

# PERFORMANCE ANALYSIS AND REVIEW OF ANT COLONY OPTIMIZATION BASED HYBRID ACTIVE POWER FILTER FOR THREE PHASE FOUR WIRE SYSTEM

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## ABSTRACT

*This paper explains the dynamic behavior of ant colony optimization based Hybrid Active Power Filter (HAPF) accomplished for harmonic compensation under varying source/load conditions. ACO based controller is employed to extract fundamental component of current from non-sinusoidal currents of the considered supply system. Ant colony optimization (ACO) is a novel searching technique used in optimization problems. This paper describes ACO approach for optimization of coefficients of digital filters. In a design example, the order of a low pass filter and the parameters of its coefficients have been optimized in a discrete search space. AC analysis of the optimized filter has been conducted. Hybrid filter utilizing the merits of both shunt passive filter and shunt active filter for better compensation performance is applied in this work. Simulation and analysis of three phase four wire hybrid active power filter under distorted source conditions have been incorporated using MATLAB/ SIMULINK. The detailed simulation level results have been presented to validate the proposed methodology. The results so that filters obtained by ACO have simpler structures and better performance.*

**KEYWORD:**Hybrid active power filter, THD, Ant Colony Optimization, PI controller.

## I.INTRODUCTION

In recent years, the increasing use of power electronics based non linear loads continuously deteriorated quality of power. Many of the important international standards define power quality as to maintain purely sinusoidal current waveform in phase with purely sinusoidal voltage waveform. Therefore, a power quality problem exists if any of the voltage, current or frequency deviation from sinusoidal nature occurs. Power quality problems are common in industrial, commercial and utility networks as power electronics appliances are widely used in these fields. These appliances generate harmonics and reactive power. Therefore it is very important to compensate the dominant harmonics and thus Total Harmonic Distortion (THD) below 5% as specified in IEEE 519 harmonic standard [1]. The passive filtering is the

simplest conventional solution to eliminate the harmonic distortion and power factor improvement in the power system utilities. Although with various advantages such as simplicity of construction, easy to Accuracy of this hybrid active power filter is depending upon the calculation of harmonic current and generation of reference current. In this paper, a three phase three wire ACO controlled shunt hybrid active power filter is proposed [3], [4], [5]. To make the shunt active power filter model more dynamic and robust in nature in this paper an ACO controller has been used to facilitate the calculation of reference currents. ACO controller is used to generate fundamental from non- ideal voltage source. The extracted fundamental currents are then subtracted from source current to evaluate the reference signal i.e. harmonic current. The proposed controller has self-learning with high accuracy and simple architecture and it can be successfully applied for harmonic filtering under various power system operating conditions. This paper, therefore, presents a hybrid power filter using ACO - implement and cheaper, the passive filter suffer from many disadvantages such as tuning problems due to tolerance, resonance, fixed compensation characteristics for fixed value of L & C and their bulky size. To overcome this problem Active Power Filter (APF) is brought in effect. Active power filter is a dynamic and flexible solution for the mitigation of harmonic current due to their compact size, no requirement of tuning and stable operation. Active power filter acts as harmonic current source to provide emphatic result to compensate for harmonic currents as well as reactive power. It has the capability to inject harmonic current into the ac system with the same amplitude but in opposite phase of the load [2]. As the HAPF is complex with cost effective parameter control, the hybrid active power filter has been preferable in the subject of harmonic solution. Hybrid active power filter gives the efficacious combination of passive and active filter, which implies the advantages of both and eliminates the short-comes of each one shown in figure1 [1],[2]controller to control the harmonics under different non- sinusoidal source/load conditions for its performance. Three-phase three-wire loads generate positive/negative sequence (pn-seq) current harmonics. These harmonics give rise to resonances, voltage distortion, overheating, increase in losses, malfunction and premature ageing of electrical equipment, etc. Single-phase nonlinear loads are usually connected between the phase and neutral conductors, and, additionally, originate zero sequence (z-seq) current harmonics—typically with 3rd, 9th, and 15th harmonic order. Harmonics with order of multiple of three resulting from several single-phase loads are summed up in the neutral conductor, which can result in a harmonic current in the neutral conductor up to three times higher than in the phase ones. Z-seq harmonic currents, also causing characteristic problems related to pn-seq harmonic currents, can give rise to neutral conductor overload, common mode neutral to earth voltages, increase of phase voltage distortion, and transformers overheating.

