iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** II **Month of publication:** February 2016

DOI:

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www.ijraset.com
IC Value: 13.98

Volume 4 Issue II, February 2016
ISSN: 2321-9653

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Modified PSO Based SAPF Control Strategy for Harmonic Elimination and Power Factor Correction in Distribution System

G. Shobana[1], Dr. R.Arivalahan[2]

[1]PG Scholar, [2]Associate Professor

Department of Electrical and Electronics Engineering, Valliammai Engineering College, Chennai.

Abstract— the shunt active power filter is a device which is widely used to eliminate harmonic currents and to compensate reactive power for nonlinear loads. This paper represents the simulation and analysis of using active filter to compensate harmonics in three phase system .The proposed shunt active filter model presents a novel approach(Modified PSO) is to determine the reference currents of the shunt active power filter (SAPF) for compensation under distorted conditions in steady state. The proposed method is compared with the Genetic Algorithm. Results obtained by simulations with MATLAB/Simulink shows that this proposed method is more effective than the other approaches on compensating reactive power and harmonic/neutral currents of the load. In addition to that this method yields a simplified control on SAPF.

Keywords—Shunt Active Power Filter (SAPF); Harmonic Elimination; Modified Particle Swarm Optimization (PSO); Genetic Algorithm (GA); Total Harmonic Distortion (THD).

I. INTRODUCTION

The APF is an effective means of Harmonic Suppression, it utilizing the pulse width modulation (PWM) technique is used to generate switching harmonic current, which is power grid leakage at high frequency and it should be eliminated by output filter[1]. Output filter connected between the inverter and grid connection, as shown in Fig 1. As the complexity of its working principle, must be synthetically considered the compensation performance of APF and filtering performance of output filter etc, and this is a multi-objective optimization problems. Multi-objective optimization algorithm is from all the possible scenarios to find the most reasonable and most reliable solution. In this paper, the multi objective optimization and parameter design based on modified PSO Algorithms design was adopted [2]. This Algorithm starting from any initial population by selection, resulted in a group of individuals better adapted to the environment, so that group evolved into the search space better and better area, so continued to multiply from one position to evolve, Finally converged to a group of individuals best adapted to the environment, and sought the optimal solution.

After the introduction of a multi-objective modified PSO Algorithm, the optimization model of switching harmonic filter and optimization method based on this algorithm are presented [3]. Optimized switching harmonic filter can perform harmonic elimination and also used to enhance the compensation ability of the APF [3] in effective. Filter inductor is used to eliminate the harmonics in the output which is fed to the DC voltage loads. Here, the DC Capacitor is connected across the voltage source inverter (VSI) that supplies the capacitor reference voltage. These two components together perform a filter operation.

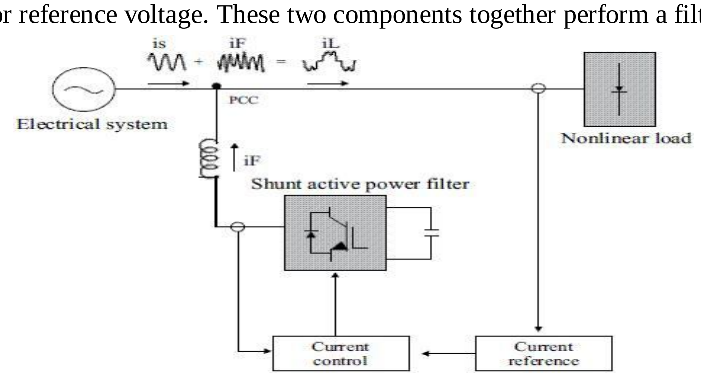

Fig 1- Shunt Active Power Filter

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Volume 4 Issue II, February 2016
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II. WORKING PRINCIPLE FOR HARMONIC FILTER

Active filters are designed using passive and active components, and require an outside power source. Operational amplifiers are used in design of active filter[4]. These can have high reactive power and quality factor, and can achieve resonance without using inductors. However, their higher limit is limited by the bandwidth of the amplifiers used in that system. Filters having multiple elements are usually constructed as a sequence network. These can be designed as a continuation of the L, T and π format of filters. More elements are required when it is desired to improvise some parameters of the filter like stop-band rejection, slope of transition from pass band to stop band.

