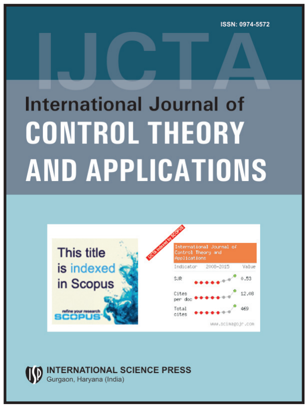

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Optimum Shunt Active Power Filter based on Artificial Bee Colony Algorithm

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Abstract: Today the loads with non linear characteristics have risen to harmonic problems. Harmonics leads to disoperation in sensitive loads connected at PCC. Shunt Active Power Filter (SAPF) is used to improve Power Quality under non linear load condition by compensating the current harmonics. The operation of SAPF depends on the controller used for SAPF. Artificial Bee Colony (ABC) optimization technique is one of the new method based on the inspiration of the foraging behavior of honey bees. ABC optimization is a meta-heuristic approach of swarm intelligence. In this paper the performance of ABC based SAPF is compared with other regular optimization techniques.

Keywords: Harmonics; Shunt Active power Filter; PI controller; Optimization Techniques; Artificial Bee Colony (ABC).

1. INTRODUCTION

Recently, tremendous use of power electronic applications raising the harmonic pollution in AC mains. This harmonic pollution mainly affects the distribution networks leading to many problems and causing disoperation of sensitive loads connected at PCC [1]. Harmonic can be reduced in two ways. One is by better design of the non-linear loads. Example for this is using multilevel topology for high power appliances. Second solution is installing harmonic filters. The SAPF became a feasible alternative over the Passive Filters to solve power quality problems. The SAPF injects the compensating current to turn the non sinusoidal source current into sinusoidal current hence the Current harmonics can be eliminated with SAPF.

In this paper, ABC algorithm is proposed to optimize gains of the PI controller. In this paper performance of ABC is compared with regular optimization methods. The proposed ABC algorithm is giving better results than other methodologies to reach the solution.

2. SHUNT ACTIVE POWER FILTER

In distribution networks with non linear loads, the source current waveform can be maintained sinusoidal by connecting the SAPF. Figure 1 shows the Electrical Circuit diagram of SAPF.

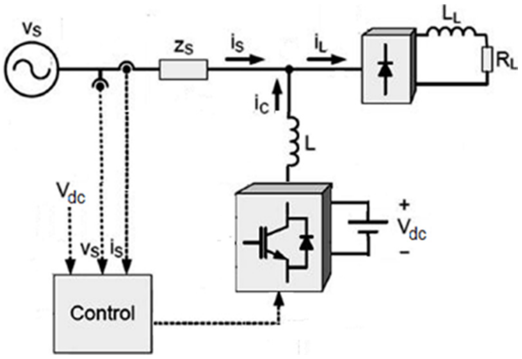

Figure 1: Shunt Active Power Filter

The compensating current required to cancel harmonics on AC side is supplied by SAPF and hence source voltage becomes in phase with source current. Figure 1 outlines compensating methodology of SAPF.

When nonlinear load is connected to the distribution system, equation (1) gives instantaneous load power.

$$p_L(t) = v_s(t) \times i_L(t) \tag{1}$$

where, $v_s(t)$ is instantaneous source voltage and $i_L(t)$ is instantaneous load current.

