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Design and Implementation of Enhanced Artificial BEE Colony Algorithm for Single Phase Shunt Active Filter

Murugan.M
Assistant Professor, Government College of Engineering, Bodinayakkanur, marimurugan81@gmail.com
Vinod A
Assistant Professor, Government College of Engineering, Dharmapuri, vinodnash@gmail.com

Abstract: In this research paper anew hybrid optimization approach, named Enhanced Artificial Bee Colony Algorithm (EABC) for identifying the optimal controller gain for single phase Shunt Active Power Filter (SAPF) is proposed. The proposed algorithm EABC, optimizes the controller gain values in order to improve the time domain specification and integral performance measures of PI controller in SAPF. In this Novel hybrid EABC, a modified version of Particle Swarm optimisation (MPSO) is integrated with Artificial Bee Colony (ABC) algorithm to improve the optimisation efforts of ABC and this hybridization greatly improves the convergence characteristics of conventional ABC. This novel hybrid ABC is applied for minimization of various Integral performance measures such as Integral Square Error (ISE), Integral absolute Errors (IAE) and time weighted integral performance measures. The proposed optimisation approach is implemented using MATLAB and various experimentation was carried out to study about steady-state and dynamic operating conditions. The experimental results establish that the proposed controller design outperforms the classical PI, and ABC-PI controller with improved settling time, less peak overshoot of DC link voltage and THD of source current within a limit.

Keywords: SAPF, ABC, Enhanced ABC

I. Introduction

The usage of power electronic equipment in industries, commercial and domestic applications have resulted in huge current harmonics. This nonlinear load causes harmonic propagation over electrical network. The propagation of generated harmonics reduces the system"s efficiency, poor power factor, creates additional heating losses and cause malfunctioning of many sensitive equipment"s that is connected to the power system. To eliminate the harmonics, passive filter, active filter and hybrid filters can be used. In commercial and industrial applications, the passive filters are most commonly used due to its simple design, high efficiency and minimum cost rating. However, these filters are very huge in size and does not filters all harmonic frequencies. These numerous limitations of passive filters single frequency tuned filters made the researchers to concentrate on active filters. In series combination of filters. The filter has to be designed with more current handling capacity as the filter has to carry the load current. Hence the SAPF for harmonic mitigation is gaining its popularity very rapidly. The SAPF extracts the harmonic current and inject back the negative harmonic sequence into the electric network and makes the supply current to the sinusoidal shape with fundamental frequency. In recent years the usage of power electronic based devices in the home appliances has increased rapidly [1]. Hence this research is focused on the design of single phase shunt active filters.

The single phase SAPF consisting of a voltage source inverter. A DC link capacitor act as the constant voltage source to the inverter and the inverter generates the negative sequence compensation current. The compensation current is injected to the grid at the point of common coupling. The extraction of the harmonics is mainly depending on controlling DC link capacitor voltage at a constant value [2]. To maintain the DC link Capacitor Voltage various control algorithms were proposed by the researchers such as Adaptive Neuro Fuzzy Inference System, Fuzzy Logic Controller, Neural Network Based Model Predictive

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Controllers, and Model Predictive Controllers [3]. These Controllers have huge computation complexity and they involve lot of mathematical calculations to predict the future behavior of the plant and to generate control action. Over these control algorithms the Proportional and Integrator (PI) control techniques very simple to implement and can be implemented easily and also this algorithm requires very less mathematical calculations for determining the control action. Due these advantages the PI control is most widely used in the industries. In the literature the gain for the controller used in the SAPF was found using Trial and error search or mathematical approaches [4]. This trial and error and mathematical approach doesn"t always guarantee the optimal value. [5] proposed a system, this paper presents an effective field programmable gate array (FPGA)-based hardware implementation of a parallel key searching system for the brute-force attack on RC4 encryption. The design employs several novel key scheduling techniques to minimize the total number of cycles for each key search and uses on-chip memories of the FPGA to maximize the number of key searching units per chip.