A three-phase system connected with an inverter load has been considered to study the operation of the SAPF. It has been concluded that due to the characteristics change of power electronics loads the Total Harmonic Distortion of source current and terminal voltage fall below the IEEE-519 standard and in main APF system is used to inject a current with equal magnitude but opposite in phase to harmonic current to get a pure sinusoidal current waveform in phase with the supply voltage[7]. Fig 2 shows the control strategy for proposed method. The main component of the Active Power Filter is the IGBT based Voltage Source Inverter. A dc capacitor is used to deliver power for the inverter circuit. For the desired operation of APF, capacitor voltage should be minimum of 150 % of maximum line to line supply voltage.

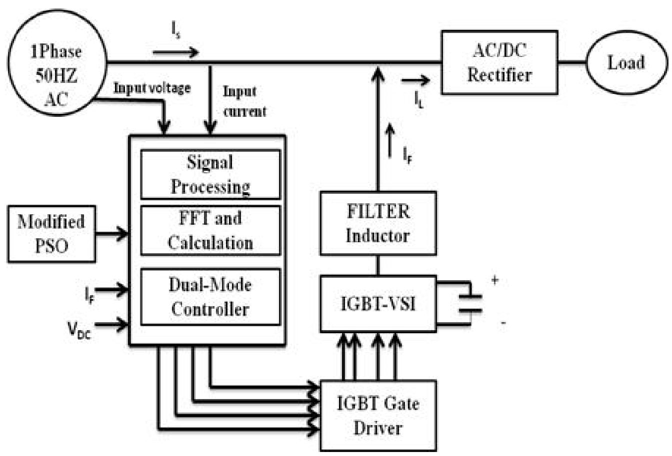

Fig 2– Proposed SAPF control strategy

Since the PWM VSI is assumed to be instantaneous and has fast response to track the compensation currents, it is designed as a current amplifier with unity gain[10]. Whenever, rectifier load is connected on distribution side it generates harmonics. In order to eliminate those harmonics, shunt active power filter based on Particle Swarm Optimization is performed. Using DSP processor signal conditioning methods are carried out. It consists of dual mode controller to generate the reference currents. Here, modified PSO Algorithm is performed to get the optimized controller gain values[4]. According to that, PI controller and Hysteresis controller operates and generates reference currents. Based on that, pulses are generated and it is applied to IGBT-VSI through gate driver circuit.

III. PROPOSED CONTROL ALGORITHM

PSO is a population based algorithm that seeks to exploit the population of individuals in order to seek promising areas (optimum solution) in the entire search space. The ideas that underline PSO are inspired by not only in natural selection but also by the activity of flocking organisms, such as swarms of birds and fish schools[5]. Each particle specifies a new solution which is possible to perform the optimization task at hand. Assuming swarm size is N, the position is a D-dimension space coordinate of every particle can be indicated as $\chi_i = (\chi_{i1}, \chi_{i2}, \chi_{i3})$ and flight velocity of particles I in d^{th} dimensional subspace may be modified as follows:

$$V_{id} = w_{vid} + c_1 rand_1(p_{id} - \chi_{id}) + c_2 rand_2(p_{gd} - \chi_{id}) \quad (1)$$

$$V_{id} = V_{max} \text{ if } V_{id} > V_{max} \quad (2)$$

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$$V_{id} = -V_{max} \text{ if } V_{id} < -V_{max} \quad (3)$$

Where

P_{gd} = the best position (old) of the entire swarm P_{id} is the best position (old) of the current swarm

$P_{gd} - \chi_{id}$ = used to set the directional random movement of current particle.

C_1, C2 = acceleration coefficient to determine relative influence of the social and global components often set the same value.

W =called inertia weight which can be changed with running time.

New position of particle is calculated using

$$\chi_{id} = \chi_{id} + V_{id} \quad (4)$$

During iteration, every particle moves depend on its own personal best solution in the specified direction found so far, and also in the direction of the global best position found so far and it is used by any of the particles in the search. Generally, the movement of particle is carried out by considering about the influence of the optimum of individual swarm and it effectively leads the general movement of particle swarm. So it is effectively suitable for many optimization problems.