## **STUDY OF THE HARMONICS**

The electric signals present on the networks (especially currents) are often disturbed and they are not perfectly sinusoidal. In the field of the power quality of energy, it is essential to know well all the energy exchanges between the network and various loads in order to be able to compensate for the possible disturbances. The

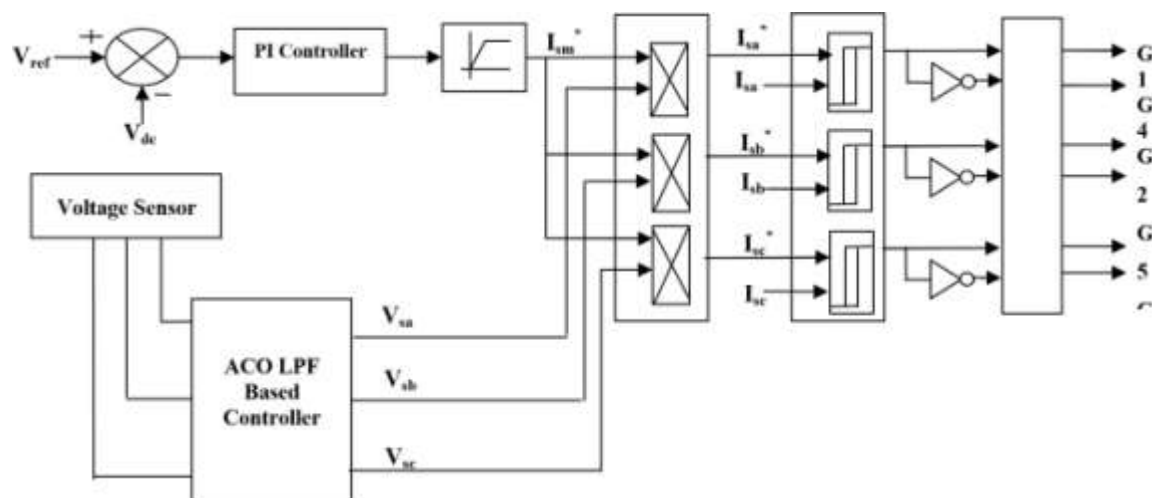
mathematical concepts is used, which allow the decomposition of the disturbed electric signals (non sinusoidal) in ideal components and disturbances. The concept of harmonic introduced by Joseph Fourier [14], shows that any no sinusoidal periodic signal can be represented by a sum or series of sinusoids of discrete frequencies. Component zero of the series known as of Fourier is the component continues, the first component is called component fundamental. In the case of the systems connected to the supply, this one is a component at three Phase Shunt Hybrid Filters for the Current Harmonics Suppression and the Reactive Power Compensation the rated frequency of the supply (50Hz). The remainder of the components of the series are called harmonic and are multiple fundamental frequency[14].

## **PROPOSED TOPOLOGY**

Three phase four wire hybrid power filter. Shunt active power filter is used to generate compensation current in opposite phase. Power circuit for APF is proposed as an IGBT based three-phase voltage source inverter with 2 DC storage capacitor for better compensation of non-linear loads. Active power filter has two different control schemes; one is ACO based controller that accounts for reference current generation and second PI controller for DC voltage regulation. ACO extract the fundamental components of the three phase voltages from non-sinusoidal supply [6]. The capacitors are designed to limit the dc voltage ripple to a specified value, typically 1 to 2 %. In this case the capacitor should be designed for the worst case. Since the active filter will operate in several modes, then the injection of compensation current is done in order to nullify or mitigate the harmonic currents. Injection of this compensation current gives improved power quality. The performance of the active power filters is dependent to a great extent upon the method used for the calculation of reference current.

## **CONTROL STRATEGY**

The main function of control scheme is shown in figure 2 to maintain supply current waveform sinusoidal, identification of harmonic content, regulation of DC voltage and controlling scheme of HSAPF is compulsory which provides compensating current to the power system as well as supplies harmonic currents to the three phase non-linear load at the same instant. For the proper response of APF the extraction of fundamental component of current from non-sinusoidal input, reference current generation, DC voltage regulation and injection of compensation currents are essential tasks . These tasks can be achieved only by using various controlling schemes. The indirect method of current/voltage sensors is used. The three phase unit voltage vectors ( $v_{sa}$ ,  $v_{sb}$ ,  $v_{sc}$ ) are obtained from the supply voltages. These unit vectors, when multiplied with reference supply current ( $I^*_{sm}$ ), result in three phase reference supply currents ( $I^*_{sa}$ ,  $I^*_{sb}$ ,  $I^*_{sc}$ ). The reference supply currents and sensed supply currents ( $I_{sa}$ ,  $I_{sb}$ ,  $I_{sc}$ ) are the inputs for the pulse generator, which generates the firing pulses for the gating signals to the IGBT's of the active power filter[11], [12],[10].