In very recent years various bio inspired global optimization techniques have been used to find optimal proportional and integral gain. Some of them are Genetic Algorithm (GA), Ant Colony Optimization technique, particle swarm optimization (PSO), Bacterial Foraging (BF) technique, Gravitational search Adaptive Tabu search and Genetic Algorithm, Enhanced Bacterial foraging approach, cuckoo search algorithm. In these algorithms the ABC optimization algorithm is believed to excellent optimization capabilities and most likely to find a global minimum point optimization algorithm when compare to other evolutionary techniques. Also in other optimization techniques there is more number of algorithm parameters that directly influence the performance of the algorithm. In GA if the value of Crossover rate and mutation rate is not correctly set then the quality of the results become worse and the algorithm may even diverge. Similarly, in ACO, the pheromone evaporation and deposition rate, Number of ants, number of tours, has to be set correctly and there is no straight guidance available to select the values for these algorithm parameters. But in ABC the number of algorithm parameters is minimum and the optimization effort is better than other optimization algorithms. Because of these advantages, since its introduction the ABC is found its application in almost all engineering fields. In ABC algorithm unconstrained optimization problems yields generalization [8]. However, conventional ABC algorithms suffer from poor convergence rate because of less exploration and exploitation.

The paper is organized as follows: In section 2, the brief literature review and the major contribution of the research is presented. In Section 3 the ABC based Controller design for SAPF is described. In section 4 the design of novel hybrid optimization technique is proposed and the controller performances are presented to show the effectiveness of the proposed controller design. Finally, the paper ends with logical a conclusion in section 5.

II. LITERATURE REVIEW

Improve the convergence rate of existing ABC, the Enhanced ABC algorithm is proposed. In proposed EABC algorithm a novel method based on the particle swarm optimization is used to improve the quality of the food source identified by the honey bees. Some positive aspect of proposed EABC is improvement of local search by providing guidance by using bird flocking behavior. The proposed algorithm EABC is described in the section 3. [6] proposed a system, Low Voltage Differential Signaling (LVDS) is a way to communicate data using a very low voltage swing (about 350mV) differentially over two PCB traces. It deals about the analysis and design of a low power, low noise and high speed comparator for a high performance Low Voltage Differential Signaling (LVDS) Receiver. The circuit of a Conventional Double Tail Latch Type Comparator is modified for the purpose of low-power and low noise operation even in small supply voltages. The circuit is simulated with 2V DC supply voltage, 350mV 500MHz sinusoidal input and 1GHz clock frequency. LVDS Receiver using comparator as its second stage is designed and simulated in Cadence Virtuoso Analog Design Environment using GPDK 180nm .By this design, the power dissipation, delay and noise can be reduced.

The main contribution of this research over previous research work are listed as follows:

- A single objective function based on the integral performance criteria cost function is designed to find out the optimal values of controller for nonlinear SAPF.

- A Hybrid novel ABC algorithm is proposed to increase the convergence characteristics of conventional ABC by combining Particle swarm optimisation is designed.
- A detailed analysis on the proposed EABC PI, ABC PI and Conventional PI controller based SAPF is done in MATLAB/Simulink system environment.

III. Implementation of Artificial Bee Colony Algorithm for Optimal PI Gain Selection

Meta heuristic-population based optimization algorithm Artificial Bee Colony (ABC) is based on swarm intelligence. Compared to other optimisation techniques such as simulated annealing (SA), ACO, GA and DE, the ABC algorithm has simple implementation structure with less number of algorithm parameters and also inherent convergence agility.

The algorithm relies on bees foraging behaviour of the honey bee. The colony consists of three main group of bees namely employed, onlooker and scout bees. The population size of the colony decides the number of employed bee and other bees. Half of the population is made as employed bees. The remaining includes onlooker bees and scout bees. Initially the Employee bee searches the availability food source around the food source in their memory, in the meantime employee bee send the nectar information about the all identified food sources to onlooker bees. The onlooker bees will select the food source that has high nectar values founded by the employed bees, and also carry out the additional search. Scout bees are requested to replace the abandoned food sources by random search.

