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Mitigation of Grid Current Harmonics by ABC- ANN based Shunt Active Power Filter

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ABSTRACT

Harmonics are being introduced into power system networks as a result of the increasing use of nonlinear devices. These harmonics cause distortion of current and voltage signals, which in turn causes damage to power distribution systems. As a result, the suppression of harmonics is of extreme significance in power systems. This paper proposes Shunt Active Power Filters (SAPF) based on neural network algorithms like Artificial Neural Network (ANN) as a feasible approach to mitigating harmonic distortion and raising power quality in electrical distribution systems. This research shows that using shunt active power filters (SAPF), which use the Artificial Bee Colony Optimized Artificial Neural Network Controller (ABC-ANN), is an efficient method for enhancing power quality and minimizing harmonic distortion in distribution systems. The ABC-ANN algorithms have been produced for SAPF with the goal of improving system performance by reducing Grid current Harmonics. In the first stage of this work, PSO Technique is used to tune a standard PI controller to its optimum gain values (K_i ,K_p). Then, these target and input data of PSO tuned PI controller will be supplying inputs to the ANN controller. To find the optimal weight and bias values, this ANN controller has been tuned with the help of the ABC algorithm. Using MATLAB/SIMULINK software, we compare the performance of the proposed algorithm to that of other optimization algorithm like Differential Evaluation (DE) algorithm, as well as the PSO tuned PI controller and traditional PI controller. The findings from the simulation suggest that a SAPF utilizing an ABC trained ANN controller could improve THD in the supplying current while maintaining harmonics within IEEE-519 accepting levels.

1. Introduction

Power electronics components and large quantities of non-linear load bring about destructive harmonics in Grid current at the Point of Common Coupling or P.C.C [1]. Because harmonics in distribution system current can trigger an extensive range of problems, including loss, instability, noise, heating appliances, and so on, In order to reduce potential harm, it is essential to reduce them to an acceptable level of Total Harmonic Distortion [2] as defined by the IEEE-519 guidelines.

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In the 1970s, Gyugyi [3] was the first to discuss the power quality problems that arise when the current changes. Power quality analyzers and synthesizers, also known as shunt active power filters, can be used to fix the problem of current variation. Active filters dealing with power quality variations and their measurement in processed control and power utility systems were also stressed by Akagi [4], another notable researcher. Power engineers and researchers are on the lookout for transit solutions to maintain the distributed side of the system in light of the development of flexible AC transmission devices in the transmission line, which lower the operational cost without raising the installation cost. Typically, these are referred to as "custom power devices" (CPDs). Shunt active power filters are one low-cost method for lowering current fluctuations. Topological structures, sizes, optimal placement, and control factors for SAPF have all been investigated. These have left a few gaps, including issues with improper compensation and switching. Researchers looked into improved filter architecture as a solution.

One possible way to deal with current harmonics, reactive power, and poor power factor is to install a shunt active power filter (SAPF). The SAPF configuration shown in Figure 1 consists of a voltage source inverter (VSI) and an active filter controller. For the VSI to inject compensating reverse current at PCC, the control unit must provide timely and accurate firing signals [5,6].This will make it possible for the VSI to accomplish its goal. Reactive power control is provided to the grid via a DC-link capacitor installed on the VSI's input side [7].

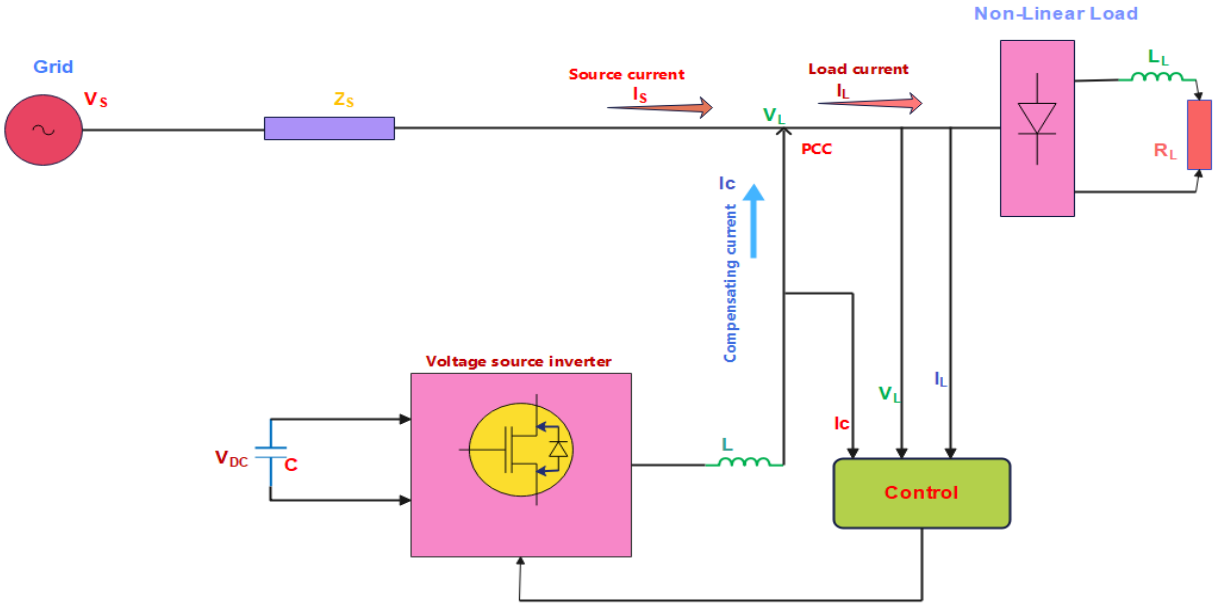


Fig. 1. Circuit diagram of the shunt active power filter

Either reference generating methods or control strategies can be utilized in the process of analyzing the VSI switching operation. Compensating signals are extracted from distorted signals using reference current generation theories, and then appropriate firing signals are generated using signal determined reference techniques to control the SAPF switching devices [8]. These two steps together constitute the SAPF control techniques. These are the two steps that are able to be implemented. Numerous authors have made comparisons between the various SAPF control strategies [9,10].