The assumption is a basic concept of PSO [5]. In the this algorithm, instead of using existing operators to create and design algorithms, for a different optimization problem, a flock of particles are kept in a specified direction into the d-dimensional search space with random velocities and positions with their previous new best solution (P_{best}) and the position in the search space. The velocity and position of each and every particle, is adjusted depending on its own flying experience and as well as based on the other particle experience in flying. For example, the i^{th} particle is represented as $x_i = (x_{i,1}, x_{i,2}, \ldots, x_{i,d})$ in the search space. The best solution of the previous position of the i^{th} particle is recorded and it is given by:

$$P_{besti} = (P_{besti,1}, P_{besti,2}, \ldots, P_{besti,d}) \quad (5)$$

The sequence of best particle among all other particles in the group is taken as g_{bestd}. The velocity for particle *i* is given as $v_i = (v_{i,1}, v_{i,2}, \ldots, v_{i,d})$. The new velocity and new position of each and every particle can be calculated using the present velocity and the distance is determined from $Pbest_{i,d}$ to $gbest_d$ as shown in the below formulas [13]:

$$v_{i,m}^{(t+1)} = w.v_{i,m}^{(t)} + c_1 * rand() * (Pbest_{i,m} - x_{i,m}^{(t)}) + c_2 * Rand() * (gbest_m - x_{i,m}^{(t)}) \quad (6)$$

$$x_{i,m}^{(t+1)} = x_{i,m}^{(t)} + v_{i,m}^{(t+1)} \quad i=1,2,\ldots n;\ m=1,2,\ldots, d \quad (7)$$

Where

n = Number of particles, d be the dimension of each particle

t = iterations pointer

$v_{i,m}^{(t)}$ = Velocity of particle i at iteration t

$$V_d^{min} \le v_{i,d}^{(t)} \le v_d^{max}, \quad (8)$$

w = Inertia weight factor

c_1, c_2 = Acceleration constant

rand() = Random number 0 - 1

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$x_{i,d}^{(t)}$ = Current position of particle *i* at iterations

P_{besti} = Best previous position of the i_{th} particle

g_{best} = overall Best particle out of all the particles in the population.

Initializing the number of populations is the first step of designing a PSO. The population is composed of the chromosomes that are real codes. This above assumption of a population is called the "fitness function".

The fitness function is defined as follow:

$$PI = MIN\_offset - \Sigma|e| \quad (9)$$

Where PI = the fitness function value, e is the speed error.

After the fitness related function is calculated, the number of the generation and the fitness value is determined to check this procedure is stopped or not (Maximum iteration number reached). In the following, determine the P_{best} of each and every particle consists g_{best} of population which is the best movement of all particles[8]. Supposing S is the number of the particle population, f is the fitness function of i^{th} particle, f_{avg} is the present average fitness function of the population, σ is the variance of the 319 population's fitness. By using the fixed value of above parameters, PSO program can be iterated and give the suitable results for that corresponding system.

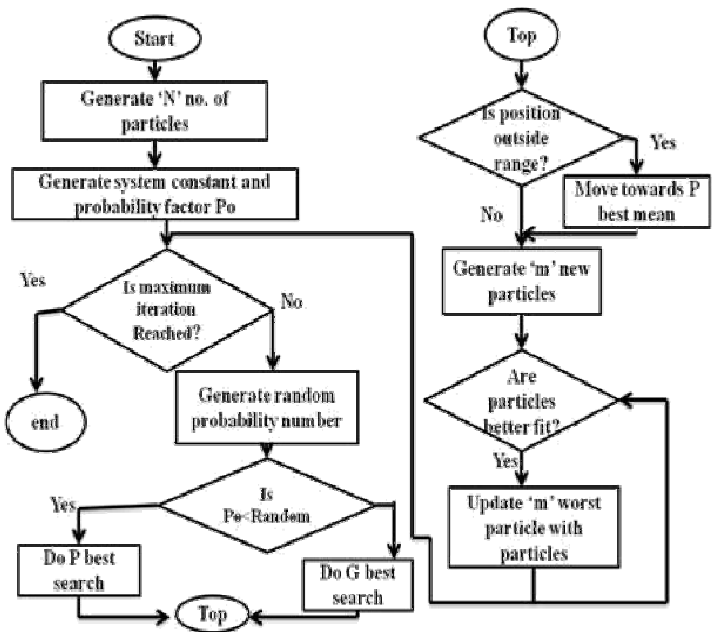

Fig 3- Process Flow of Modified PSO Algorithm

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IV. SIMULATION RESULTS AND DISCUSSION