In the proposed approach a model of single phase SAPF is developed in MATLAB Simulink and the ABC is implemented in the MATLAB script. As ABC is iterative the MATLAB script passes the food sources to the Simulink to evaluate the fitness value of the food source on each cost function evaluation. The detailed steps of ABC algorithm for optimal PI controller design are described as follows:

Step 1: All algorithm parameters are initialized

Choose the upper and lower bound for PI controller parameters (Kp, Ki)

Colony size = 20

Number of food sources=10

Maximum Iteration =1000

Trail limit=100

Initially reset trial counters.

Step 2: Identify random food source. If the randomly identified food source value is higher or lower than the bound constrain then the food source is resettled to satisfy the bound constraints of controller parameters.

Step 3: Based on the objective function value, the identified food sources are passed to fitness function determine it"sthe fitness value.

Step 4: EMPLOYED BEE PHASE

Produce mutant solutions based on following relationship

$$x_{i,j} = x_{\min,j} + r*(x_{\max,j} - x_{\min,j}) \quad (1)$$

Where r is a random number between 0 and 1, $x_{\min,j}$ is the lower bound limit of optimisation parameter j , $x_{\max,j}$ is the upper bound limit of optimisation parameter j, "i" is the number of food sources and j is the dimension of the optimisation problem. Each food source is evaluated to find the fitness and objective value. A greedy search is applied between solution "i" and with its new variant. If the mutant solution is better, then replace the solution "i" with the mutant and reset the trial counter of „i" and if the solution „i" did not improved then trial counter of "i" is incremented. Each food source is assigned with a probability that is proportional to the quality and A food source with the more probability is selected by the employed bees.

Step 5: ONLOOKER BEE PHASE

Calculate the new solutions based on the following relationship. Where j are the number of parameters to be optimised.

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$$v_{i,j} = x_{i,j} + \Phi_{i,j}(x_{i,j} - x_{k,j}) \quad (2)$$

Where $\Phi_{i,j}$ is the velocity information about the food sources from the employed bee.

If the controller parameters are out of bound constraints the margin, then the solutions out of bound are shifted into the margin. If the mutant result is better than the current solution, replace the current solution with mutant. Find out the solution that has minimum objective function. If the solution „i" cannot be improved, increase its trial counter. A food source is chosen with the probability which is proportional to its quality.

Step 6: SCOUT BEE PHASE

If the employed bee and onlooker bee cannot able to increase the fitness and the solution that has more trail counter value more than the "trail limit" is dropped and scout bee is requested to identify the random food source to replace the unimproved food source.

Step 7: Repeat Steps 4, 5 and 6to get the best values for controller gains. Optimisation can be terminated if maximum number of iteration is reached.

The number of parameter to be optimised in the controller design for SAPF is two. The Proportional gain and integral gain of the PI controller are the parameters of the optimisation problem. The objective functions are various integral performance criteria are given in the following relationships.

Integral Absolute Error

$$IAE = \int_0^\infty |e(t)| dt$$

Integral Time Absolute Error

$$ITAE = \int_0^\infty t.|e(t)| dt$$

Integral Squared Error

$$ISE = \int_0^\infty e(t)^2 dt$$

Integral Time Squared Error

$$ITSE = \int_0^\infty t.e(t)^2 dt$$

In this study the ISE is taken as cost function and optimisation is carried out. The results of simulation are discussed in the Simulation Results section.

1. Implementation of Enhanced artificial bee colony algorithm for optimal PI gain selection

The detailed implementation details of Enhanced ABC algorithm are presented in this section. In conventional ABC algorithm the scout bee replaces the abandoned food source randomly. This random replacement may not identify the good food source. To improve the searching ability of the scout bee a novel approach is proposed to guide the selection of new food source.

