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Design of optimal pi controller using particle swarm optimization for power quality

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***Abstract*—This paper presents an application ofParticle Swarm Optimization (PSO) to Shunt Active filter for power quality improvement. Synchronous Reference Frame method is employed for the calculation of reference current generation using d-q conversion. The main objective is the reduction of Total Harmonic Distortion (THD) of source current. The present work describes the optimal design parameters of PI controller to maintain the dc link voltage constant using PSO.A MATLAB environment is created using SIMPOWER SYSTEM block-set for three phase source and considering nonlinear load.**

***Index Terms*—Shunt active filter, Power Quality,Total Harmonic Distortion,Particle Swarm Optimization.**

I. INTRODUCTION

Increasing number of nonlinear loads results in the deterioration of power quality. Power quality may also be defined as the degree to which both the utilization and delivery of electric power affects the performance of electrical equipment .The issues in this regards of power quality are mostly related to the harmonic contents of source current. Harmonic pollution causes a number of problems. A first effect is the increase of the RMS-value and the peak-value of the distorted waveform. The increase in RMS-value leads to increased heating of the electrical equipment. Furthermore, circuit breakers may trip due to higher thermal or instantaneous levels.In installations with a neutral, zero phase sequence harmonics may give rise to excessive neutral currents.

To overcome the harmonic related problems in the source current Power Filters plays a major role. Traditionally passive filters have been used to limit these unwanted harmonics, but these filters have their own limitations. Passive filter consists of series circuit of reactors and capacitors offering a low impedance path at resonance frequency. A passive filter circuit may only filter one harmonic component. A separate filter circuit is required for each harmonic that needs to be filtered.So another viable solution is the Active filters.Active filters works on the principle of generating actively a harmonic current spectrum in opposition of the phase to the distorting harmonic current[1-2]. Among different types of Active filters this paper deals with shunt active filter.Fig 1 shows the block diagram of passive and active filter.

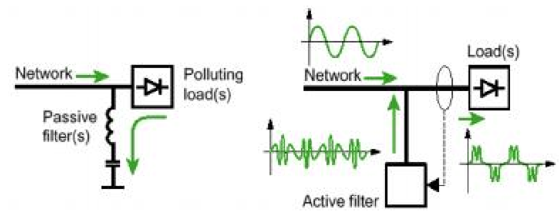

Fig 1 Block diagram of passive and active filters

The shunt active filter consists of a VSI with capacitor on the DC side. Synchronous Reference Frame Theory has been used to generate the reference source current with Hysteresis controller is used to determine the switching signals. The present research work emphasis on the application of Particle Swarm Optimization (PSO) to design the optimal gains for PI controller. Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by social behavior of bird flocking.PSO is initialized with a group of random particle and then searches for optima by updating generations over the particle's position and velocity.

A MATLAB Simulated environment is created using power system toolbox and it has been analyzed that PSO technique for finding the optimal controller parameters proves to be effective for reducing the THD of source current.

II. SHUNT ACTIVE FILTER AND CONTROL STRATEGY

Shunt active filter consists of three phase Voltage Source Inverter (VSI) with a dc energy source on the dc side. Three phase shunt active filter is connected is connected in the distribution network at the common point of coupling. . The most important feature of the active power filter is that the supply current is enforced to be sinusoidal and in phase with the supply voltage despite of the characteristics of the load. Therefore, the shunt APF is harmonics cancellation and reactive power compensation by introducing equal but opposite harmonic and reactive currents into the supply line.

Various topologies for active harmonic Filter have been proposed for harmonic mitigation[3-7].Among them Synchronous Reference frame theory has been used here. It has basically two control loops. One loop controls the Dc link voltage of capacitor to compute the losses and the second loop is used to maintain the AC voltage for reactive power compensation. Proportional –Integral (PI) controllers are used to reduce the errors. Fig 2 shows the block diagram of control strategy of active filter using Synchronous Reference Frame Theory.

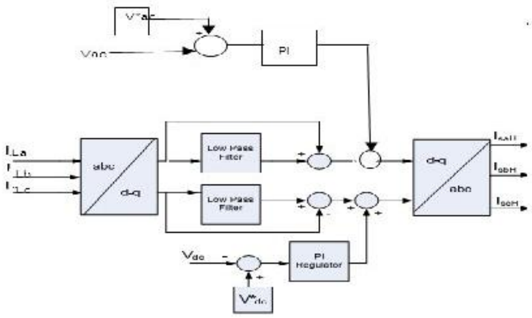

Fig 2 Control Strategy of Active Filter Using Synchronous Reference Frame Theory.