The harmonic content mitigation is performed by the PI controller that is a part of the control strategy. The PI proportional and integral gain values must be calculated for the controller. Methods such as Ziegler–Nichols and Cohen–Coon, for example, are helpful in determining the K_i and K_p values explicitly for power systems that have linear loads. These linear control strategies will not function for a system that is subjected to nonlinear loads. In the present day, intelligent and optimal tuning algorithms such as Evolutionary Programming (EP) like Genetic Algorithm (GA) , Particle Swarm optimization (PSO), Simulated Annealing (SA), Differential Evolution (DE) [11-15] .Algorithm have been developed to solve the problems of dynamic electric system problems with enhanced optimal tuning SAPF devices.

The word Artificial Neural Network shortly ANN is used to describe a system which is designed and operates similarly to the human brain. Neurons form a network all over the brain. The overall network's behavior is determined by the strength of the connections between interneuron as well as the configuration of those connections. During network training, the weights are able to and will be adjusted and changed [15]. Only for the purpose of supplying reference compensation current is SAPF currently using Artificial Neural Network (ANN) techniques [16]. This current is then utilized to manage the compensation that SAPF provides. There are a number of approaches that can be used to learn weights. Methods include the Steepest Descent strategy to learning variables, the Levenberg-Marquardt [17] method, and the Widrow-Hoff (W-H) method are just a few examples.

In this work the reference current is calculated using instantaneous active and reactive power (PQ-theory) and hysteresis current controllers estimate reference currents to generate gating pulses [18]. Regulating dc link voltage using an ANN-controller [19] based on IRP theory requires tuning of weight and bias parameters. In addition, the Artificial Bee Colony Optimization Algorithm (ABC), which was proposed and tested against other Optimization algorithm such as Differential Evaluation (DE) algorithm, was used as the motivation for this article in order to find the ideal ANN-controller weight and bias and acquire the objective function while minimizing Total Harmonic Distortion(THD).

2. PQ Theory

PQ theory-based constant instantaneous power control is for 3-phase, 3-wire power distribution systems with sinusoidal and symmetrical source voltages. To apply this theory, the three-phase source voltage (V_a, V_b, V_c) and load current (I_{la}, I_{lb}, I_{lc}) must be sensed and transformed by the Clarke transformation into the (α,β) components. These components are input for instantaneous power calculations [20]. An error signal from the reference and measured dc-link voltages determines the power losses component. To calculate power losses (Ploss), a PI-controller receives this error signal. The (α, β) components, active and reactive powers, and current calculation are used to estimate the reference (α, β) components. An inverted Clarke transformation (α, β) transforming these components to three phase abc values ($I_{abc,}V_{abc}$) as shown in Figure 2 to obtain the desired reference current signals.

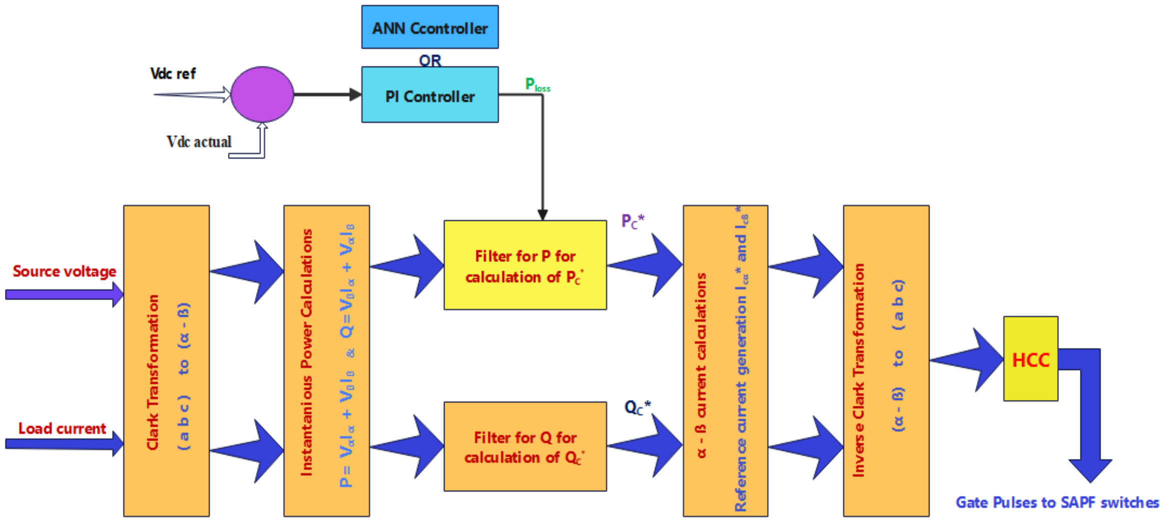


Fig. 2. Reference current generation with IRP (PQ) Technique

3. Structure of Artificial Neural Network (ANN)

The term artificial neural networks or ANN refers to a type of algorithm that is modeled after the way the brain operates and is used to model complicated patterns and predict future events. The concept of the Biological Neural Networks found in the human brain was the inspiration for the development of a technique known as the Artificial Neural Network, or ANN. An attempt was made to model the behavior of the human brain, which led to the development of artificial neural networks (ANN). The functioning of ANN is strikingly comparable to that of biological neural networks, despite the fact that the two systems are not identical. The ANN algorithm will only take in data that is numeric or structured.

