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Ant Colony Optimization Technique Based Harmonic Suppression in Active Power Filters

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Abstract

This work recommends an innovative scheme for atonement of the reactive powers and minimization of harmonics with the application of ant colony based optimization algorithm (ACOA) to achieve a preferred proportional and integral controller gain, which is applied to the shunt connected active filters. The utilization of dynamic eager heuristic, +Ve feedback &distributed evaluation are the key preferences for the ACOA algorithm. An ACOA constructed improved PI controller is recommended to supersede the common PI controller which contributes in exceptional trail of DC power in APF under nonlinear load (NLL) circumstances. Moreover, there is a demand to confirm the strength of the ACOA algorithm, the outcomes are presented and equated to the particle swam optimization (PSO) based PI controller. The active filters are utilized in this analysis to minimize the global harmonic distortion of the source current in addition to the further parameters like active & reactive powers are observed and correlated by applying nature influenced algorithms like ACOA and PSO to attain the superior results. The suggested investigation can be carried out in the Matlab/Simulink software

1. Introduction

Applications involving the use of power converter like SMPS, telecommunication networks with rectifier circuits, domestic devices, UPS and variable speed drives are developing into extremely prevalent in present society [1]. These aforementioned loads serve as current sources, produces harmonics at PCC into the system, resulting in overheating of machines involved like motors & transformers and creating malfunction in the protection devices. Besides, it also results in minimized efficiency and causes interference in distribution systems of the surrounding communication networks. It is precarious to put in an appropriate compensating device to get rid of the harmonics formed by NLLs so as to mitigate the intrusion induced by harmonics to the currents present throughout the distribution network. Owing to the nonlinear characteristics of the input current, the energy supply should produce an extremely huge value of re-active power through the energy source. There are equivalent schemes to relieve the weakening impacts of harmonic distortion, one such device is a passive filter (PF)[2].

PFs are powerless in a range of conditions which includes resonance, transients& harmonic distortions of higher order problems moreover, they comprise a great & distinct compensation characteristic. In order to solve the issue of harmonics and reactive power, investigators are concentrating in the development a modernized power converter interface scheme namely APF or active power line conditioner [10]. APFs have been confirmed

to be considerably potent, especially due to their steady compensation, and their installation is a significant problem that leading to number new reviews subjects. The APF allotment is prompted by numerous specifications like the state of pollution, harmonic measure, location, size and system topology, [5]-[9].
In the various literatures, diverse harmonic load current extraction techniques have been reported. While comparing the other methods, the instantaneous true & reactive power values (PQ Values) based harmonic extraction method possesses desirable properties [11]. The PQ technique is applied to obtain values of current reference generation in this study. In the APF, the capacitor is needed on the DC side, and its adjustment shows a basic role of the APF. The CVC is significant for sustaining a stable potential under NLL variations. For the control of capacitor voltage in APF, classical PI controllers have been reported in the articles. The detriments of the classical PI controller consist of high start overshoot, tedious tuning gains, and inferior response to precipitous abnormalities [11]-[12].

Owing to its limited size current distortion and reducing reactive power demands. The aforementioned aspirations for an APF and lack of dependence on power system impedance, APFs are regarded as a feasible substitute for lessening harmonic can be achieved dynamically[13]. Nevertheless, of the numerous advantages of APF, the complexity & cost of the network have ever been prejudices [20]-[24]. The amalgamation of a passive component with an APF produces a hybrid system that greatly reduces the price of an APF.

The actions of ACOA are meant to resemble those of actual ants. Actual ants use pheromone in foinstead of the pictorial hints to find the shortest journey since the food source towards its nest[3]. When travelling, actual ants put down a few quantities of pheromone marks over the ground&every ant favours to take a pathway that is abundant in pheromone dropped by former ants over a pathway that is abundant in pheromone dropped by later ants. Currently, the scientific world has become increasingly interested in ACOA. In actuality, there are a range of ACOA applications available for various optimization challenges. Such methods are typically impractical in practice, while the relative procedure can be useful for quickly locating high-quality solutions. People are using ACOA to solve various industrial complications due to its broad applicability to academic problems, indicating the usefulness of the ACOA technique in more practical applications also [14]. The ACOA has been utilized to solve a variety of power network issues, such as partial load flow analysis, capacitor bank location, & economic load dispatch, to name some of the issues. A 3-phase & 3-wire ACOA method applied shunt APF is recommended during this research to improve THD & capacitor potential management. In part II, the APF's control methodology is discussed in detail. The optimization approaches are detailed in depth in part III of this paper. The simulation results and its deliberations are examined and detailed in section IV with the help of Matlab software. Finally, in part V, the conclusions are presented.

