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Identification and mitigation of disturbance with Active filters based on soft computing techniques

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***Abstract*— Active filter for harmonic mitigation and reactive power compensation with nonlinear loads in present day power systems has been a mature technology. In general active power filters are connected in parallel, series or combined depending upon the requirement to mitigate voltage and current harmonics. The reference currents are generated through neural networks. The pulses are generated for current and voltage source inverter of two wire through a regulator. The two wire configured active filters like active series, active shunt and combination of both as unified line conditioners are used to enhance the power quality. Further it is optimized using soft computing techniques. The effective simulations are carried out in Matlab/Simulink environment.**

***Index Terms*— Active power Filter (APF), Neural Networks(NN), Power Quality (PQ), Total Harmonic Distortion (THD)**

I. INTRODUCTION

As the technology is increasing, the nonlinear loads are also increasing. Due to the nonlinear loads, harmonic pollution increases. In order to reduce this harmonic pollution, power system and power electronic engineers had exhausted interest to create dynamic and adjustable solutions to these power quality problems. The harmonics can be produced in any device which has nonlinear operating characteristics. The passive filters have the disadvantages such as tolerance, resonance and their bulky size. For this disadvantage of passive filters, active filters are used to eliminate harmonics in the system.

The two wire nonlinear loads such as ovens, televisions, Xerox machines act as nonlinear loads which create power quality problems .There are active series, active shunt and combined series shunt type of filters. The principle of active filters is to cancel the harmonic current components produced by the nonlinear load. The unified line conditioners are those which are used to improve the quality of power. Two wire (single phase) active filters are used to meet the demand of two wire nonlinear loads. Reference compensation currents are generated through neural networks. Series active filters eliminate voltage harmonics such as sags, swells. Shunt active filters eliminates current harmonics and reactive power compensation. Single phase active filters are developed using current source inverter with inductive energy storage and voltage source inverter with capacitive energy storage.[1].Figure below shows the basic circuit diagram of active filters.

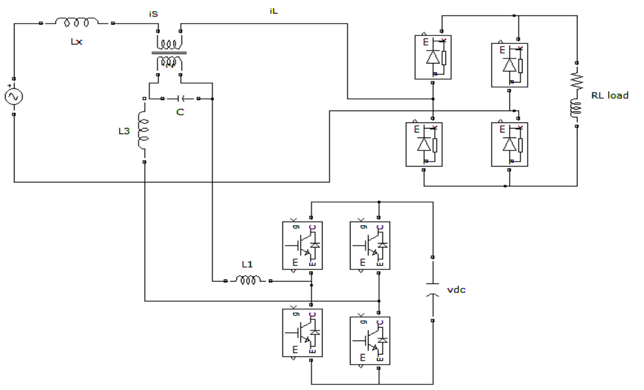

Fig.1: Two wire Series Filter.

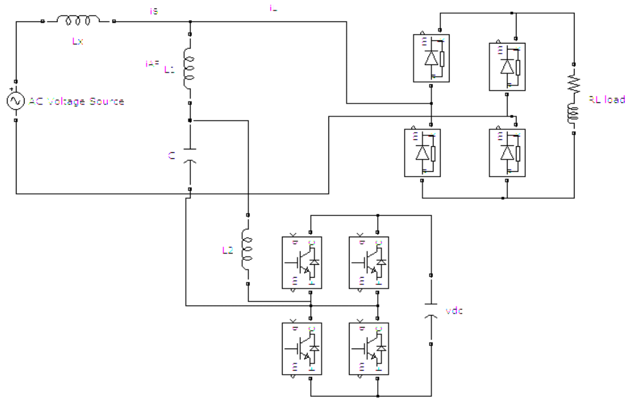

Fig 2: Two wire Shunt Filter.

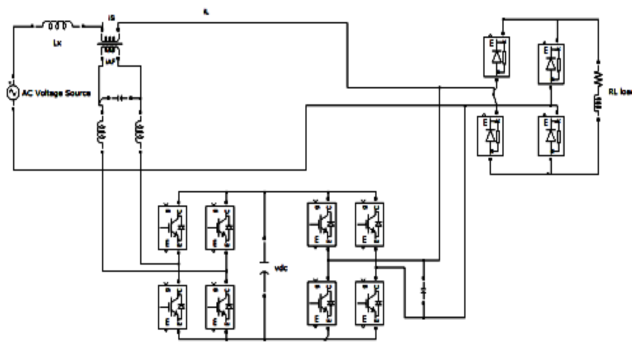

Fig 3: Two wire Combined Series Shunt Filter

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The integral term in a PI controller causes the steady state error to be zero with step input. Neural networks have the advantages of Adaptive learning, Self-organization.