- The architecture of the network is composed of three levels: the input layer, the hidden layer and the output layer as shown in Figure 3. As a result of the many layers, they are often referred to as the MLP (Multi-Layer Perceptron).
- The hidden layer can be thought of as a "distillation layer" that takes the most important patterns from the inputs and sends them to the next layer for more analysis. It speeds up the network and makes it more efficient by picking out the most important information from the inputs and getting rid of the rest.
- The activation function is useful for two reasons. First, it enables you to turn on your computer.
    - The presence of non-linear interactions between the inputs is captured by this model.
    - It aids in the transformation of the input into a more useable output.
- To construct an effective model, it's important to find the "optimal values of W—weights" that minimize Mean Square Error. This is done by the "back propagation algorithm," which turns ANN into an algorithm that learns from mistakes.
- The "gradient descent" method is used to measure prediction errors in the "optimization" approach. To find the best value for W, small changes are made and the effects on prediction errors are looked at. Lastly, those W values are chosen as the best because changing W any more doesn't make mistakes less likely.

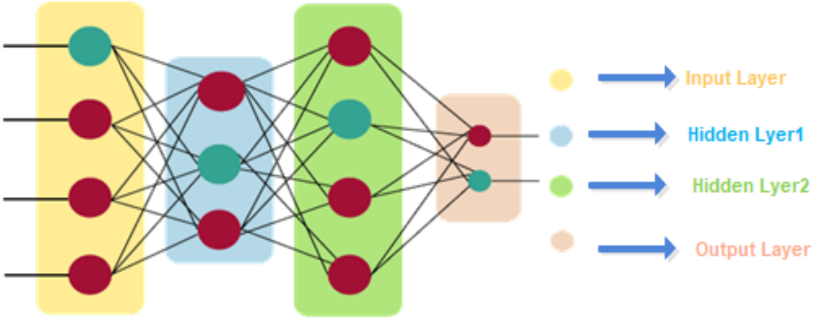


Fig. 3. Architecture of the artificial neural network.

To extract a fundamental component from SAPF while avoiding harmonic pollution, ANN architecture was utilized. For a given source voltage, it can be ensured by accurately predicting the reference current in ideal and real-time load applications. In the context of increasing reliance on nonlinear loads in residential and industrial applications, the mitigation of harmonic pollution has been a significant problem. ANN has been proven to be more applicable than p-q theory in circumstances of inaccurate voltage involving harmonic contamination in the source current and additional harmonic contamination due to the load current.

4. Artificial Bee Colony (ABC)

The ABC optimization method is an example of a meta-heuristic approach. Karaboga [21] came up with this idea first. The main idea behind ABC is how honey bees get food. In the ABC algorithm, there are three groups: worker bees, watcher bees, and scout bees. Bees were sent around the hive at random to find out where food was coming from. This information is shared with onlookers, who then decide which food source to choose. The random search is being done by Scout.

Figure 4 shows how honey bees act in general. Let's say that A and B are food. One of the possible bee starts out as a jobless bee. It has two options: it could be looking for food (S) or it could be doing the waggle dance (R). After it finds a food source, it will remember where it is and start taking advantage of it. Now, the Bee is a working bee. Once the food is turned into nectar, the same bee has three choices. may it lose its job, find new nest mates, and go back to the food source or keep looking for food in the same place.

The probability of a food source is given by the equation (1).

$$P_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_i} \tag{1}$$

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

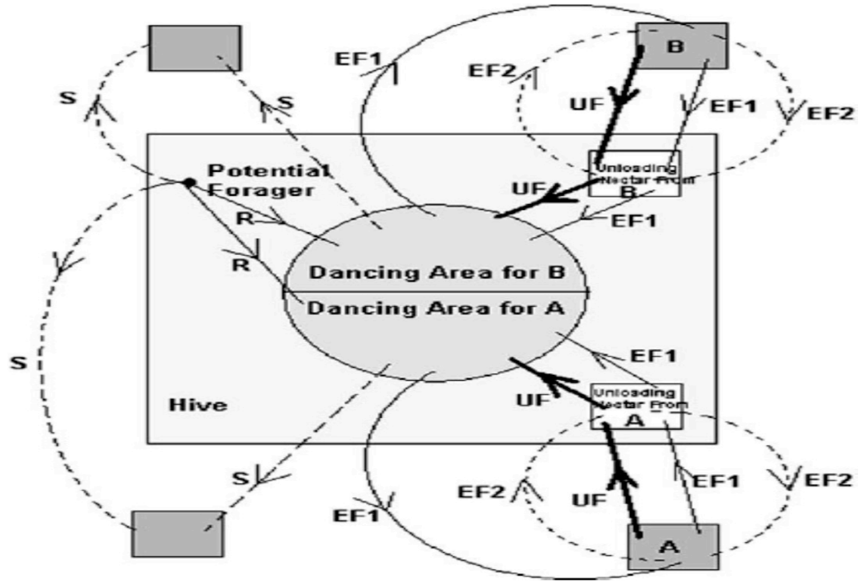


Fig. 4. ABC architecture

The candidate's food position from memory is given by equation (2).