2. Control Methodology of APF

The general block representation of APF is depicted in Figure number 1and Figure number 2 displays a control structure of ACOA technique. The reference signal is generated using P-q theory. Clarke's transformation (abc-αβ) is used to convert a three-phase network into a two-phase network. The NLL's actual and reactive powers are calculated using the converted numbers listed below. Both AC and DC components are included in the p-q quantities.

$$\begin{bmatrix} v_{s0} \\ v_{s\alpha} \\ v_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_{L0} \\ i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_{s0} & 0 & 0 \\ 0 & v_{s\alpha} & v_{s\beta} \\ 0 & v_{s\beta} & -v_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{L0} \\ i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \tag{3}$$

Using the p-q technique from Clarke translation, the following equations (4) and (5) give the active and re-active power.

$$p = \bar{p} + \tilde{p} \tag{4}$$

$$q = \bar{q} + \tilde{q} \tag{5}$$

The following equation number (6) will display the reference currents in αβ – coordinates.

$$\begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} = \frac{1}{v_{s\alpha}^{2} + v_{s\beta}^{2}} \begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ v_{s\beta} & -v_{s\alpha} \end{bmatrix} \begin{bmatrix} -\tilde{p} + \overline{\Delta p} \\ -q \end{bmatrix} \tag{6}$$

Surplus average power is required to compensate for VSI deficits produced by power electronics switch switching, and it is expressed as

$$\overline{\Delta p} = \overline{p_0} + \overline{p_{loss}} \tag{7}$$

The average losses in the inverter are represented by ($\overline{p_{loss}}$). Once the actual DC link capacitor potential (Vdc) and reference value (Vdc*) are compared, the error is sent to the PI controller for further processing.

$$\begin{bmatrix} i_{ca}^{*} \\ i_{cb}^{*} \\ i_{cc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} -i_0 \\ i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} v_{sa}' \\ v_{sb}' \\ v_{sc}' \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{\alpha}' \\ v_{\beta}' \end{bmatrix} \tag{9}$$

$$\begin{bmatrix} v_{\alpha}' \\ v_{\beta}' \end{bmatrix} = \frac{1}{i_{\alpha}'^{2} + i_{\beta}'^{2}} \begin{bmatrix} i_{\alpha}' & -i_{\beta}' \\ i_{\beta}' & i_{\alpha}' \end{bmatrix} \begin{bmatrix} p' \\ q' \end{bmatrix} \tag{10}$$