The instantaneous value of source voltage is given by

$$v_s(t) = V_m \sin \omega t \tag{2}$$

The instantaneous current can be written as

$$i_s(t) = i_L(t) - i_c(t) \tag{3}$$

Due to harmonic content the load current has fundamental component and harmonic component. The load current is given by

$$\begin{aligned} i_L(t) &= \sum_{n=1}^{\infty} I_n \sin(n\omega t + \varphi_n) \\ &= I_1 \sin(\omega t + \varphi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \varphi_n) \end{aligned} \tag{4}$$

Substitute equation (2) and equation (4) in equation (1), then The instantaneous load power expressed as

$$\begin{aligned} p_L(t) = v_s(t) \times i_L(t) &= V_m I_1 \sin^2 \omega t \times \cos \varphi_1 + V_m I_1 \sin \omega t \times \cos \omega t \times \sin \varphi_1 \\ &+ V_m \sin \omega t \times \sum_{n=2}^{\infty} I_n \sin(n\omega t + \varphi_n) = p_f(t) + p_r(t) + p_h(t) \end{aligned} \tag{5}$$

from (5), the active power drawn by the load is

$$p_f(t) = V_m I_1 \sin^2 \omega t \times \cos \varphi_1 = v_s(t) \times i_s(t) \tag{6}$$

From (6), the source current after compensation is

$$i_s(t) = p_f(t))/(v_s(t)) = I_1 \cos \varphi_1 \sin \omega t = I_{sm} \sin \omega t \tag{7}$$

where, I_{sm} the maximum value of the loss current. For harmonic mitigation, SAPF is must provide compensating current $i_c(t)$ such that $i_s(t)$ must not have any harmonics. The $i_c(t)$ can be given as

$$i_c(t) = i_L(t) - i_s(t) \tag{8}$$

From the (8), the current $i_s(t)$ must be estimated to generate instantaneous and accurate compensation current. This $i_s(t)$ is the fundamental component $i_L(t)$. The variation of DC link voltage leads to variation in maximum value of I_{sm}. The aim of ideal compensation is that $i_s(t)$ must be sinusoidal and must maintain in phase with $v_s(t)$. After the compensation, source currents given as

$$\begin{aligned} i_{sa}^{*} &= I_{sm} \sin \omega t \\ i_{sb}^{*} &= I_{sm} \sin(\omega t - 120) \\ i_{sc}^{*} &= I_{sm} \sin(\omega t + 120) \end{aligned} \tag{9}$$

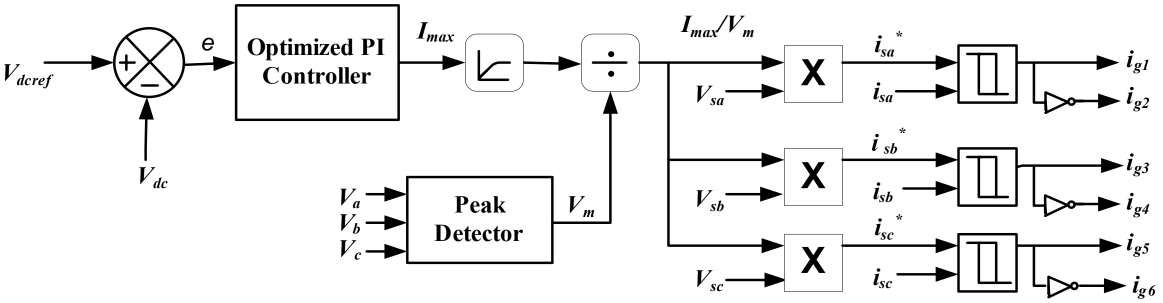

Figure 2: Block diagram of the controller

where, i_{sm} is the maximum value of the desired source current. The source voltage will gives the phase angle. Hence, i_{sm} is needed to be calculated.

The Proportional and Integral (PI) controller is used to process the error between The DC capacitor voltage and reference voltage. The amplitude of the desired source current is given by the PI controller. Unit sine vectors are generated from the source voltages. Product of peak value and unit sine vectors gives the reference currents. Figure 2 shows diagram of the controller.