$$v_{ij} = x_{ij} + {}^{\Phi}{}_{ij}(x_{ij} - x_{kj}) \tag{2}$$

$k\boldsymbol{\varepsilon}\{1,2,\ldots..SN\}andj\boldsymbol{\varepsilon}\{1,2,\ldots..D\}$, ϕ_{ij} random [0,1]
The following is a list of the stages that constitute the algorithm's procedure:

1. Read data
2. Read data
3. The distribution of working bees across various food sources
4. Distribute onlooker bees to the food sources in proportion to the amount of nectar they collect.
5. To find fresh sources of food, you should send the scouts to the area that is being searched.
6. In the meantime, keep the knowledge you've acquired regarding the greatest food source in storage.
7. Determine whether or not the requirements have been fulfilled.

5. Proposed Implementation

5.1 PI tuning with PSO Algorithm

The key function of SAPF is dependent on the abilities of a standard PI controller's regulation of the DC link voltage. It is probable that this controller produces for K_p and K_i will not be optimal values. Because it needs a great degree of mathematical calculation The PSO method can be used to determine the best possible values for both K_p and K_i.

As shown in Figure 5, the PSO-PI controller will be given an error signal based on the difference between the actual and reference dc voltages. To acquire the ideal gain values, the PSO method must minimize the Integral Absolute Error (IAE) objective function. With 1000 maximum number of iterations and 50 Populations, the Optimum values of gains (K_i, K_p) are 5.65119 and 7.93019. We set the bare minimum and highest possible values for K_p and K_i respectively at 0 and 200.

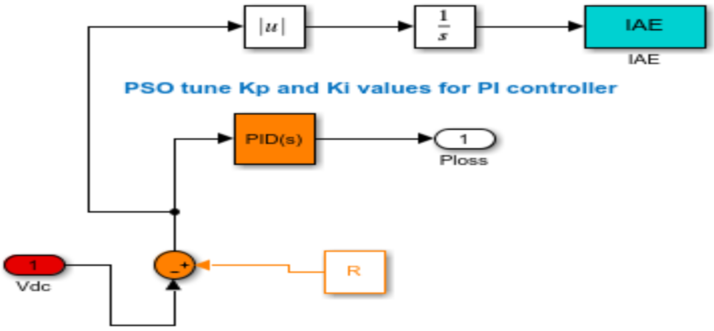


Fig. 5. DC link voltage regulation by PSO trained PI based SAPF

5.2 ABC Trained ANN Algorithm

The goal of ANN algorithm is to get the weights and biases of the network to be as accurate as possible. ANN's weights and biases are given the right values by using a variety of methodological approaches. This paper used a method called ABC. Figure 6 shows that The inputs (e) and outputs (out) of the PSO-PI controller are going to be used as a source of data for the neural network controller.

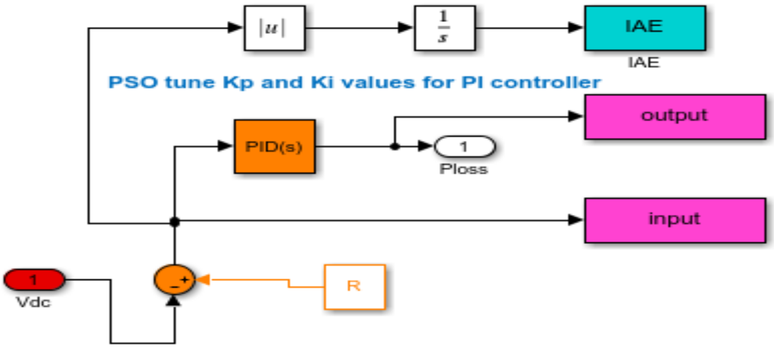


Fig. 6. PSO tuned PI controller’s input and target extraction

The necessary code to set up the neural network is provided below. The PSO-PI controller's input and target values are retrieved, hidden neurons are initialised.This data is used to configure the ANN, and finally, the network's weights and biases are extracted. Then, we'll define a pre-trained neural network's weights and bias using the ABC algorithm, with the objective function defined as the root mean square error.

Initialization of ANN

- I = input(e)';
- T = output(out)';
- N = 12;
- Nnet = Feedforwardneuralnet (N);
- Nnet = configurate (Nnet, I, T);
- getingwb(Nnet) (W- weight and B- biases)
- Root-mean-squared error in expressing (g) is the objective function. and it is determined by the weights, bias(y), Nnet, I, and T.
- The ABC algorithm should be used to train the neural network.Weights, bias, and error (y, e), all updated, can be calculated from this.
- Nnet = setingwb(Nnet, y');

- getingwb(Nnet)
- error= T - Nnet (I);
- difference = mean(error.^2)/mean(var(T',1));
- generatesim(Nnet)