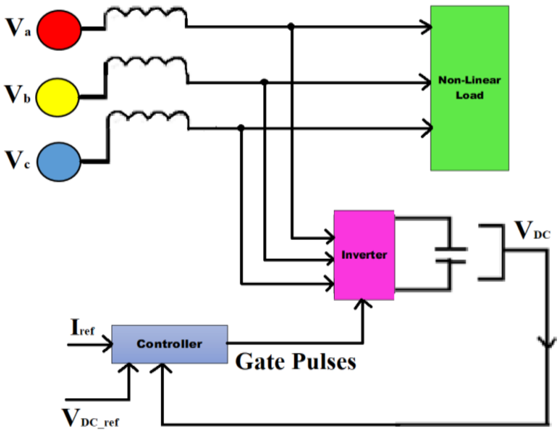


Fig. 1 *General schematic representation of APF*

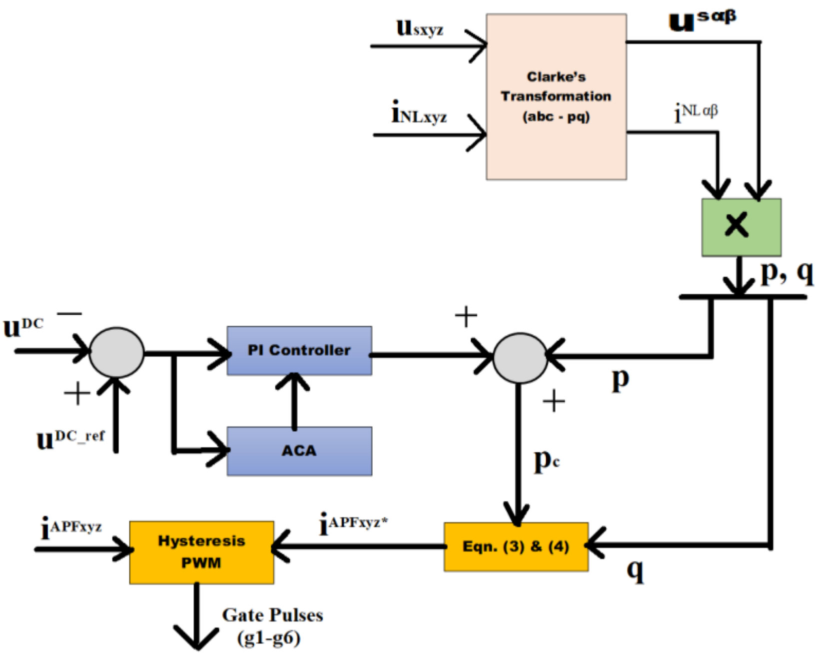


Fig. 2 *Control schematic of ACO trained PI controller*

3. Proposed Optimization Techniques

3.1 ACO Methodology

Creating a matrix with all of the currents and voltages is the first stage in implementing the ant colony algorithm. After that, an appropriate count of ants is picked. Over-all number of ants chosen for this scenario is two. Every ant commences their journey by randomly picking a first-stage condition. Each ant picks a stage at random and then travels through all of the states.

The ACOA was stimulated through the foraging activity of ants. According to researchers, ants usually find the shortest gap amongst the food &ant's shelter, since they construct pheromone traces that allow the ants to connect with one another and share info about food pathways. Typically, a swarm of ants will begin their quest for food by following random trails. Throughout the early explorations, ants put aside continuous concentration traces relating to their travels throughout time. As a result, the density of tracks on shorter path ways rises, making it easier for them to determine the shortest path to food.

To begin, an equal amount of pheromone is given to each stage's state. M ants then begin their journey based upon the pheromone intensity, heuristic data, & a probability function. Subsequently examining all positions, the pheromone of all positions is updated locally. In addition, the cost of objective function is determined for each ant. The goal of this project is to determine the ideal values for the controller gains KP and KI. The state that minimizes cost of objective function to the greatest level is chosen as the optimal result. The best ant then performs an over-all updation of the pheromone values in all states that the ant has gone through. This is done until you reach the maximum number of iterations. The ACOA, which is based on ant sanctions, commences a search inside a population by evaluating the fitness of every different associates of the populace using a cost function till everyone converges on the best answer.

In recent years, ANN and genetic algorithms have gained popularity. The study applies ant colony search methods to power system harmonic problems, replicating ant foraging behaviour, with the goal of determining its use in power system optimization. The algorithm's collaborating agents (ants) work together to find a good solution to the optimization challenges. The flowchart of the proposed method is shown in the figure number 3

3.2 ACO Algorithm

- Step 1: The start of the pheromone trail is the first step.
- Step 2: The iteration stage follows the first, in which each ant builds a complete solution to the problem using a probabilistic state transition mechanism. The state transition rule is mostly determined by the pheromone's state.
- Step 3: A global pheromone update rule is executed in two phases after all ants have generated a solution.

- Step 4: An evaporation phase in which a portion of the pheromone evaporates.
- Step 5: A reinforcement phase in which each ant deposits an amount of pheromone proportionate to the solution's fitness.
- Step 6: This operation is repeated until the stopping criteria are met.