This section presents the simulation parameter with test system and shows the effectiveness of proposed SAPF by using the Modified PSO Algorithm tuned PI controller [9]. This test system consists of three phase AC source and non linear rectifier R-L load through the line. The test system specifications, simulation parameters, error minimization using convergence curve are shown in *(i)***,** *(ii)* and *(iii)* and test system without SAPF and with Modified PSO based SAPF are shown in (iv) and (v) respectively.

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Volume 4 Issue II, February 2016
ISSN: 2321-9653

A. Test system specifications

Table 1: shows that the test system parameters for the three phase AC system connected with R-L rectifier load.

S.No.	Parameters	Values
1	Three phase AC source voltage	415V,50Hz
2	Source resistance and reactance	1Ω, 25mH
3	DC Capacitor	2mF
4	DC Capacitor reference voltage	50V
5	R-L Load on DC side of nonlinear load	64Ω, 1mH

B. Modified PSO Program Parameters

Table 2: shows that the fixed parameters for modified PSO algorithm in order to obtain the optimized controller values.

S.No.	Parameters	Values
1	Number of iterations	30
2	Number of particles	20
3	Probability factor	0.7
4	Inertia weight damping factor	0.9

C. Error Minimization

The below given figure explains the variation of square error with respect to the number of iterations while using Modified PSO Algorithm. For the above mentioned parameter values, error can minimize at the range of (20 - 25) iterations.

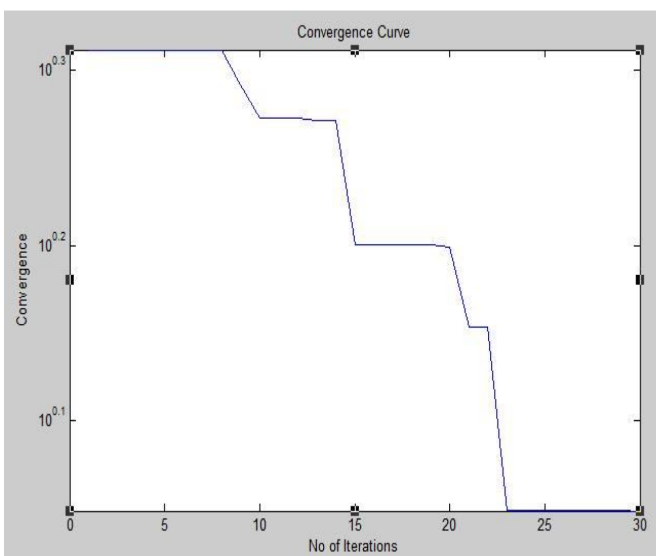

Fig 4– Convergence Curve

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Volume 4 Issue II, February 2016
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D. Test System without SAPF