The three phase currents, load currents the PCC voltages and dc bus voltage (vdc) of active filter are sensed as feedback signals. Load currents are transformed into synchronously rotating reference frame d axis and q axis by using cos θ and sin θ where θ is derived from three phase PLL circuit.

The PI controller consists of proportional term and integral term. PI emphases on the difference (error) between the Vdc reference voltage and Vdc bus voltage. PI controller algorithm involves two separate parameters; the Proportional and the Integral. Proportional value governs the reaction to the voltage error; the Integral determines the reaction based on the sum of recent errors. The weighted sum of these two actions is used to eliminate the error. By "tuning" the two constants in the PI controller algorithm, the PI controller offer control action designed for specific process requirements.

The output of PI (proportional-integral) controller at the dc bus voltage of Shunt Active Filter is considered as the current (iloss) for meeting its losses.

$$i_{loss(n)} = i_{loss(n-1)} + k_{pd}(v_{de(n)} - v_{de(n-1)}) + k_{id} v_{de(n)} \qquad (1)$$

where, $v_{de} - v_{de(n-1)}$ is the error between the reference(vdc* and sensed (vdc) dc voltage at the nth sampling instant. Kpd and Kid are the proportional and the integral gains of the dc bus voltage PI controller.

The reference source current is therefore expressed as,

$$i_d^* = i_{ddc} + i_{loss} \qquad (2)$$

Similarly PI controller is used to regulate the AC grid voltage to a reference value , expressed as

$$i_{qr(n)} = i_{qr(n-1)} + k_{pq}(v_{te(n)} - v_{te(n-1)}) + k_{iq} v_{te(n)} \qquad (3)$$

where, $v_{te(n)} = v_s^* - v_{(n)}$ denotes the error between reference (vs*) and actual (vs(n)) terminal voltage amplitudes at the n sampling instant. Kpq and Kiq are the proportional and the integral gains of the dc bus voltage PI controller.

The reference supply quadrature axis current is expressed as

$$i_q^* = i_{qdc} + i_{qr} \qquad (4)$$

Hysteresis Controller

Fixed band hysteresis current control formulates the switching of the inverter from the comparison of current error to keep the current with in the hysteresis band. The switching frequency can be changed by the width of the hysteresis band hb.The Hysteresis current controllers of the three phases are designed to operate independently. Each current controller determines the switching signals to the inverter. The error signal reference and actual source current are calculated and compared within a small hysteresis band (hb) .The switching logic for phase A is formulated as below:

If i_{fa}<(i^*_{fa} -h_b) upper switch of VSC TURNED is OFF and lower switch is ON

If i_{fa}<(i^*_{fa} +hb) upper switch of VSC is turned ON and lower switch is OFF

In the same fashion, the switching of phase B and C devices are derived.

III. PARTICLE SWARM OPTIMIZATION

PSO is similar to genetic algorithm in a sense that the system is initialized with a population of random solutions. PSO serves as a simple and powerful tool for solving optimization problems PSO tracks the optimal solution not by survival of the fittest but by a process motivated by the personal and social behavior of a flock of birds.PSO performs the search process by a population of particles called a swarm.The particle is characterized by D-dimensional vector representing the position of the particle in the search space.[8] The position vectors represent a potential solution to an optimization problem. During the evolutionary process, the particles transverse the entire solution space with a certain velocity. Each particle is associated with a fitness value evaluated using the objective function at the particle's current positions. Each particle memorizes its individual best position encountered by it during its exploration and the swarm remembers the position of the best performer among the population. At each **iteration** the particles update their position by adding a certain velocity. The velocity of each particle is influenced by its previous velocity, the distance from its individual best position and the distance from the best particle in the swarm [9]. A weighted combination of these three parameters gives the new velocity. Fig 3 shows the block diagram of PSO algorithm

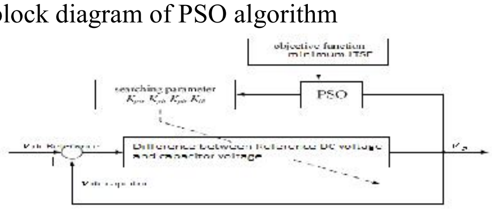

Fig.3 Block Diagram of PSO Algorithm

PSO algorithm will search for the optimal parameters for PI parameters for maintaining the DC link voltage(Kpv, Kiv) and also for PI gain parameters for maintaining the AC voltage for reactive power compensation(Kpr, Kir).The objective function W is defined as

$$w(error) = \min\left(\int time.(error)^2\right)$$

Where error is defined the difference between reference dc voltage and capacitor voltage.