II. SYSTEM CONFIGURATION

A single phase, 230V, 50Hz supplied Active Filter is developed in MATLAB/SIMULINK using Simpower System toolbox.

A. *Design Parameters of Active Filter:* Active filter consists of single phase, 2 pulse voltage source inverter. The rms voltage is considered as 230V. The designs for dc bus capacitor, dc bus voltage are as follows

(i) *DC Capacitor Voltage:*

The minimum dc bus voltage should be greater than twice of the peak of the phase voltage of the system. The dc bus voltage is calculated as

$$vdc = vac = 2vpeak/\pi$$

$$vrms = vpeak/\sqrt{2} \quad (1)$$

Where, Vpeak is the average peak voltage.

(ii) *DC Bus Capacitor:*

The value of dc bus capacitor (Cdc) is given by

$$\frac{1}{2}C_{dc}[(V_{dc}^{2}) - (V_{dc1}^{2})] = v(ai)t \quad (2)$$

Where, Vdc is the reference dc voltage and Vdc1 is the minimum voltage level of dc bus, a is the over loading factor taken as 1.2, V is the phase voltage, I is the phase current and t is time by which the dc bus voltage is to be recovered .

III. CONTROL STRATEGY

(A). Instantaneous real and reactive power theory:

The p-q theory is widely used for three wires three phase power system and also extended to four wires three phase power system[8]. This theory can be used for single phase active filter by duplicating two more current and voltage signal with 120º angel shifting. Consider load current of single phase load as phase “a” and others phase are generated by duplicating technique. The load current can be assumed as phase “a” current and with be expressed mathematically as shows in eq. (3). By assuming that eq. (3) as phase “a” load current, load current for phase “b” and c can be represented as eq. (4) and eq. (5).

$$ia = \sum_{i=0}^{n} \sqrt{2}\, Ii \sin(wi + \theta i) \quad (3)$$

$$ib = \sum_{i=0}^{n} \sqrt{2}\, Ii \sin(wi + \theta i - 120^{\circ}) \quad (4)$$

$$ic = \sum_{i=0}^{n} \sqrt{2}\, Ii \sin(wi + \theta i + 120^{\circ}) \quad (5)$$

Determine the α-β reference current by using Clarke transformation as shown in (6) for load current and in (7) for load voltage.

$$\begin{bmatrix} i\alpha \\ i\beta \\ io \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} v\alpha \\ v\beta \\ vo \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} va \\ vb \\ vc \end{bmatrix} \quad (7)$$

The active and reactive power is written as:

$$p = vaia + v\beta i\beta + voio \quad (8)$$

$$q = vaia - v\beta i\beta \quad (9)$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v\alpha & v\beta \\ -v\beta & v\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \quad (10)$$

Active power and reactive power consist of two part which are mean part and oscillating part also known as DC part and AC part. The equations power and can be given as:

$$p = \bar{p} + \tilde{p} \quad (11)$$

$$q = \bar{q} + \tilde{q} \quad (12)$$

From DC part active power and reactive power, the α-β referencecurrent can be represented in (13).

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = 1/\Delta \begin{bmatrix} v\alpha & -v\beta \\ v\beta & v\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (13)$$

Where $\Delta = v\alpha^2 + v\beta^2$

The three phase current reference of active power filter is given in (14) before the signal will subtract to load current. Hysteresis band will produce six PWM signals and for single phase active filter it is only two are used as input of hysteresis band.

$$[i*abc] = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} [i*\alpha\beta] \quad (14)$$

(B).Hysteresis band current control:

Hysteresis current control technique is employed to design the control part of the APF [3] . In this controller actual current is forced to track the sine reference within hysteresis band by back and forth (or bang-bang) switching of the upper and lower switches. So the inverter then becomes a current source, which is controlled within the band and makes the source current to be sinusoidal.