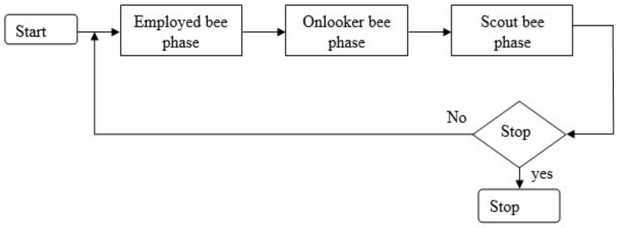

Fig.1. ABC optimization Flowchart

The proposed guided approach uses a modified particle swarm optimization method where the social and cognitive attraction factors are adaptively changed. The pseudo code of proposed enhanced ABC and algorithm are shown in below. The flowchart of ABC and EABC algorithm with optimal PI gain value selection of SAPF is shown in following Fig.1 and 2. The algorithm parameters of ABC and enhanced ABC have been given in Table 1. and Table 2 respectively.

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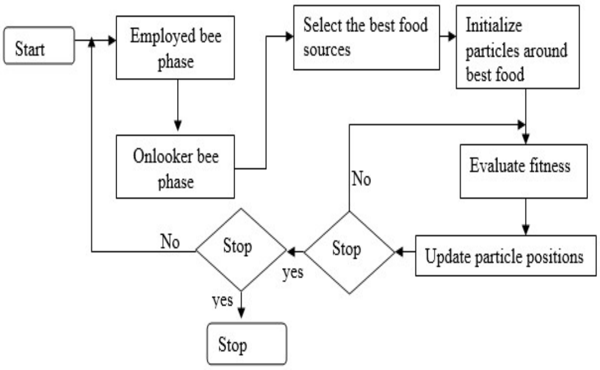

Fig.2. Proposed Enhanced -ABC optimization Flowchart

Table .1 EABC Parameters.

	Initial values
Population size P_S	10
Swarm size	20
Particle length	2
Cognitive attraction factor	1
Social attraction factor	1
No. of Iteration of PSO	20
Number of Cycles in ABC	100

The Hybrid ABC has the following steps:

Steps for EABC PI Tuning method to SAPF

The steps 1-4 are similar to conventional ABC algorithm

Step 1: All PI Tuning parameters are initialized

Step 2: Reset trial counters

Step 3: Employed Bee Phase

Step 4: Onlooker Bee Phase

Step 5: Modified Scout Bee Phase

Initialize the PSO parameters such as cognitive attraction C1=1 social attraction, C2=1, velocities. The p_{bests} and g_{best} are initialized to zero.

Step 6: select the best food source from the colony and create a new solution particle near to it. And evaluate cost of each individual particle. For every individual, compare the p_{best} value with its cost function value. If the value of $p_{best}$is greater than the current fitness, then assign the current fitness to p_{best}. The best fitness among the current fitness value is assigned to global best(g_{best}).

Step 7: reposition the particle using new velocity „v" of each individual

$v_j [i+1] = v_j[i] + c2* r* (p_b- Current\_Par) + c2 * r* (g_b - Cu\_sol)$

J=1, 2…n, (n-Number of particles)

Where,

V_j – Velocity of particle j

C_1-Cognitive attraction factor

C_2 – Social attraction factor

rand – Random number between 0 and 1

P_b – pbest of particle j

g_b – gbest of the group

Cu_sol- current solution

r-random number

Step 8: Apply bound constrains on the velocity update value v_j [i+1] to maintain in the range of particle between upper and lower bound of controller parameters

Step 9: Update the position of each individual

new_position[i+1] = persent_position [i] + v_j[i+1]

Step 10: If the number of iterations reaches the maximum set value then do the step 11, otherwise go to the step 7.

Step 11: Terminate the velocity update and add the latest $g_{best}$to the population

Step 12: Repeat Steps 2, to 12 until get the best solution of controller parameters and Terminate the iterative process, when there is no any further execution of iteration.

This additional guidance to the scout bee increases the convergence rate and the quality of the food source identified by the scout bee.

2. Simulation Results and Discussions

MATLAB software is used to simulate Simulink model of single phase SAPF.The error between reference DC Link voltage and actual DC link voltage is used as an input signal for PI controller.