ANALOG CONTROLLER HYSTERESIS DELAY

UNIT MULTIPLIER

Figure- block diagram of control strategy for shunt active power filter

Hysteresis current control is a method of controlling a voltage source inverter so that the output current is generated which follows a reference current waveform. **4.1.** Ant Colony Optimization based Controller ACO takes inspiration from the foraging behaviour of some ant species. These ants deposit pheromone on the ground in order to mark some favourable path that should be followed by other members of the colony. As time passes by, most ants will take nearly optimal path in unison [14, 15]. Such property of the behaviour of ant colony implies efficacious solutions to a range of combinatorial problems in circuit design. To utilize ACO, however, the search space must be a discrete one rather than continuous ones which are commonly encountered in the optimization of filters. For an ant A whose corresponding transfer function is HA, the average error of gain between HA and the design objectives in the pass band is estimated by

$$E_{pass} = \frac{20}{N_p} \sum_{f_p \in F_{pass}} \left| \log \left( \frac{g_{fp}}{g_{pass}} \right) \right|$$

where  $g_{fp} = |H_A(j2\pi f_p)|$  is the gain at frequency  $f_p$ . Note that the error is measured in dB. The situation in the stop band is a bit more complicated, as gain below  $g_{stop}$  is satisfactory while gain above  $g_{stop}$  is not. Hence

$$E_{stop}(A) = \frac{20}{N_s} \sum_{f_s \in F_{stop}} \log \left( \frac{g_s}{g_{stop}} \right)$$

in which  $g_s = |H_A(j2\pi f_s)|$  is the gain at frequency  $f_s$ . Likewise, the gain in transband should be below the straight line connecting the corner points  $(lgf_{pass}, 20lgg_{pass})$  and  $(lgf_{stop}, 20lgg_{stop})$  in the Bode plot, thus the error in transband is estimated by

$$20 \log \left( \frac{g_{trans}}{g_{pass}} \right) - \frac{20 \log \left( \frac{g_{stop}}{g_{pass}} \right) - 20 \log \left( \frac{g_{pass}}{g_{pass}} \right)}{f_{stop} - f_{pass}} (f_{trans} - f_{pass})$$

$$= \sum_{f \in F_{trans}} \log\left(\frac{g_{ftrans}}{g_{trans}}\right)$$

Etrans(A) = in which  $g_{fs} = HA(j, \pi, ft)$  and

$$\frac{\log\left(\frac{g_{stop}}{g_{pass}}\right)}{\log\left(\frac{f_{stop}}{f_{pass}}\right)} \log\left(\frac{ft}{f_{pass}}\right) + \log g_{pass}$$

Log gtrans = is the logarithm of desired gain at frequency ft. Furthermore, by taking weighted sum of Epass, Estop, and Etrans, the overall error between HA and design objectives can be measured by  $E(A) = C_{pass}E_{pass}(A) + C_{stop}E_{stop}(A) + C_{trans}E_{trans}$  (in which Cpass, Cstop and Ctrans reflect the relative importance of design objectives. Thereby the performance of the filter denoted by ant A is defined as  $\eta(A) = 1/E(A)$  indicating that an ant having lower error value performs better and thus have a higher value of  $\eta$ 2) Calculation of the probabilities of selecting components. A probabilities table of components is calculated based on TNcxm such that the probability of a component being selected is proportional to the amount of pheromone associated with it. If there is no pheromone distributed in a particular step, all components in that step will have equal chance of being selected. 3) Construction of solutions : First, calculate the initial  $\eta$  for all ants when no component is selected. Then for all  $i < N$ : repeatedly select components for ant  $A_i$  according to the table described in step 2), until a newly selected component cannot improve  $\eta(A_i)$ . 4) Update pheromone distribution In each iteration, the pheromone value  $\tau_{i,j}$  associated with component  $c_{i,j}$  is multiplied by a decay factor  $\rho$ . In the  $r$ th iteration, the ant will release pheromone  $\Delta T_k$  on the components it selects. In order to improve performance and attenuate excessive complexity of filters, the incremental pheromone is designated as

$$\Delta T_k(r) = \eta(A_k(r)) / L_k(r)$$

where  $L_k$  is the number of coefficients selected by and  $\eta(A_k)$  is the normalized performance of And the pheromone in the next iteration is updated as

$$\tau_{i,j}(r+1) = \rho \tau_{i,j}(r) + \Delta T_k$$

$$\tau_{i,j}(r+1) = \rho \tau_{i,j}(r) + \sum_k \Delta T_k$$

5) Evaluation of the colony The optimization process ends if termination conditions are met, e.g. the colony converges or the maximal iteration number rmax is reached; otherwise go to 2). The flow chart of optimization process is depicted in Fig. 3.