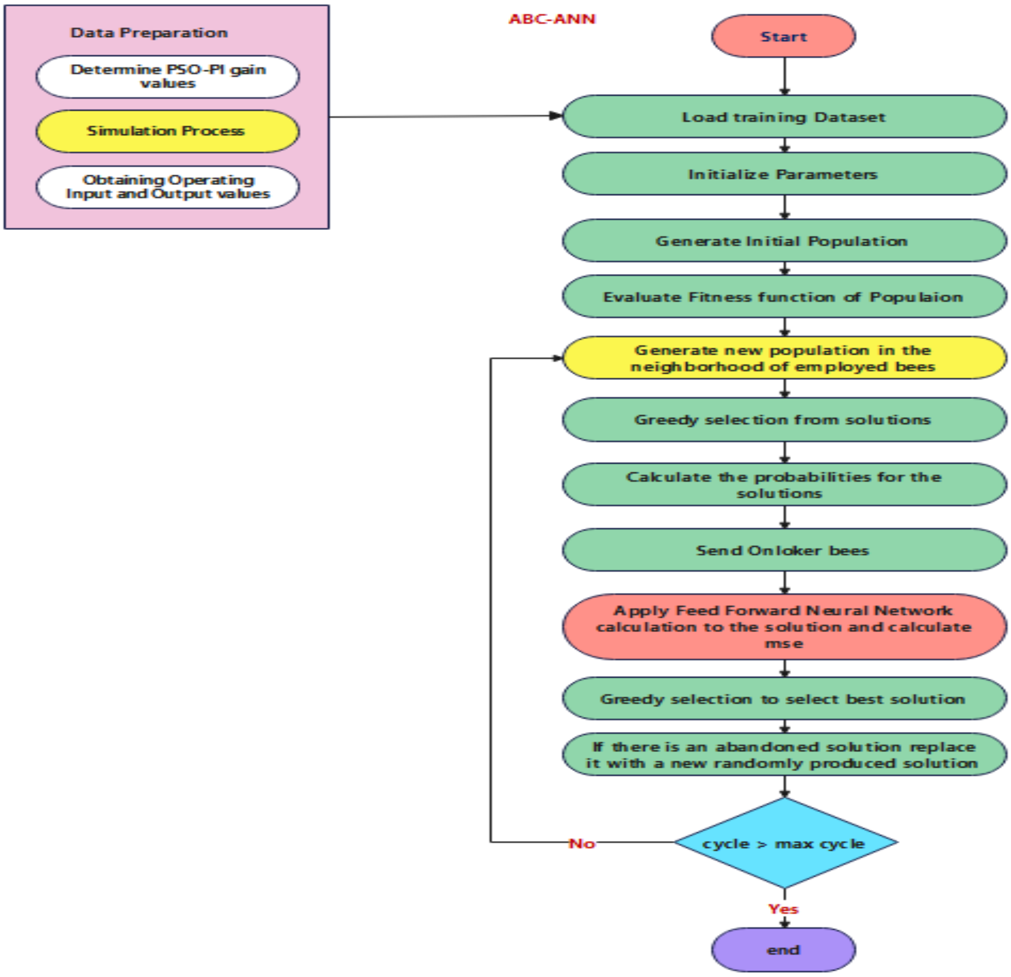


Fig. 7. Flowchart representation of ABC-ANN algorithm

Once the converges reaches steady state and the Mean Square Error (MSE) of the network decreases below a specific threshold, the network has reached convergence. Another way to stop learning is to limit the number of times something can be tried. The flowchart for the training algorithm is shown in Figure 7. Therefore, The PSO-PI controller will replace the feed-forward neural network shown in Figure 8 when input and output data are provided.

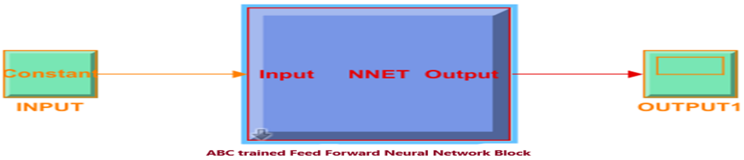


Fig. 8. Simulink block of ABC-ANN algorithm

6. Results and discussions

This section contains a discussion of the simulation results that were obtained using MATLAB. It is simulated both for the proposed ABC-ANN based controller as well as for the TLBO-ANN and DE-ANN controller based SAPF, and then comparing all of the obtained results.

The ANN- controller's weights and bias are adjusted to improve the source current THD value. Then, the controller's performance is measured with a static non-linear load connected to the PCC. The following situations were used to carry out this evaluation.

I. Without SAPF

In this case, SAPF is turned off, and a Fast Fourier Transform (FFT) analysis was used to figure out that the nonlinear load caused a 18.42% of THD change in the source current as shown in Figure 10 and Figure 9 shows how the source and load currents look in a three-phase simulation.