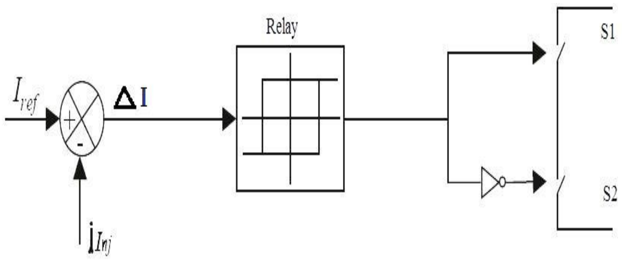

Fig.4: Hysteresis band current control

The switching takes place when carrier signals crosses the error signal of iref and iac. The PWM switching law described below:

If (iact) > (iref + hb) upper switch of a leg is ON and lower switch is OFF

If (iact) < (iref + hb) upper switch of a leg is OFF and lower switch is ON

(C) PI controller:

The PI controller consists of (Kp) and (Ki)[6]. The pi controller produces an output signal consisting of two terms, one is proportional to error signal and the other is proportional to the integral of error signal. The reference currents for the control of active filter are generated through PI controller.. The output of PI controller at the dc bus voltage of active filter is a current and it is considered as the current for meeting the injection requirements of voltage through current source inverter or voltage source inverter.

$$i_{loss(n)} = i_{loss(n-1)} + k_p(v_{sn} - v_{s(n-1)}) + k_i v_{sn} \qquad (15)$$

The error between the reference (Vdc*) and sensed (Vdc) dc voltage at the nth sampling instant.

(*D*) *Neural Networks:*

It is a technology to extract information from the process signal by using expert knowledge. ANN is a collection of techniques working in a complementary way to build robust system at low cost. A Neural network can give better sinusoidal wave for linear and nonlinear load conditions[7]. There are two types of networks feed forward ANN and feedback ANN. Feed forward ANN allows signals to travel one way only, from input to output. Whereas feedback networks can have signals travelling in both directions by introducing loops in the network. ANN consists of three layers a layer of input unit is connected to the layer of hidden layer which is connected to a layer of output.

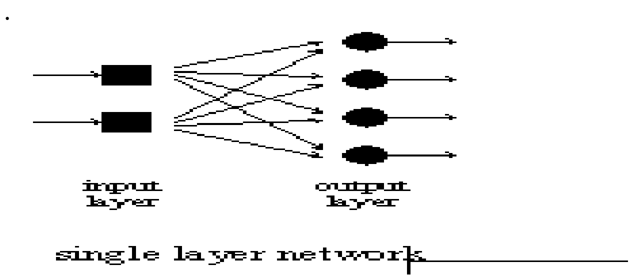

Fig 5: single layer network architecture

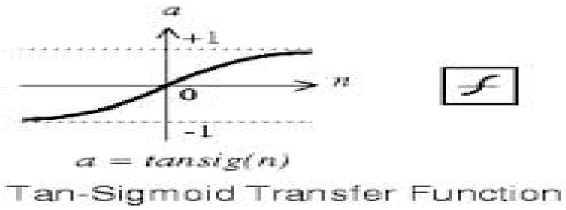

Fig 6: sigmoidal transfer function

The results obtained with ANNs are often better than those of traditional methods. In this work the PI controller is replaced by ANN for better and fast response. It is difficult and time taking process of tuning Kp and Ki values of PI controller for varying loads but in ANN they optimize simultaneously weights and biases in an on-line training process, they are able to adapt themselves to any system [6]. The placement of ANN controller is shown in fig.7.

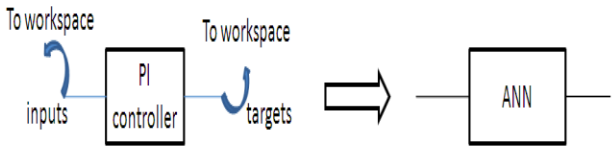

Fig.7: Replacement of PI controller with ANN controller

(E). Partical Swarm Optimization:

Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by social behaviour of bird flocking or fish schooling [10-11]. The moments of the birds are reflected as and we call it as moments of "particle". All particles have fitness values which are evaluated by the fitness function to be optimized, particles. This paper employs the objective function as minimization of Total Harmonic Distortion (THD). The fitness function is defined as follow:

$$F = f_{THD} \qquad (16)$$

The optimization parameters are proportional gain (Kp) and integral gain (Ki), the transfer function of PI controller is definedby:

$$G_c(s) = k_p + \frac{k_i}{s} \qquad (17)$$

The gains Kp and Ki of PI controller are generated by the PSO algorithm for a given plant. As shown in Fig.8.