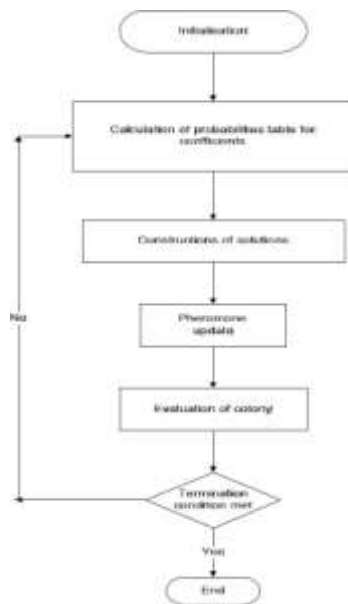


Figure 3 Flow chart for ant colony PI controller algorithm involves two separate parameters; the Proportional and the Integral. The Proportional value determines the reaction to the current error; the Integral determines the reaction based on the sum of recent errors. A comparison of the average and the reference values of the dc bus voltage for the shunt AF results in a voltage error, which is fed to a proportional integral (PI) controller and the output of the PI controller is multiplied by the mains voltage waveform  $V_{sa}$ ,  $V_{sb}$ ,  $V_{sc}$  in order to obtain the supply reference currents  $i_{sa}^*$ ,  $i_{sb}^*$ ,  $i_{sc}^*$ . A PI controller used to control the DC-bus voltage is shown in Figure 6 whose transfer function can be represented as

$$H(S) = k_p + k_i/s \text{ Where, } k_p$$

is the proportional constant that determines the dynamic response of the DC-bus voltage control, and  $k_i$  is the integration constant that determines its settling time[14],[15].

Figure 4. PI controller for DC-bus voltage control

It can be noted that if  $k_p$  and  $k_i$  are large, the DC-bus voltage regulation is dominant, and the steady state DC-bus voltage error is low. On the hand, if  $k_p$  and  $k_i$  are small, the real power unbalance gives little effect to the transient performance. Therefore, the proper selection of  $k_p$  and  $k_i$  is essentially important to satisfy above mentioned two control performances. The computed three-phase supply reference currents are compared with the sensed supply currents and are given to a hysteresis current controller to generate the switching signals to the switches of the shunt AF which makes the supply currents follow its reference values . 5.



## RESULT

The system parameters: Load resistance  $R_L=50\Omega$ , Load inductance  $L_L=80\text{mH}$ , Supply Phase voltage= $162.63\text{V}$  (rms), and peak voltage of  $230\text{V}$ , Supply line parameters  $R_s=1\Omega$ ,  $L_s=0.05\text{mH}$ , Filter coupling inductance  $R_c=5\Omega$ ,  $L_c=3\text{mH}$ , Inverter DC bus capacitor is of  $1000\mu\text{F}$  each, Reference Voltage =  $480\text{V}$ , Hysteresis band limit  $=0.2\text{A}$  and Switching frequency  $=10\text{kHz}$ , PI controller parameters are  $K_i=10$ ,  $K_p=0.5$ .

### 5.1 STEADY STATE RESPONSES

In static load condition the source current is getting sinusoidal and smooth at around  $0.08\text{ sec.}$ , neutral wire current is reaching zero at around  $0.05\text{ sec.}$