3. FITNESS FUNCTION

The gains of PI controller are approximated using linear modeling of converter circuit. By using small signal perturbation technique, The characteristic equation is given as follows [6]:

$$1+\left(K_p+\frac{K_1}{s}\right)-\frac{3\left[V_s - sL_f I_{fo} - 2I_{fo}R_f\right]}{sC_{dc}V_{dco}}=0 \tag{10}$$

where, K_p, K_i is proportional gain and integral gains respectively, C_{dc} and V_{dc} are DC side capacitor and its Voltage, V_s is ac side voltage, L_f and R_f are Filter inductance and resistance, I_{fo} and V_{dco} are steady state operating points of I_f, V_{dc}.

In this paper, the ABC optimization scheme has been applied to tune the parameters of PI controller. The integral time square error (ITSE) is considered as the objective function "J" for optimization[11].

$$J = \text{ISTE} = \int_0^t \left(e_r^2 \times t\right) dt \tag{11}$$

where, $e_r = V_{dcref} - V_{dc}$

The coefficients (K_p, K_i) optimized at a particular load condition may not give the satisfactory performance at all of the load conditions.

4. OPTIMAL TUNING OF PI CONTROLLER

Population based optimization techniques are classified in to two types. One is evolutionary algorithms and second one is swarm intelligence based algorithms. Genetic algorithms (GA), particle swarm optimization (PSO), Bacterial Foraging (BF) and Artificial Bee Colony (ABC) techniques comes under the Swarm intelligence based optimization techniques.

Artificial Bee Colony (ABC)

ABC optimization technique comes under the category of meta heuristic approach. Karaboga [9] first proposed this method. How the honey bees collecting food is the basic idea to ABC. Employed bees, onlooker bees and scout bee are the three groups in ABC algorithm. Employed bees randomly around the hive and collects the information of food source. This information is shared with onlookers and then onlooker takes a decision to select a food source. Scout is the one carrying the random search.

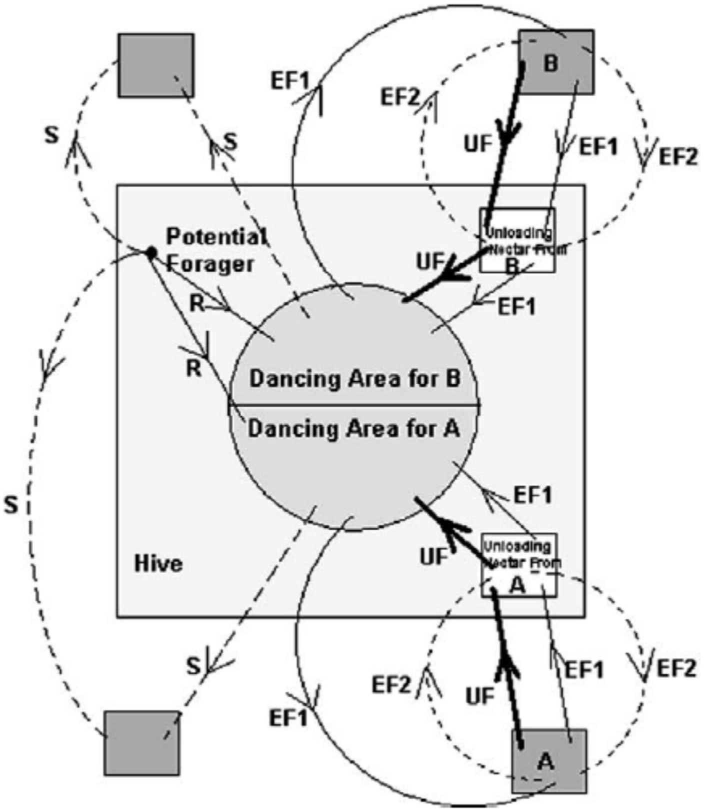

Figure 3: Behaviour of Honey Bees

Basic behavior of honey bees is given in Figure 3. Let assume A and B are Food sources. One of the potential bee starts as unemployed Bee. It has two options, One is searching for food (S) and other is it may be in waggle dance (R). After finding food source, It will remember the food source location and starts exploiting it. Now the Bee becomes employed bee. After unloading the food in to nectar, the same bee has three options-may it becomes an unemployed Bee, may it recruit nest mates and return to food source or continue to forage from same food source.

