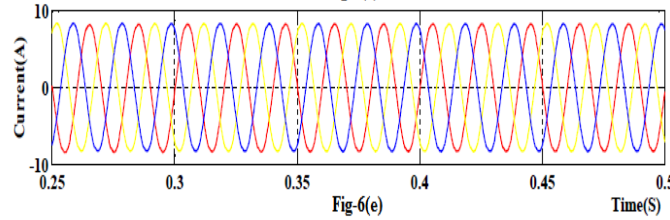
The SRF controlled shunt active power filter is connected to the system, applying amount of power for mitigation current source harmonic problems. The DC-interface voltage is controlled with the PSO-PI controller. From the comparison with the PI controller, the PSO-PI controller given better power factor enhancement and harmonics and the waveforms are observed in fig-6. The waveforms of compensated source current in per phase as shown in fig-6(b). Fig 6(c) indicates the load current waveform. Fig-6(d).shows the injected current wave shape. Fig-6(e). Shows the compensated source current in three phase and fig-6(f). Is the injected compensating current in three phase. Fig-6(g) shows the DC-link voltage wave form.

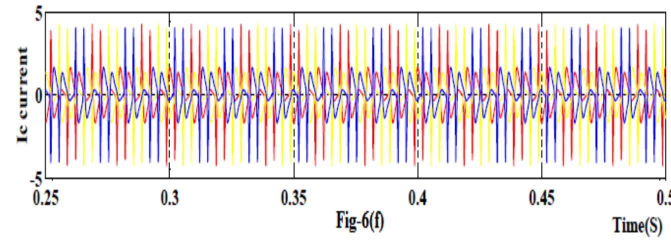












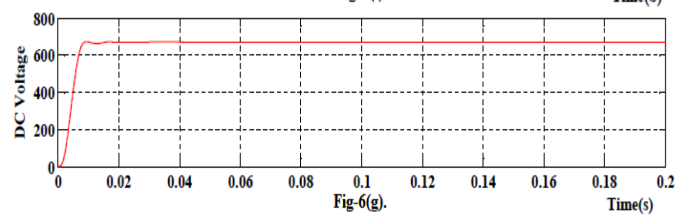


Fig.6-(a). Source voltage per phase wave form, (b). Per phase compensated source current wave form, (c). Per phase Load current wave form, (d). Per phase injected compensating current waveform, (e).Three phase source current waveform, (f). Three phase injected compensated current waveform, (g).DC-link voltage waveform, Under nonlinear load distribution system with PSO-PI controlled shunt active filter.

D. Comparison of DC-link voltage (PI &PSO-PI controller)

The dc-link voltage wave form is compared with PI and PSO-PI controller as shown in fig-8. As compared to PI controller, it states that the settling and transient time of PSO-PI controller is better.

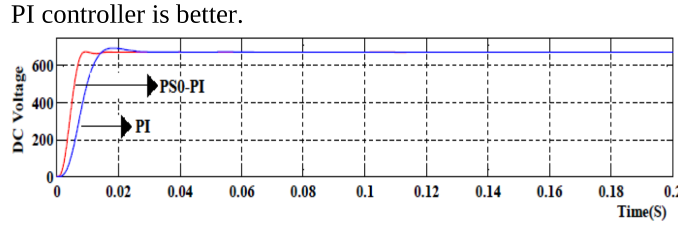


Fig-8. Voltage of DC link comparison with PI and PSO-PI controller.

VI. Conclusion

In this paper, the execution of shunt active power filter has been examined by utilizing the synchronous reference frame control theory for the compensation of harmonics and power factor enhancement for three phase three wire non linear load of distribution system. The simulation result for the proposed system is investigated and contrasted independently using PI and PSO-PI controller. The voltage of dc link is kept up consistent for under all disturbance conditions with the two controllers. The two controllers providing good compensation, however PSO-PI controller giving predominant execution under nonlinear load conditions. The simulation results are acquired in MATLAB/SIMULINK programming. It shows that the obtained PI values using PSO calculation gives greater system dynamic reaction and hence it enhances transient state and power quality as compare with the ordinary PI controlled shunt active power filter.

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