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The gain values of the PI controller states the voltage response and damping factor, the minimum value of gains for the PI controller can be calculated using Eq.3 and 4.

$$k_p \geq 2C\xi\omega \quad (3)$$

$$k_i \geq C\omega \quad (4)$$

Where k_p represents proportional gain, k_i represents integral Gains, C represents the capacitance of DC link capacitor, ξ represents damping factor (0.707) and ω represents angular frequency. SAPF is highly nonlinear system and mainly depends on system parameters and load conditions. Hence calculated PI controller parameters don"t meet the system requirement in all conditions. So in this proposed work ABC optimization is used to optimize the gain values of PI Controller. The ISE error criterion function exhibits less overshoot and faster settling time when compare to IAE, ITAE and ITSE.

The ISE error criterion is used as objective function "j" for optimization is represented by the following equation

$$J = ISE = \int_o^t (e_r^2 * t)\, dt$$

$$e_r = V_{dc,ref} - V_{dc}$$

Where e_r is the error signal generated by a comparator which is equal to the difference between reference DC link voltage $V_{dc,ref}$ and actual DC link voltage V_{dc} and t is the time.

This section presents various performance analyses of single phase SAPF using different controller design methods such as conventional PI, ABC and Enhanced ABC based PI controllers. The proposed offline EABC based PI and conventional algorithms have been implemented using Matlab programming language. In simulation the minimum objective function achieved during each iteration is monitored for estimating the optimization efforts and also the quality of the food source identified by the scout bee is also monitored. The observed values are plotted in fig. 3

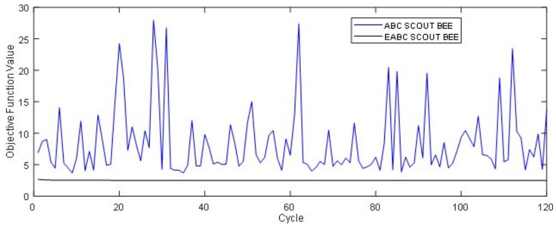

Fig. 3. Food source from scout bee of EABC algorithm

From the plot it is clear that the generated food source from scout bee of EABC algorithm is better than the conventional ABC algorithm. Because of the improvement in the optimization efforts made by Scout bee the proposed EABC converges so quickly at the minimum point.

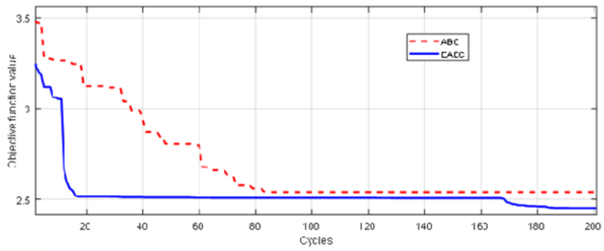

Fig. 4. Statistical Analysis of Food source from scout bee of EABC algorithm

This is clearly indicated in the convergence analysis plot. The Statistical analysis of convergence plot is presented in the table. From the statistical values of EABC such as low mean, low minimum value it is very clear that the proposed algorithm achieves better results in controller design. The numerical values of the statistical analysis of the Scout bee fitness curve are shown in Table2

Table 2 : statistical analysis of the Scout bee fitness

Parameter	ABC	EABC
Mean	8.755	2.499
Median	6.199	2.5
Standard deviation	5.89	0.02
Minimum value	3.386	2.452
Maximum value	31.51	2.666

The proposed EABC based optimum controller design yields better controller parameter values and this design outperforms the conventional tuning and conventional ABC based Controller. The corresponding optimized PI gain values (k_p, k_i) found to be 0.33 and 4.29 respectively. To

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simulate the harmonic source in the system a single phase H bridge inverter is considered as nonlinear load. And this nonlinear load is connected to the system at the point of common coupling. Before turning on the filter compensation is zero and the THD for the source current is 28.47 %. After turning ON the single phase SAPF, the harmonics are eliminated to 3.53 THD and this is well below the standard given by IEEE from supply current.

Table 3 Performance assessment of Single phase SAPF for conventional PI, ABC-PI and EABC-PI.