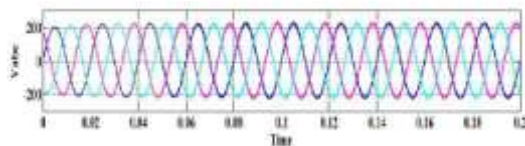


Fig 5. 3-phase source voltages

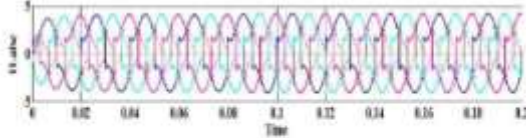


Fig 6 . 3 -phase load currents

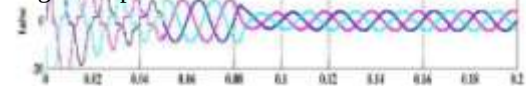


Fig 7 . 3 -phase source currents

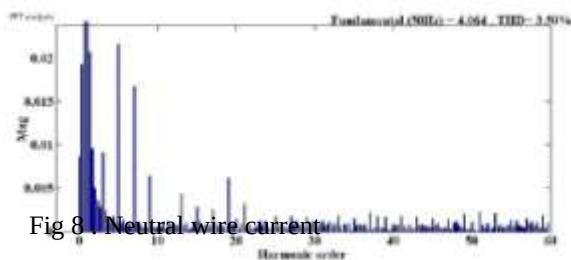


Fig 8 . Neutral wire current

Fig.9 FFT analysis of %THD

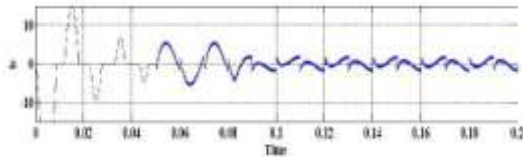


Fig.10. Phase 'c' compensating current

5.2 DYNAMIC STATE RESPONSES After adding the dynamic load of  $RL = 50\Omega$ , Load inductance  $LL=80mH$ , in parallel with static load at 0.16sec., the THD% is reducing and source and load current is higher than the static source current. We can see that the smoothening work of active power filter is not affected due to dynamic load.

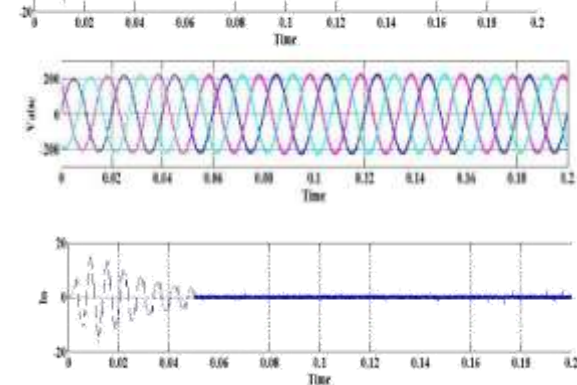


Fig 11. 3-phase source voltages

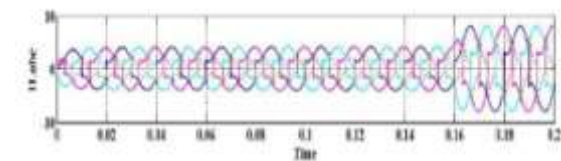


Fig 12 . 3 -phase load currents

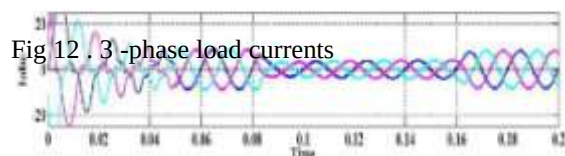


Fig 13. 3-phase source currents



Fig 14. Neutral wire current

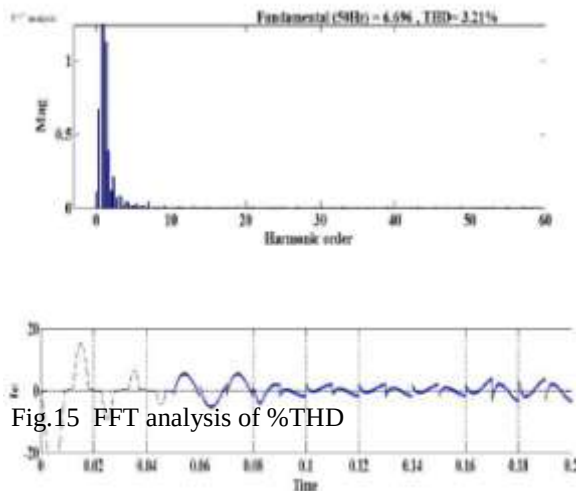


Fig.15 FFT analysis of %THD

Fig.16. phase 'c' compensating current

## CONCLUSION

The In this paper, an analysis has been carried out for the estimation of the reduction in size and cost of the active filtering unit with the passive tuned filters inserted for partial compensation. The estimation has been done for varying VAR compensation of the passive filters. The novel approach which based on intelligent ACO techniques has been proposed. The performance of the proposed ACO will be verified through simulation studies with MATLAB. Proposed controller provides the fundamental component from distorted supply accurately. The estimation further strengthens the fact that the shunt active filtering system based on the ACO control scheme can be made quite cost-effective with the addition of a passive counterpart, as required in practical applications, for power quality improvement in retrofit systems [10],[14],[15].

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