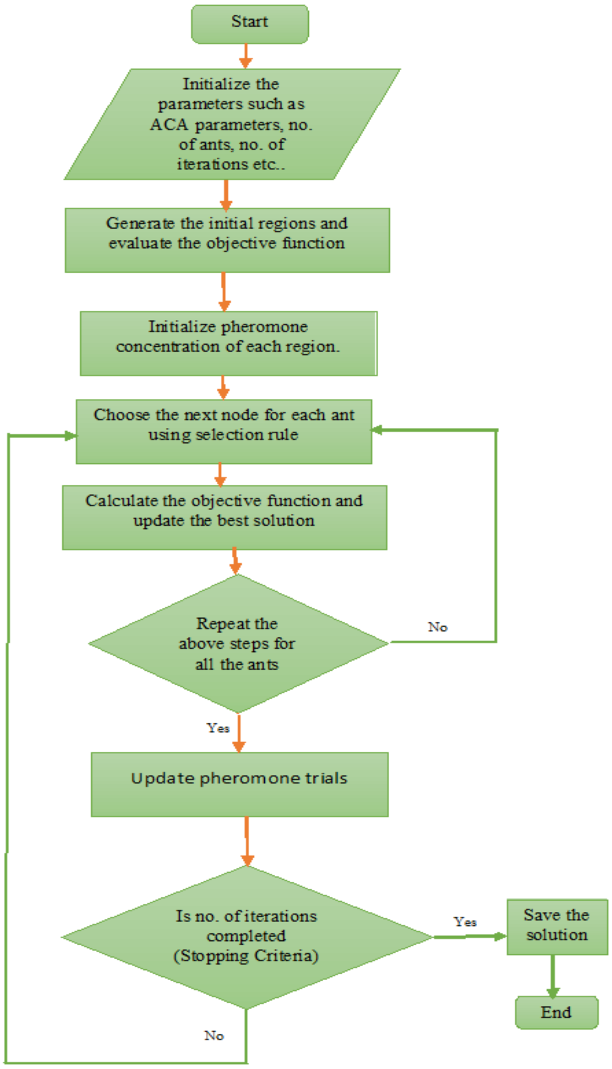


Fig. 3 *ACO methodology flow diagram*

3.3 PSO Methodology

PSO, like the ant colony search (ACS) and honey-bee modelling optimization (HBMO), is a population-based algorithm influenced by bird flocking and fish schooling. PSO was designed to tackle problems involving continuous nonlinear optimization, but with more research, it can currently handle constrained nonlinear optimization problems including both discrete and continuous variables. The steps of the PSO technique are outlined in the steps that follow.

1. Assign each particle a random location all over the interstellar space region to form the group (called as swarm).
2. Determine the fitness value of every particle.
3. The fitness rating of each individual particle is associated to the global best. If the current estimate is better than the global greatest position estimate, assign a value to it as well as the position of the current particle.
4. The particles in the swarm are classified according to the greatest solution.
5. Update the velocity & locations of all particles.
6. Repeat steps 2 through 5 to complete the stopping task.

A few fundamental parameters, a added effective memory size & a improved technique for maintaining swam diversity are among PSO's advantages. Here apparent power will be same in all case. It has reasonable value. Here Vdc is reduced for our scenario because, Load side reactive power (Lead) is injected in order to maintain load side THD to good value which in turn Source current THD is getting better value. As per IEEE standards the THD is less than 5 % in source current. That's reason we have modified accordingly.

3.4 ACO Algorithm is Better Compared with PSO in the Following Aspects

i. Inspiration:
  - ACO: Inspired by the foraging behaviour of ants, where pheromones guide the exploration of paths.
  - PSO: Inspired by the social behaviour of bird flocks and fish schools, where particles adjust positions based on their own experience and the collective information of the swarm.

ii. Mechanism:
  - ACO: Uses artificial ants that probabilistically build solutions and communicate through pheromones.
  - PSO: Involves particles moving through a search space, adjusting positions based on their own and swarm's best-known positions.

iii. Communication:
  - ACO: Communication is indirect through pheromones indicating solution quality.
  - PSO: Direct communication among particles sharing personal and swarm's best-known positions.

iv. Exploration vs. Exploitation:
  - ACO: Balances exploration and exploitation using pheromones to explore new paths while exploiting information from previous paths.
  - PSO: Balances exploration and exploitation by adjusting particle positions to explore the search space while gravitating toward the best-known positions.