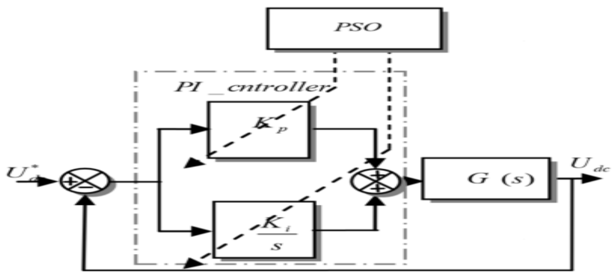

Fig.8: PI -PSO Control System.

The output of the PI controller u(t) is givenby:

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt \qquad (18)$$

The position of particle move rule is shown as follows:

$$V_s(t+1) = wV_s(t) + c_1 r_1 (p_{best} - x_s(t)) + c_2 r_2 (G_{best} - x_s(t)) \qquad (19)$$

$$X_s(t+1) = X_s(t) + V_s(t+1)$$

where $V_s(t)$ represents the velocity vector of particle s in t time; $X_s(t)$ represents the position vector of particle s in t time; $_{best}$ is the personal best position of particle s, G_{best} is the best position of the particle found at present; w represents inertia weight; c1, c2 are two acceleration constants, called cognitive and social parameters respectively; and r1 and r2 are two random functions in the range [0, 1]. The flow chart of general PSO is shown in Fig.9.

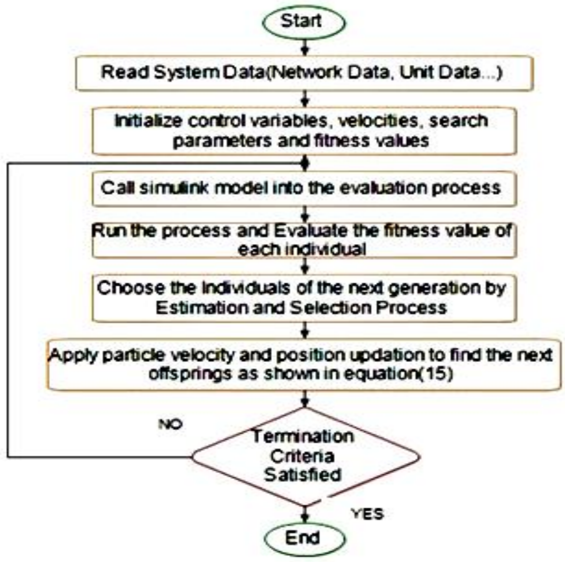

Fig.9. Flowchart of PSO algorithm

IV. SIMULATION RESULTS:

This section describes the comparison of total harmonic distortion of source current by employing series, shunt, combined series shunt active filters with PIcontroller, ANN based PI controller and PSO based PI controller.

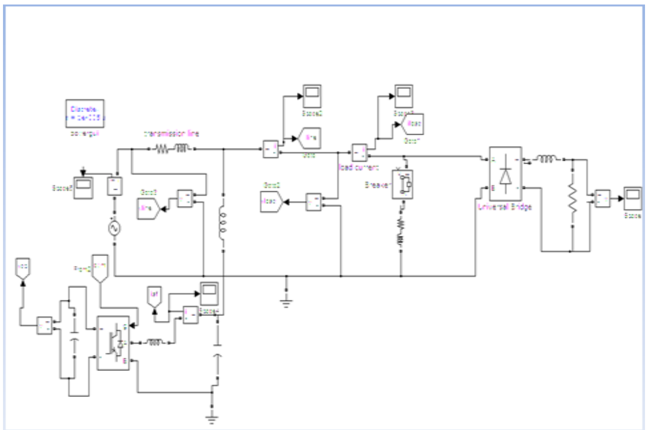

Fig 12: Matlab/simulink circuit with shunt active power filter

The output waveforms of source currents ,load current harmonics, is shown in fig.13,14 respectively.