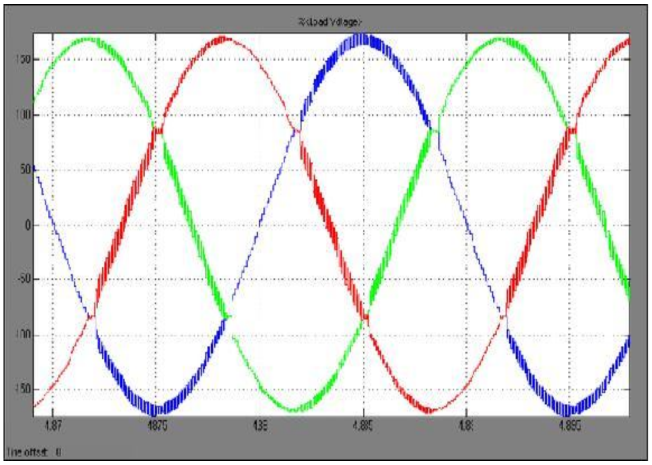

Fig 5- Load Voltage versus Time without using Active Filter

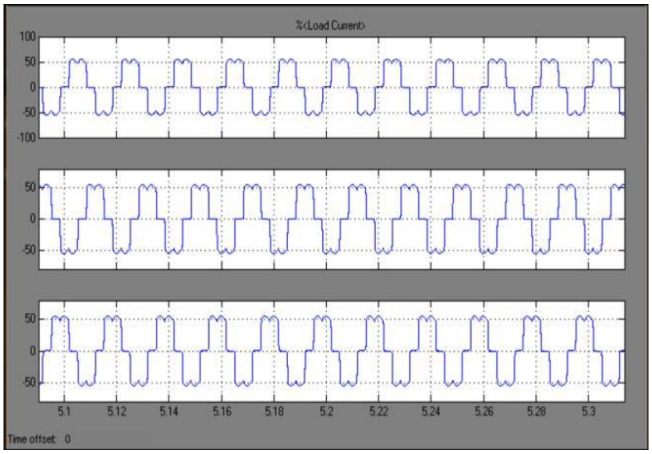

Fig 6- Load Current versus Time without using Active Filter

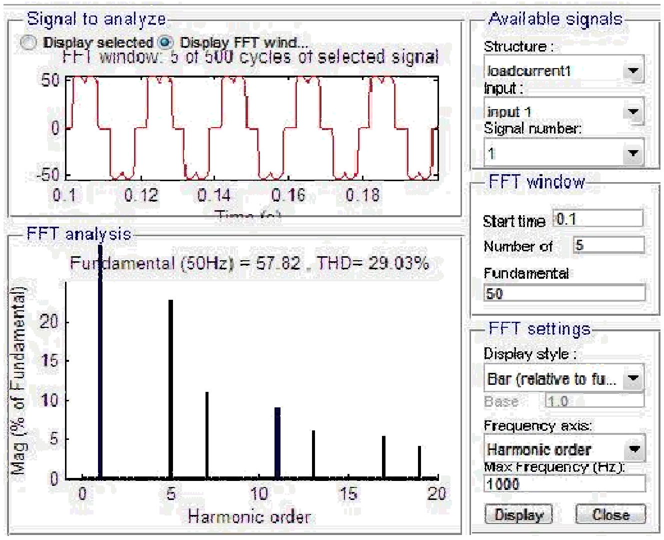

Fig 7- Harmonic spectrum for load current without SAPF

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E. Test system with Modified PSO based SAPF

This section shows the simulation results of Test power system with SAPF and change of PI values for 100 Generations. The source and load current waveforms for the optimized value of PI are given in this section[11]. Fig 11 shows the source voltage and currents of the test power system from this Fig 9 it can be seen that the waveforms are purely sinusoidal. Fig 12 shows the harmonic spectrum of a 3 phase load current and it can be seen that THD is 9.76%.

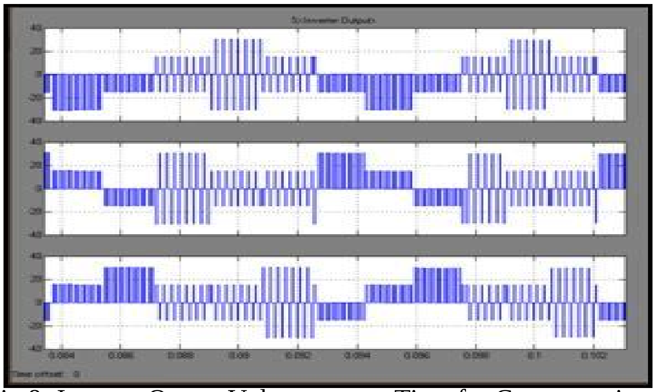

Fig 8- Inverter Output Voltage versus Time for Compensation

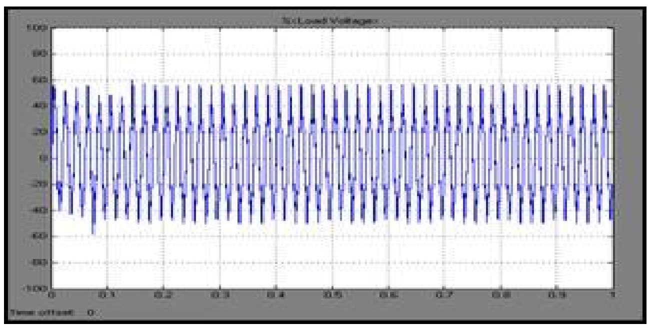

Fig 9- Load current versus Time (with SAPF)