v. Global Information:
  - ACO: Global information is distributed through the pheromone trail.
  - PSO: Global information is directly shared among particles.

vi. Convergence Speed:
  - ACO: Tends to converge more slowly, especially in complex problems.
  - PSO: Often converges faster, especially in simpler problems.

vii. Applicability:
  - ACO: Well-suited for combinatorial optimization problems, such as path finding and routing.
  - PSO: Versatile, applicable to a wide range of optimization problems, including continuous and discrete optimization.

viii. Robustness:
  - ACO: Robust to changes in problem parameters and adaptable to dynamic environments.

PSO: Sensitive to certain problem characteristics and parameter settings, may require careful tuning.

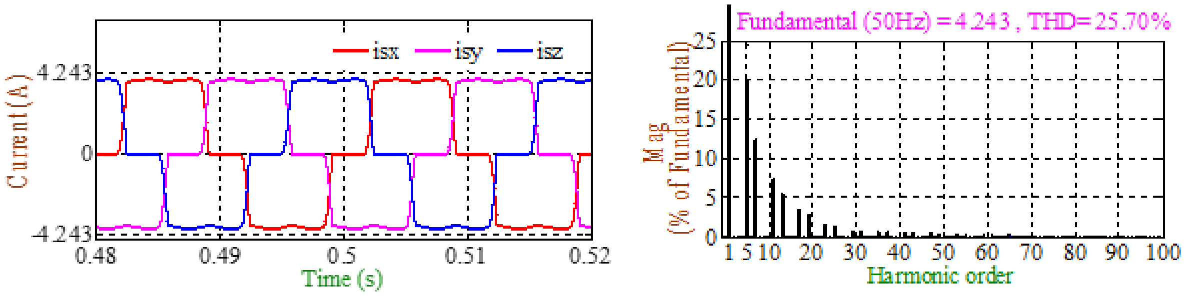
3.5 Simulation Results & Deliberations

The proposed ACOA based PI controller circuit is simulated using MATLAB / Simulink. The results obtained are presented in this section. The simulation system parameters are listed in the table 1.

Table 1 *Simulation input parameters*

Network Parameters	Corresponding Values
Network Parameters	
Grid Potential	415 Volts
Resistance of the Source side	0.1 Ω
Inductance of Source side	0.15 mH
Resistance of Load side	100 Ω
Inductance of Load	200 mH

side	
Inductance of the Filter	15 mH
Capacitance of the Filter	2200 µF
ACOA Method Parameters	
Number of cycles	3
Number of Ants	2
α	0.8
β	0.2
ρ	0.7



(a) **(b)**

Fig. 4 *Graphs pre-compensation (a) Input current; and (b) Input current's THD*

The graph of the source currents for the proposed SAPF system and its associated THD spectrum without any controller are shown in figure 4. As can be observed, when the SAPF is operated without a controller, it creates a lot of harmonic content, and the source current waveform is distorted and not sinusoidal.

Figure 5 and 6 shows the waveform of the input source current and its matching THD spectrum from the PSO &ACOA approach respectively. Figure 7 & 8 shows the 3-phase input current& output current for the PSO &ACOA constructed system respectively, and it is sinusoidal in both these cases

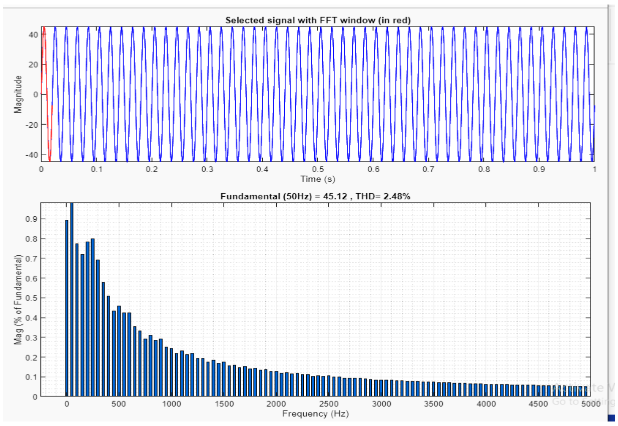


Fig. 5 *Graph for (a) Grid/Source current; and (b) Grid/Source currents THD of PSO method*