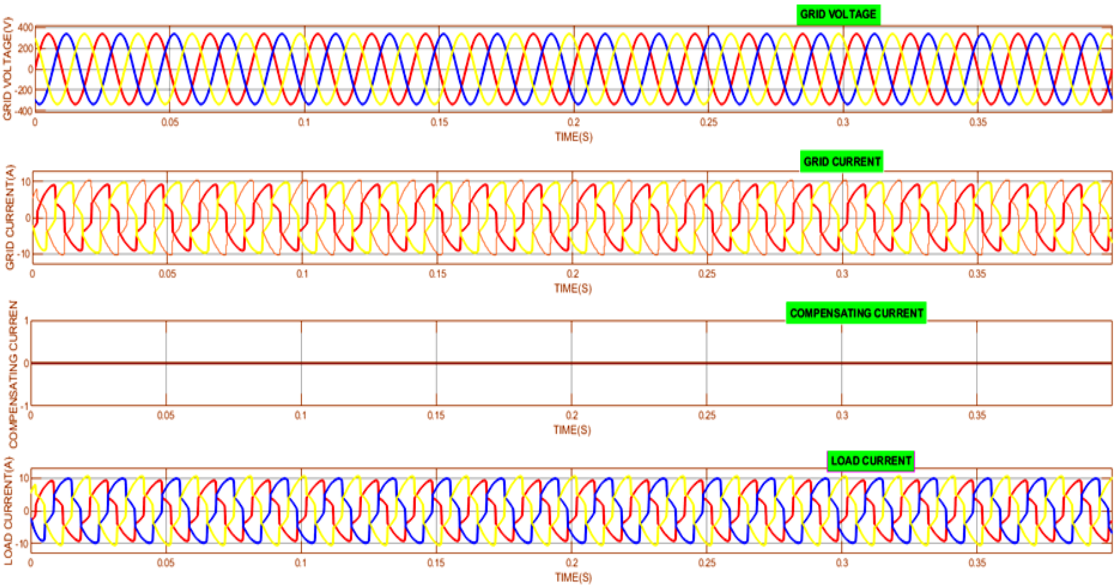


Fig. 9. The waveforms of the I_L, I_S, I_C, I_S, without using SAPF

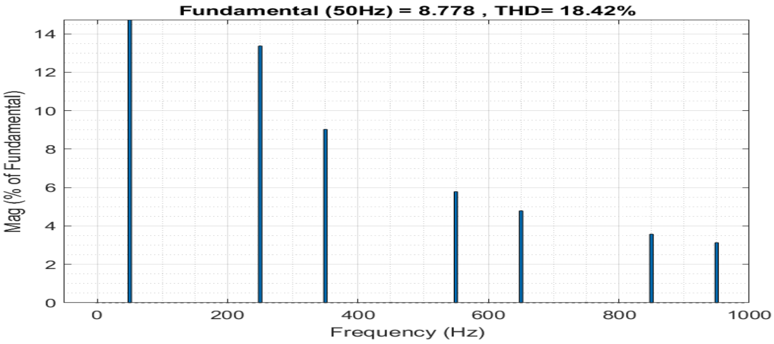


Fig. 10. THD result of source current without using SAPF

II. PI Controller based SAPF

Here, SAPF is attached to PCC, and conventional PI controller gains were used to obtain simulated results. Following the use of SAPF compensation, the distortion in the supply current was cut down to 3.76 percent from its initial value. Moreover, the harmonic spectrum of the source current may be seen in Figure 11, as depicted correspondingly.

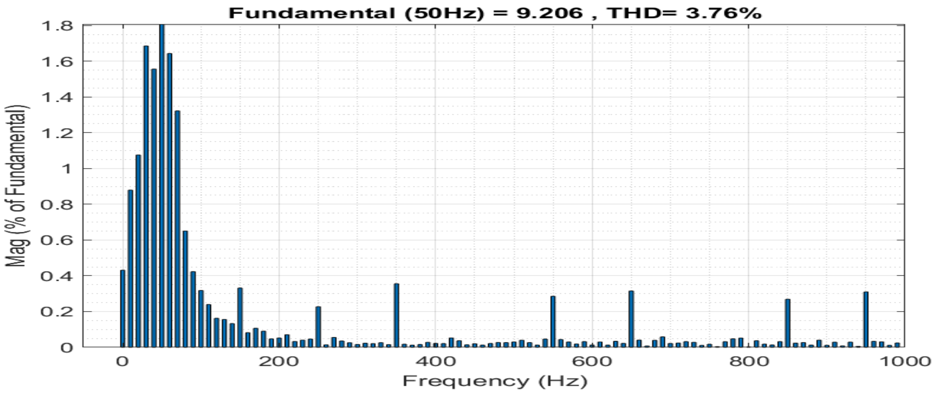


Fig. 11. THD result of I_S (Grid current) by PI based SAPF

III. PSO-PI based SAPF

In this present scenario, the SAPF compensation action was used to run the simulation, and the PI-controller gains were adjusted with the help of the PSO Algorithm. Both of these procedures were carried out in order to achieve the best possible results. According to Figure 12, the findings that were collected point to the possibility that there has been a significant decrease in the THD of the source current to an extremely manageable level of 0.93%.

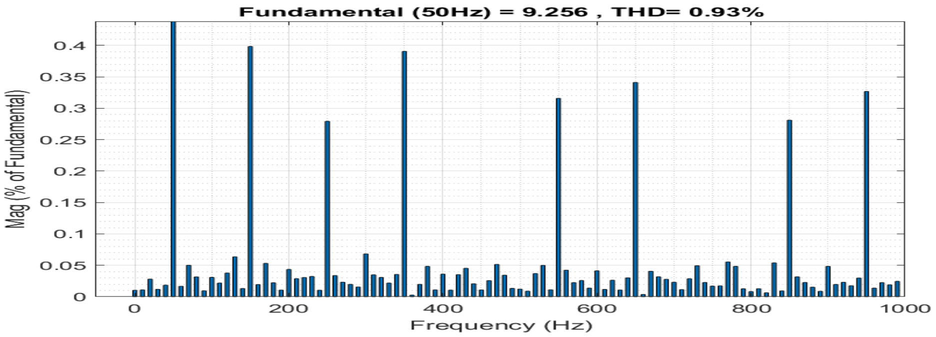
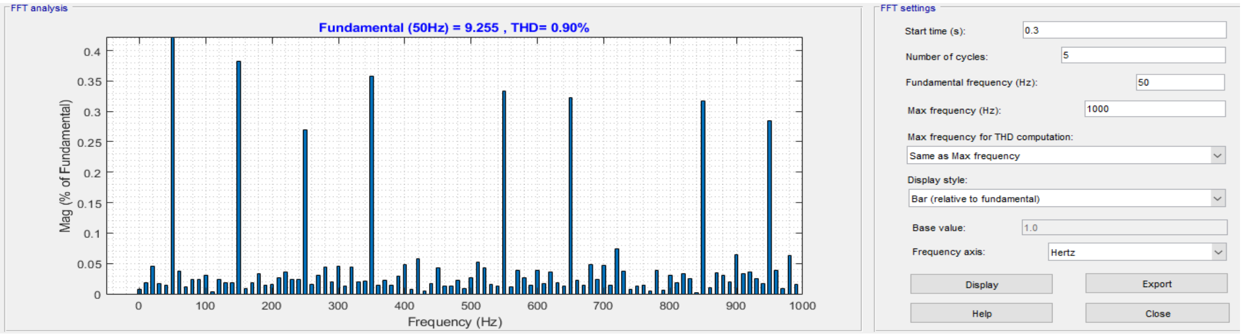