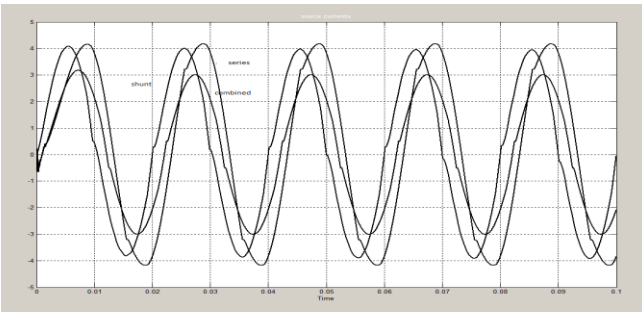

Fig 13: source currents

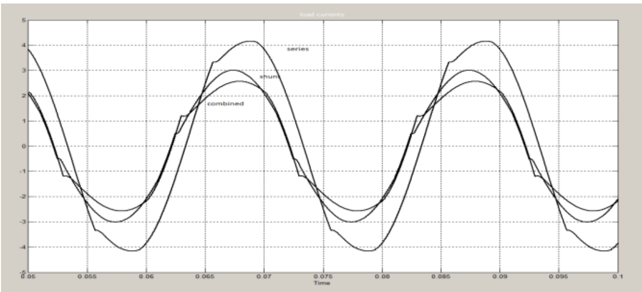

Fig 14 : Load current harmonics

THD convergence illustration of PI-PSOalgorithm and THD analysis of source currents in bar graph representation are shown in fig below.

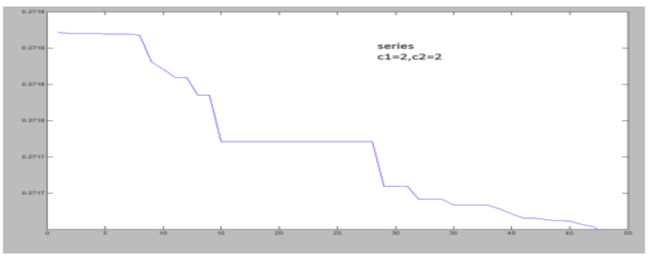

Fig 15: THD convergence illustration of seriesfilter

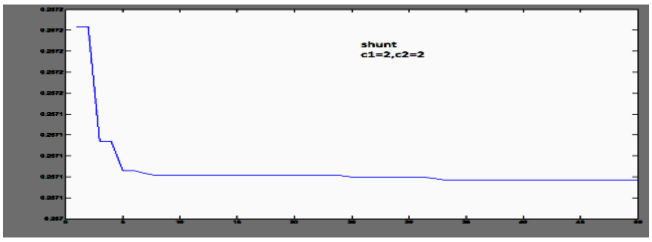

Fig 16: THD convergence illustration of shunt filter

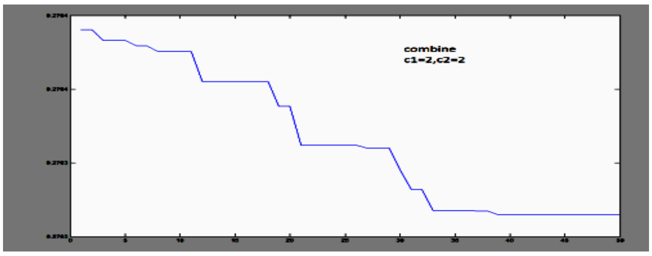

Fig17:THD convergenceillustration of combinedfilter

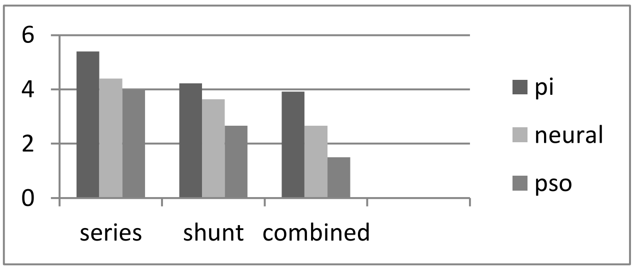

Fig 18: THD analysis of source currents

In Table 1 source current THD is given for different controllers with different filters

Table 1:THD values of different type of filters.

Types of filters	PI controller	Neural network	PSO
Series	5.39	4.40	3.97
Shunt	4.22	3.63	2.50
Combined	3.92	2.66	1.50

The PI-PSO optimization has run for 50 iterations considering 10 populations with 20 divisions each.

V. CONCLUSION

In this paper PQ theory is used to generate reference currents to control filters which is used to compensate reactive power and harmonic currents with different type of controllers .At this level comparative studies between conventional PI controller, ANN based PI controller, and PSO based PI showed that PSO has been proved to be better in terms of harmonic reduction in source current and compensating reactive power. It has been found that these robust and nonlinear controllers prove to be better than conventional controllers.

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