The equation (12) gives probability value of food source

$$p_i = \frac{fit_i}{\sum_{n=1}^{\mathrm{SN}} fit_n} \tag{12}$$

where, fit_i is fitness value and SN is number of food sources.

The food position of candidate from old memory is given by

$$v_{ij} = x_{ij} + \varnothing_{ij}(x_{ij} - x_{kj}) \tag{13}$$

where, $k \in \{1, 2, \ldots, \mathrm{SN}\}$ and $j \in \{1, 2, \ldots, \mathrm{D}\}$, $\varnothing_{ij}$ is random number [–1, 1]

The procedure steps of the algorithm are as below:

1. Read data
2. Repeat
3. Allocation of employed bees on food sources
4. Depending on their amount of nectar, allot onlooker bees on the food sources
5. To discovering new food sources, send the scouts to the search area for
6. Until this, store the information about best food source found
7. Check for requirements are met or not

5. SIMULATION RESULTS

The proposed controller based SAPF applied to distribution system is developed in MATLAB. The system specifications are: $V_S = 230$V, $f = 60$Hz, $R_f = 0.1$ ohms, $L_f = 0.66$mH, $C_{dc} = 2000$mF, $V_{dcref} = 200$V, $R_s = 1\Omega$, $L_s = 0.15$mH, $R_L = 10\Omega$, $L_L = 20$ mH. For simplicity, only phase- quantities are shown in the simulation results. A non linear load is considered. The SAPF compensates the harmonics in source current and made the source current as sinusoidal.

The performance of the conventional, GA–PI, PSO-PI, BF-PI controller and proposed ABC-PI controller for the regulation of APF is analyzed by considering that the compensator is switched on at 0.05s. The performance of the SAPF with conventional PI controller is shown in Figure 4.

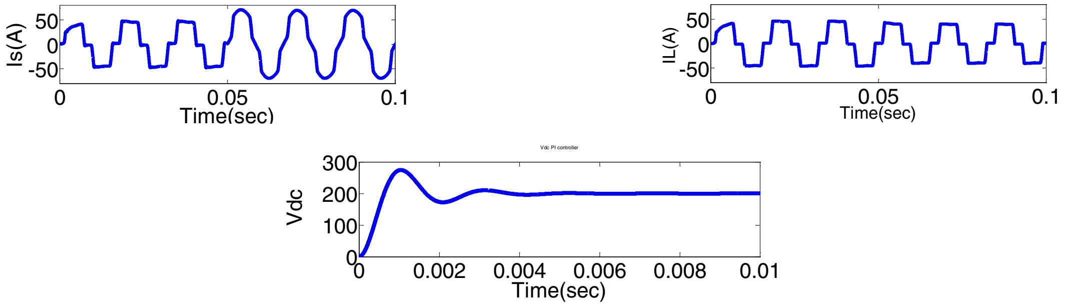

Figure 4: The performance of the SAPF with conventional PI controller

Genetic Algorithm (GA) is well known optimization technique to tune PI controller parameters. The working of the SAPF with GA tuned PI controller is shown in Figure 5. When GA is used for PI controller tuning, Vdc is settling faster than conventional PI controller.