Fig. 12. THD result of I_S (Grid current) by PSO tuned PI based SAPF

IV. DE tuned ANN based SAPF

Here, instead of using a PSO-PI controller, a DE-ANN controller Simulink block was used. THD in the source current was mitigated to 0.90%, as displayed in Figure 13.



Start time (s): 0.3
Number of cycles: 5
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Same as Max frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Fig. 13. THD result of I_S (Grid current) by DE tuned ANN based SAPF

V. ABC tuned ANN based SAPF

Here, the PSO-PI controller has been swapped out for the ABC-ANN controller Simulink part. Utilizing block of a feed-forward neural network, depicted in Figure 14. That is acquired from the Figure 9. Based on the results of the measurements, the total harmonic distortion (THD) of the source current appears to have diminished to 0.84%.

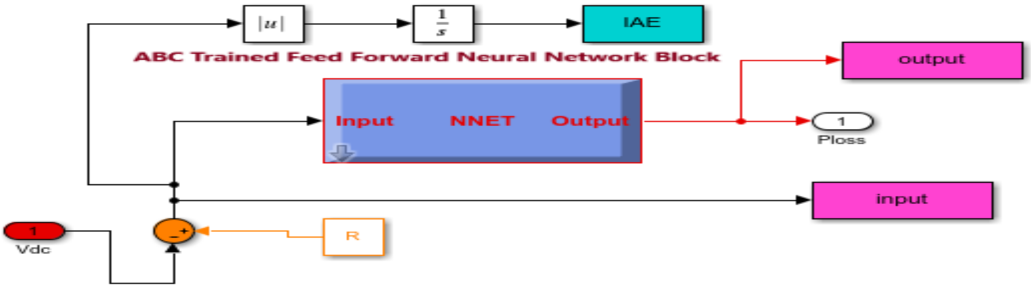


Fig. 14. Controlling the DC voltage in a SAPF with an ABC-ANN regulator

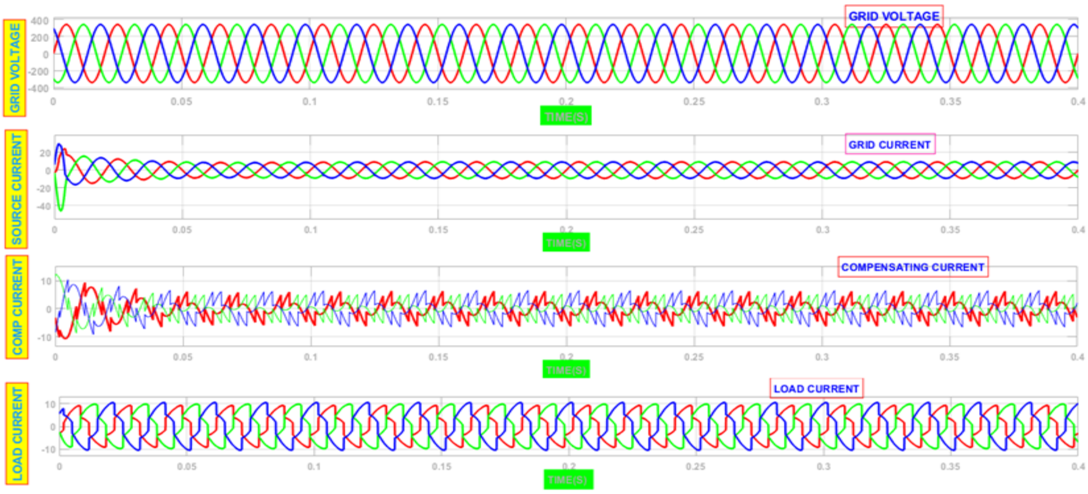
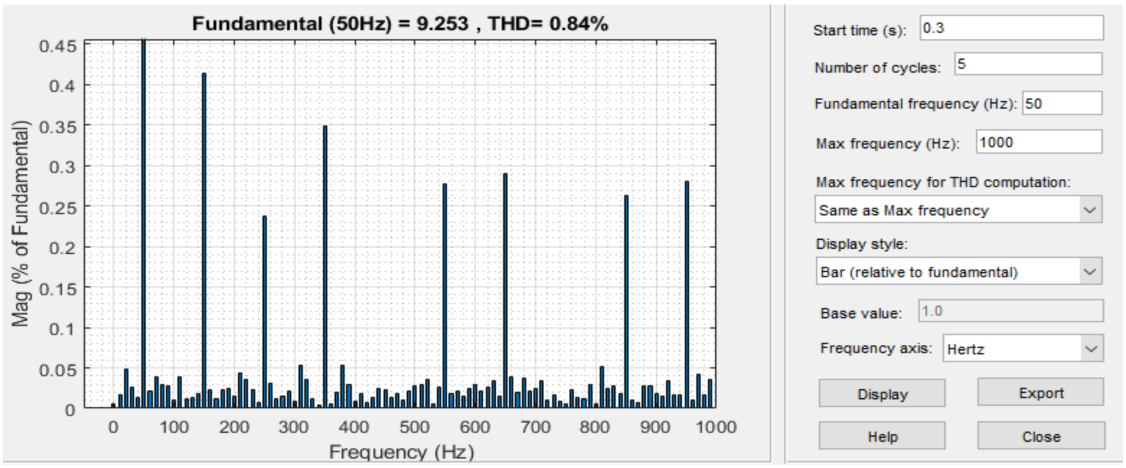