ALGORITHM

For each particle
Initialize particle
END
Do
For each particle
Calculate fitness value
If the fitness value is better than the best personal fitness value in history, set current value as a new best personal fitness value
End
Choose the particle with the best fitness value of all the particles, and if that fitness value is better then current global best, set as a global best fitness value
For each particle
Calculate particle velocity according velocity change equation
Update particle position according position change equation
End
While maximum iterations or minimum error criteria is not attained

The problem formulations adopts the Integral of time square error (ITSE criteria) of DC link voltage as the objective function, to determine the PI control parameters for getting a minimum THD of the source current. The PSO searching method will try to search the best controller parameters until the minimum W is achieved. It means that the controller parameters from the searching process provide the best performance of the vo response.

IV. STUDY CASE AND SIMULATION RESULTS

This section explains simulation results of a simplified three phase distribution system equipped with Shunt Active Filter. Characteristics of the system resulting from the operation of the Shunt Active Filter are simulated by using the MATLAB simulation. The specification of the test system is given in TABLE 1.

TABLE 1 Parameters of the System

Source voltage and frequency	415 V (L-L) and 50Hz
Three phase linear load	Phase a- 25 ohms Phase b -10 ohms and 80e-3 H Phasec-10 ohms and 80e-3 H
Non- Linear load	Three phase full rectifier drawing 5 A of current
Dc Link voltage	2200e-6 F
Reference voltage	750 V
Hysteresis current	0.2Amp

The dynamic performance of non-linear unbalanced load condition with active filter using SRF is implemented for Harmonic Reduction. The source voltage, source current, loads voltage, load current without filter are shown in Fig 4. Fig 5 demonstrates the constant capacitor voltage.

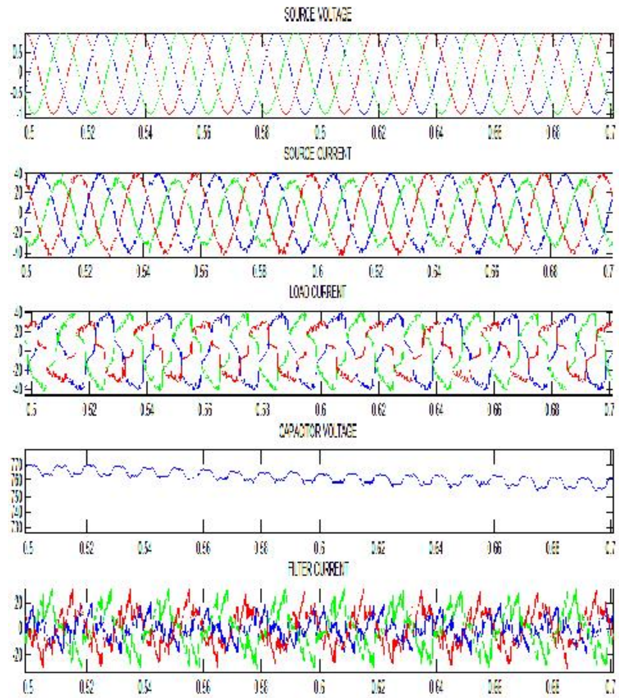

Fig 4 Dynamic performance of Shunt active filter showing source voltage,source current,load current,capacitor voltage,filter current.

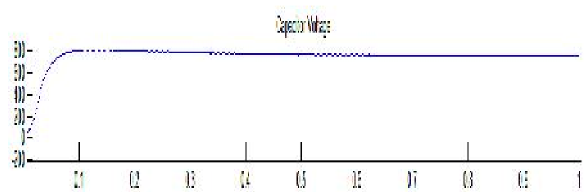

Fig 5 Capacitor Voltage

Harmonic distortion of load current without filter for Phase a is 14.74%..With Shunt Active Filter SRF control strategy, harmonics in source current are reduced to 3.05% for phase 'a', 3.81% for phase 'b',and3.26% for phase'c'. The FFT analysis of the phase a, phase b and phase c is shown in Fig 6.Table II gives the obtained value of PI gain parameters using ITSE as the objective function. Table III gives the comparison of the THD of phase a, phase b and phase c before and after filtering.