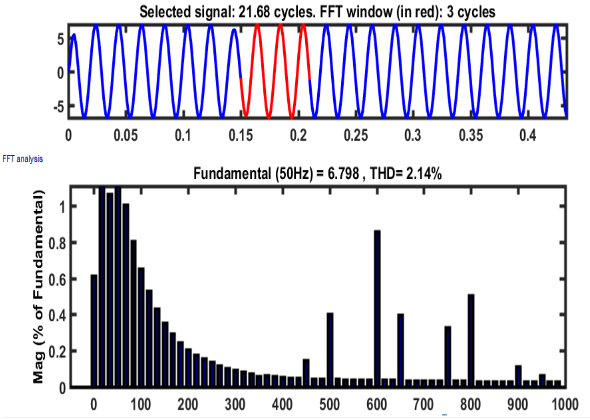


Fig. 6 *Graph for (a) Grid/Source current; & (b) Grid/Source THD of ACOA controller*

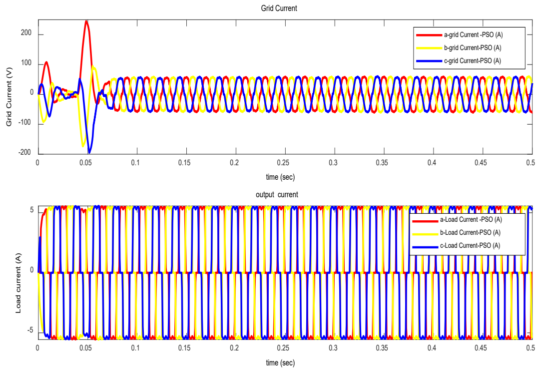


Fig. 7 *Graph for (a) Grid/Source current; and (b) Load current of PSO method*

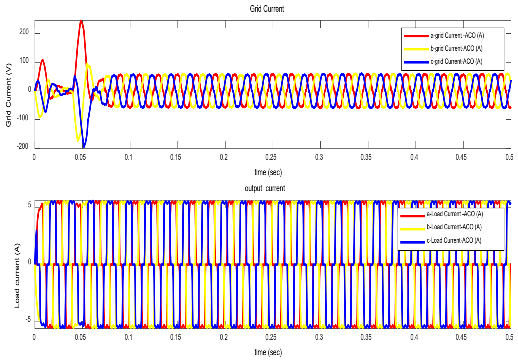


Fig. 8 *Graph for (a) Grid/Source current; & (b) Load current of ACOA controller*

Figures 9 & 10 depicts the changes in output/load 3-phase voltage & its corresponding currents for both the methods individually. A figure 11 and 12 depicts the 3-phase grid/source voltages and their currents of the PSO &ACOA techniques correspondingly. We can infer that the oscillations appear to settle quickly, resulting in a decrease in THD. Figure 13 depicts the real& re-active powers and Figure number 14 shows the voltage across the filter capacitor utilizing both the techniques.