Performance Indices	Type of Controller		
	Conventional PI	ABC-PI (ISE)	EABC-PI (ISE)
K_p	0.105	0.25	0.30
K_i	0.65	6.9	4.2
$V_{dc}\_T_s$ (ms)	670	122	103
%THD	3.8	3.56	3.53
$\%M_p$	0	4.857	1.1758
ISE	155.4	61.7207	60.2501
IAE	6.21	1.8995	1.6452
ITAE	0.9656	0.3646	0.3507
ITSE	8.451	0.6351	0.5503

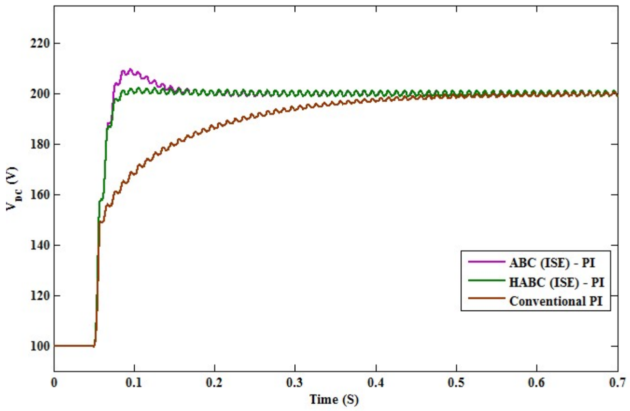

Fig. 5.DC link Capacitor voltage

Table 4. Single-phase SAPF parameters

Parameters	Symbol	Value
Supply voltage	V_s	100 V (rms)
Source resistance & Inductance	R_s& L_s	0.1Ω & 1mH
Supply frequency	F	50 Hz
APF parameters		
DC link voltage	V_{dc}	200 V
DC link capacitance	C_{dc}	800 μF
Filter resistance & Inductance	R_f& L_f	0.01Ω & 5 mH
Average Switching Frequency	F_{sw}	10 kHz
Load parameters		
AC side resistance	R_c	0.01Ω
AC side inductance	L_c	1 mH
DC side resistance	RL_{dc}	28 Ω
DC side inductance	LL_{dc}	160 mH

IV. CONCLUSION

In this manuscript a new novel hybrid ABC optimization algorithm is applied to PI controller of single phase SAPF has been proposed for nonlinear controller design and its performance is validated. The simulation and experimental results have been carried out for the three control methods, the Conventional PI, ABC-PI and EABC-PI control methods. From the results it has been found that proposed hybrid EABCcontroller outperforms the ABC and conventional PI in all performance indices such as ISE, IAE, ITAE, ITSE and other time domain performance measures such as Settling time.

The conclusion points arrived from the simulation study are listed below.

1. The Proposed controller design Effectively compensates the current harmonics and reactive power.
2. The proposed EABC optimized control technique reduces the supply current THD well below 5%.
3. SAPF with EABC optimized controller is found to be superior to the SAPF designed by ABC optimized PI controller and conventional PI controller in all operating conditions.
4. A good compromise between the THD, settling time and peak over shoot were obtained with ISE considering as cost functions.

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Dr.M.Murugan, currently working as an Assistant Professor, Department of Electrical and Electronics Engineering, Government College of Engineering, Bodinayakkanur. My area of interests are Control of Electrical Drives, Power Electronics Converter and Renewable Energy Systems. I have more teaching experience both in UG & PG level and also research experience. I have published several papers in international journals. I have presented more papers in international conference proceedings and several papers in national conference proceedings. I have guided several undergraduate projects and post graduate projects.

VINOD ARUNACHALAM is Assistant Professor at College of Electronics and Communication Engineering, Government College of Engineering, Dharmapuri. He holds Master of Engineering with specialization in VLSI DESIGN at Anna University of Technology Coimbatore. His research areas are medical image analysis, VLSI DESIGN, Genetic Algorithms and image/Signal Processing. He is a member of ISTE.He published many paper in reputed journals. He can be contacted at email:vinodnash@gmail.com