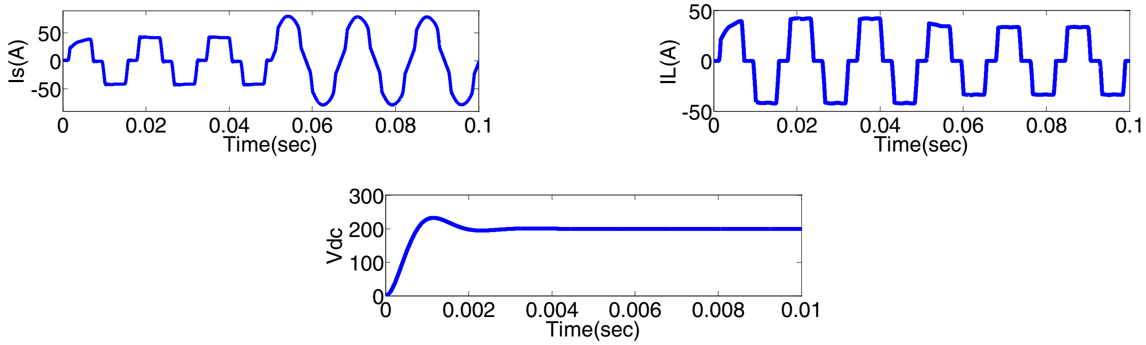

Figure 5: The performance of the SAPF with GA tuned PI controller

Partical Swarm Optimization (PSO) is another well known optimization technique to tune PI controller parameters. The working of the SAPF with PSO tuned PI controller is shown in Figure 6. When PSO is used for PI controller tuning, Vdc is settling faster than GA- PI controller.

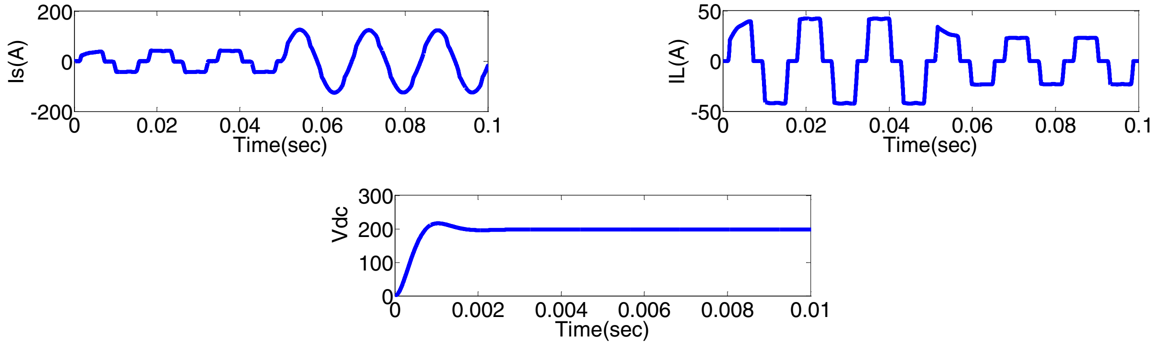

Figure 6: The performance of the SAPF with PSO tuned PI controller

Bacterial foraging Algoritham (BF) is another well known optimization technique to tune PI controller parameters. The working of the SAPF with BF tuned PI controller is shown in Figure 7. When BF is used for PI controller tuning, Vdc is settling faster than PSO- PI controller.

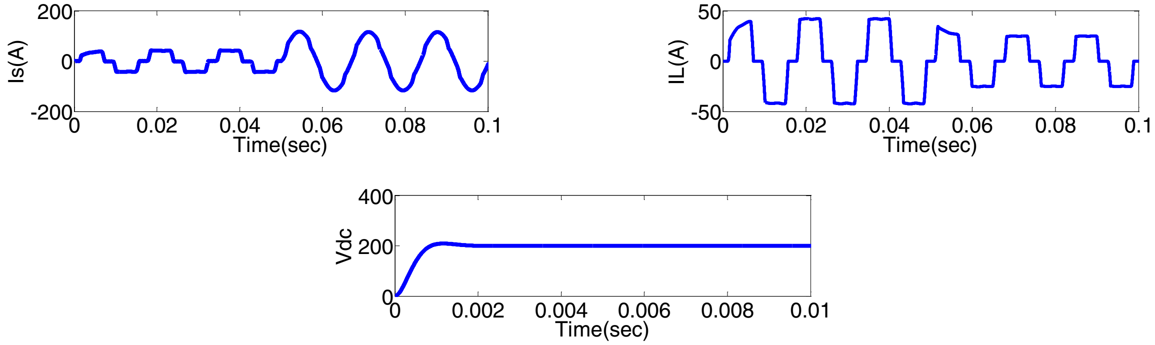

Figure 7: The performance of the SAPF with PSO tuned PI controller

The performance of the SAPF with ABC tuned PI controller is shown in Figure 8. When ABC is used for PI controller tuning, Vdc is settling faster than conventional PI controller, GA, PSO and BF tuned PI controller.