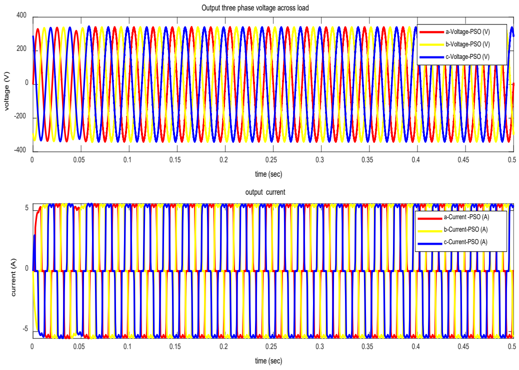


Fig. 9 *Graph for load voltage and load current PSO method*

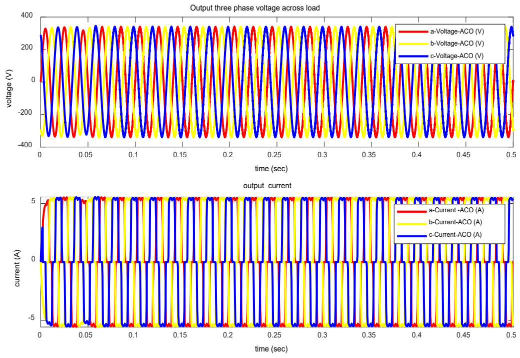


Fig. 10 *Graph for load voltage and of load current ACOA based controller*

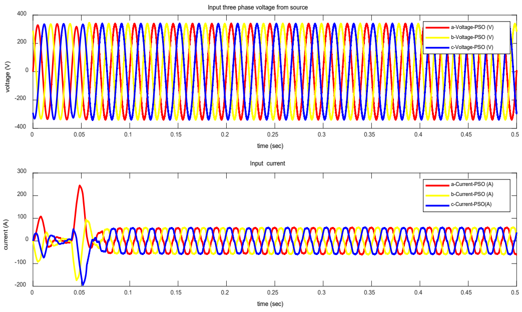


Fig. 11 *Graph for grid/source voltage & grid/source current of PSO method*

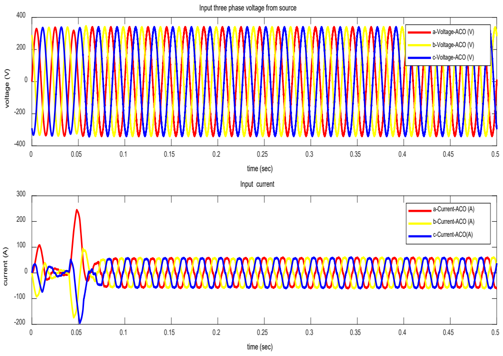
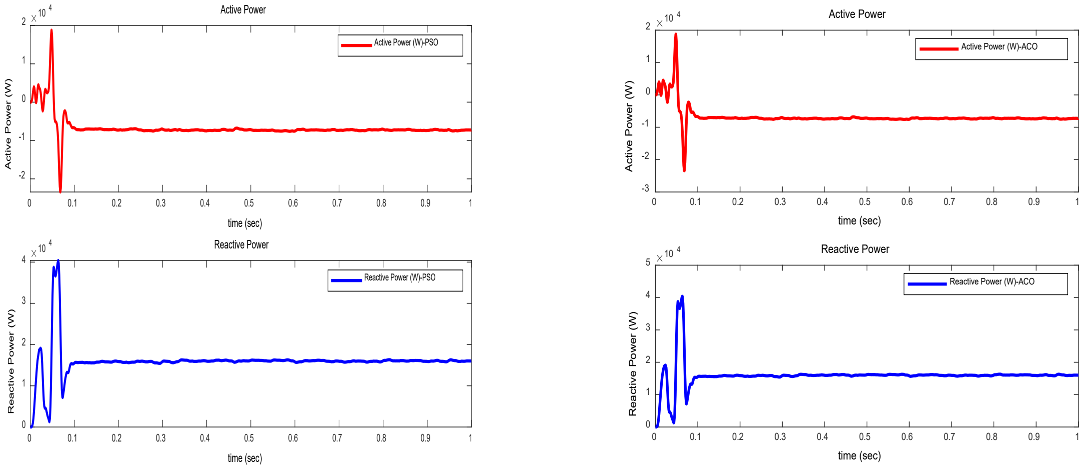