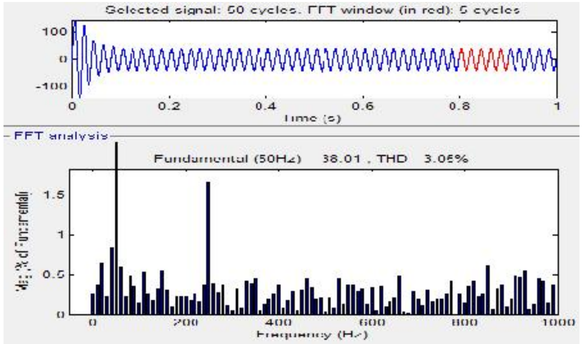

Fig 5(a) FFT Analysis of Source Current for Phase *a*

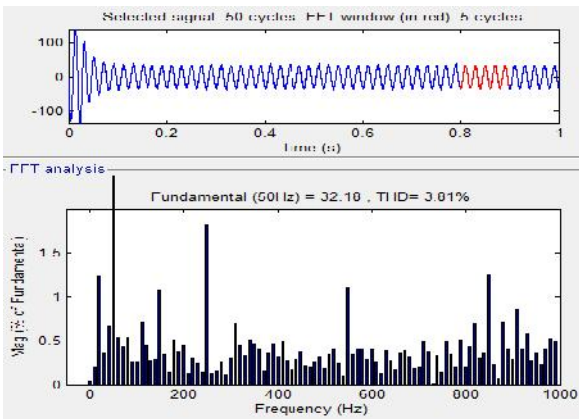

Fig 5(b) FFT Analysis of Source Current for Phase *b*

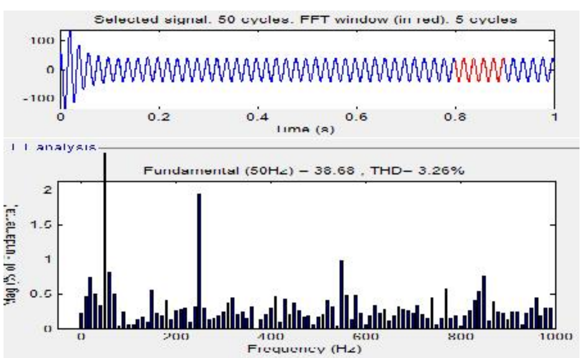

Fig 5(c) FFT Analysis of Source Current for Phase *c*

TABLE II

Obtained Value of PI Gain Parameters

AIM	Proportional Gain	Integral Gain
To maintain DC-link voltage	0.18	0.6247
To maintain ACvoltage	46.3685	1.8371

TABLE III

Percentage of THD for Three Phases

Phase a		Phase b		Phase c	
Before filtering	After filtering	Before filtering	After filtering	Before filtering	After filtering
14.74	3.05	16.27	3.81	19.66	3.26

Fig 6 shows the comparison between the uncompensated reactive power before filtering and the compensated reactive power after filtering. It can be clearly analyzed that after filtering reactive power demand of source is almost negligible.

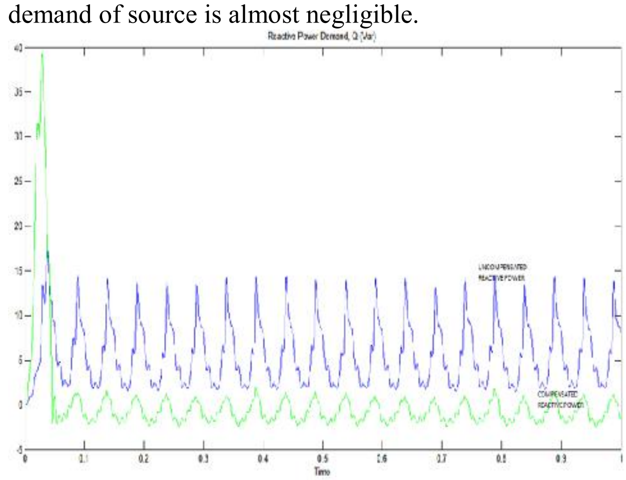

Fig 6 comparison between the uncompensated reactive power before filtering and the compensated reactive power after filtering

V. CONCLUSION

The paper presents the application of PSO with integral of time square error as the objective function for shunt active filter to improve power quality. The proposed technique design optimal PI parameter gains and is found satisfactory to reduce the Total Harmonic Reduction and thus improves the source current. The performance of the shunt connected active filter is verified under nonlinear load. Proposed active filter topology limits the THD percentage of source current under limits of IEEE-519 standard.

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