The comparison of the dc capacitor voltage regulation with the four optimization techniques is shown Figure 9. It is observed that the performance of SAPF with ABC optimization technique is quite satisfactory in terms of the rise time and settling time of DC capacitor voltage.

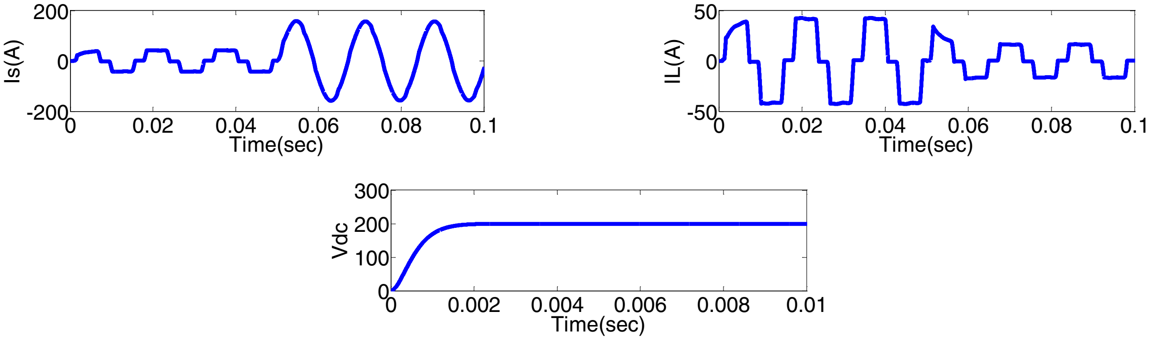

Figure 8: The performance of the SAPF with ABC tuned PI controller

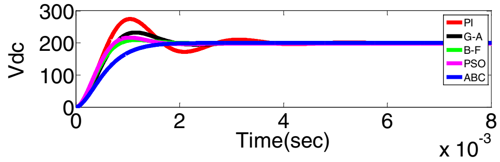

Figure 9: The comparison of the DC capacitor voltage

Table 1
Comparision of Step Responce

Controller type	*PI*	*GA*	*PSO*	*BF*	*ABC*
Rise Time	0.57	3.82	3.59	3.42	3.48
Settling Time	5.96	5.82	6.80	5.76	5.98
Settling Min	95	65	79	66	65
Settling Max	112	65	83	70	67
Overshoot	12.38	81.53	49.36	68.57	76.11

Table 2
Comparision of THD

Controller type	*With out SAPF*	*PI*	*GA*	*PSO*	*BF*	*ABC*
THD %	23.92	13.10	3.51	3.51	4.07	2.07

The comparison of PI controller gain values are shown in Table 1. The comparison of step response is given in Table 2. The comparison of THD is given in Table 3. Hence the performance of ABC tuned SAPF is giving better compensation than conventional PI controller, GA, PSO and BF tuned SAPF.

6. CONCLUSION

In this paper a novel sysntetic controller is proposed for SAPF. A comparitive application of GA, PSO, BF and ABC optimization techniques to tune PI controller coefficients in controller is done. The ABC algorithm giving better performance than conventional PI controller, GA, PSO and BF tuned SAPF in terms of settling time, rise time, over shoot and THD. The dc-link voltage settles faster in case of ABC method then other optimization techniques. Hence ABC ooptimization technique is best to aplly for SAPF controller tuning.

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