Fig. 15. The waveforms of the I_L, I_S, I_C, I_S, by using ABC trained ANN based SAPF

Figure 15 illustrates the waveforms of the currents flowing from the source, the load, and the SAPF compensating current. In order to maintain a sinusoidal source current, SAPF injects compensating current at the PCC using an ANN controller that was trained using the ABC algorithm. The harmonic spectrum of the source current is depicted in figure 16. The ABC-ANN controller's converging spectrum can be seen depicted in Figure 17. The error measured by the ABC ANN controller is shown to be smaller than that measured by the DE -ANN controller.



Start time (s): 0.3
Number of cycles: 5
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Same as Max frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Fig. 16. THD result of I_S (Grid current) by ABC tuned ANN based SAPF

ABC-ANN parameters are listed in Table 1 and Table 2 presents the results of the SAPF investigations into all six incidents.

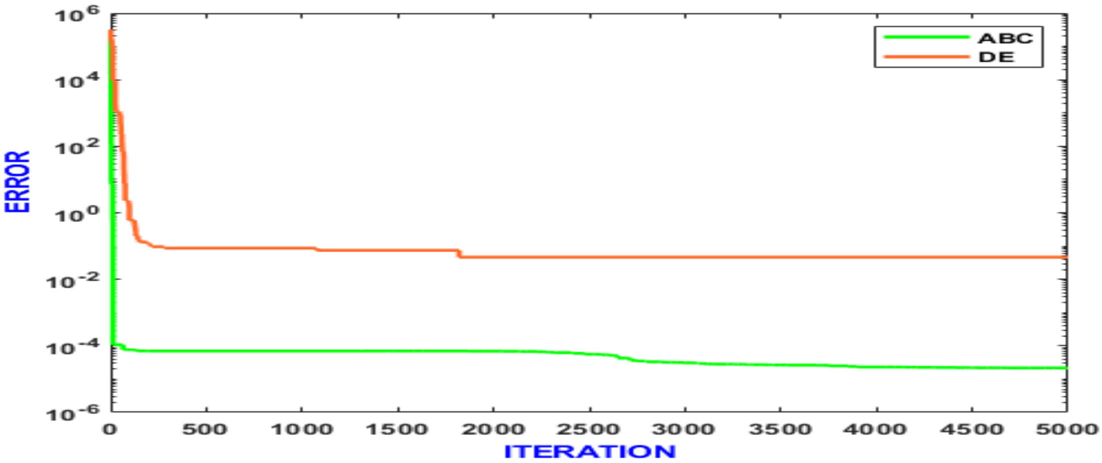


Fig. 17. Converges graph for the three optimization algorithms

Table 1
Parameters of ABC trained ANN

Total number of iterations	5000
Number of Population	25
Number of Onlooker Bees	25
Abandonment Limit Parameter	15
Acceleration Coefficient	1
Hidden number of Neurons	12
Total number of Variables	1
Max weights	200
Min weights	0

Table 2
Table of Comparisons

S_no	Type of Controller	Component	THD value(%)
1	Without using SAPF	I_S (Source Current)	18.42
2	PI based SAPF	I_S (Source Current)	3.76
3	PSO tuned PI Based SAPF [22]	I_S (Source Current)	0.93
4	DE tuned ANN based SAPF	I_S (Source Current)	0.90
6	ABC tuned ANN based SAPF	I_S (Source Current)	0.84

7. Conclusion

A novel Artificial Bee Colony based optimized Artificial Neural Network (ANN) controller is proposed for the purpose of improving the power quality in a SAPF-based power system with non-linear loads. Harmonics from nonlinearities are compensated and THD values are far below norms. This article recommends using the ABC-ANN control approach with the SAPF to reduce the THD in the power grid's source current. The successful implementation of the SAPF is evaluated and compared across a number of circumstances. The Matlab-Simulink software simulates total five situations and reports the results. Simulations show that DE-ANN, PSO tuned PI based SAPF and SAPF with PI controller minimize the THD, The ANN-ABC-based SAPF that was suggested provides better performance in terms of reducing THD in source current in comparison to other scenarios. According to the results, this improvement in performance is satisfactory (that is, within 5% of the recommended IEEE standard).

Future work will involve incorporating a hardware-in-loop implementation of the proposed shunt active filter. To further improve the SAPF's response, an ANFIS controller will be used that is predetermined with ABC and other optimization strategies.

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