Fig. 12 *Graph for grid/source voltage & grid/source of ACOA controller*



(a) PSO **(b) ACOA**

Fig. 13 *(a) Graphs representing the active; & (b) Re-active powers*

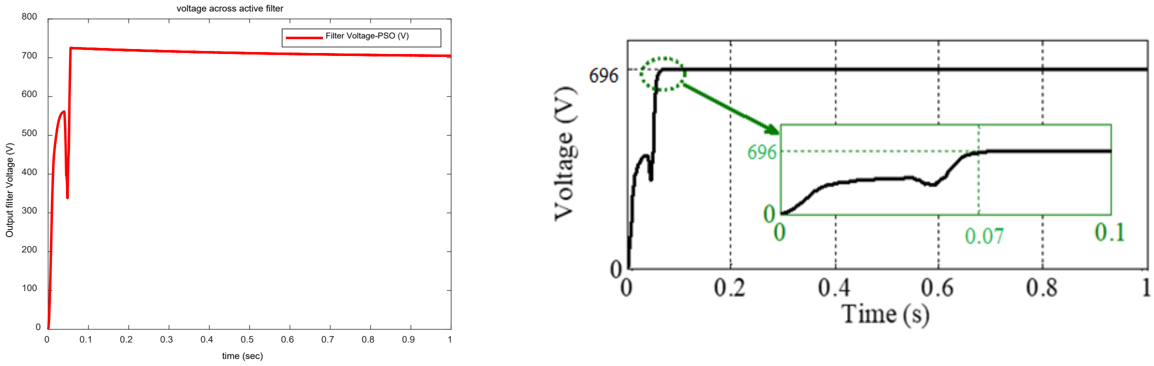


Fig. 14 *(a) Graph for capacitance voltage of PSO*

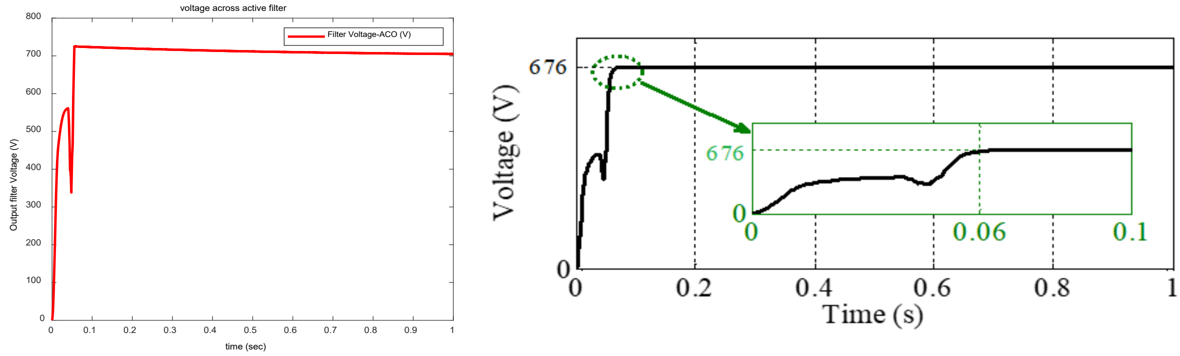


Fig. 14 *(b) Graph for capacitance voltage of ACO*

The numerical results of both the methods are tabulated below for comparative purposes.

Table 2 *Comparison of the results*

Name of the Method	THD(%)	Real power	Re-active power
PSO based Method	2.48%	5579	198.4
ACO Abased Method	2.14%	5860	125.4

For the following optimization problems, ant colony optimization (ACO) be more suitable

- Combinatorial Optimization: ACO excels in combinatorial problems like the Travelling Salesman Problem (TSP) due to its ability to explore and exploit solution space efficiently.
- Path finding and Routing: Well-suited for problems involving optimal path finding and routing, where the construction of feasible solutions is essential.
- Discrete Decision Spaces: ACO is effective when the solution space is discrete and can be represented as paths, tours, or sequences.

The pheromone evaporation rate in ACO is a key parameter that regulates the persistence of pheromones on edges. Careful tuning of this parameter is essential to ensure a proper balance between exploration and exploitation, facilitating the algorithm's ability to converge to high-quality solutions in varying problem landscapes.

3.6 Conclusion

A PI Controller trained based on ACO technique is used to enhance the harmonics for the Grid/source current in APF for NLL conditions. The suggested controller has a THD of 2.15 percent, which is lower than the PSO-based controller's THD of 2.48 percent. The simulation is done using Mat lab software in the Simulink environment, and the outcomes are presented. The ACOA-based controller gives superior outcomes than the PSO-based controller, as evidenced by the graphs and tabulated values.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm their contributions to the paper as follows: P.Srinivasa Varma and D.Lenine were responsible for the ***study conception and design. Data collection, Analysis and interpretation of results*** *were performed by M.Madhusudhan Reddy. The* ***draft manuscript*** *was primarily prepared by M.Madhusudhan Reddy with contributions from P.Srinivasa Varma and D.Lenine . All authors reviewed the results and approved the final version of the manuscript.*

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