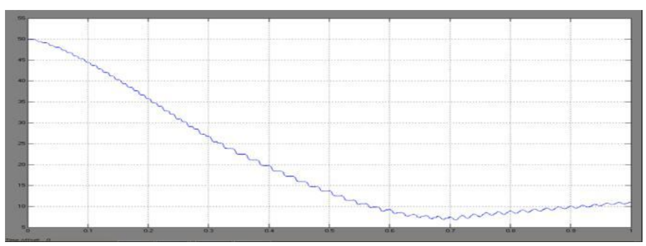

Fig 10- Voltage across the DC Capacitor versus Time

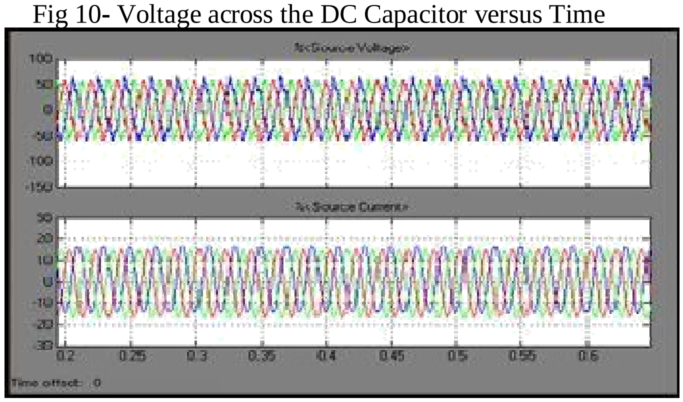

Fig 11- Load Voltage and Current versus Time (with SAPF)

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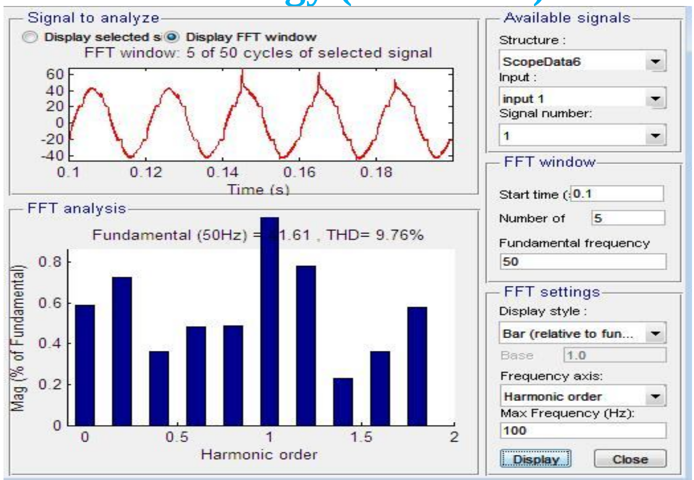

Fig 12- Harmonic spectrum of 3-Φ load current

F. Comparison between traditional and proposed Method

Method	Proportional Gain (K_p)	Integral Gain (K_i)	Total Harmonic Distortion (THD %)
without filter	-	-	29.03%
Filter with Genetic Algorithm	0.69	70.1	10.26%
Filter with Modified PSO Algorithm	0.693	70	9.76%

V. CONCLUSION

To achieve rapid error convergence and zero steady state error for harmonic current control, this paper explained the use of a modified PSO for optimizing the controller gain for shunt active power filters with high efficiency. In detail, the design methodologies for filter circuit with PI controller were discussed and presented clearly. In this design, error rectification has been done between the transient response and steady state accuracy. The simulation results conclude this technique offers the accurate control of harmonic currents in both steady state and transient conditions in the presence of change in supply impedance. The benefit of this proposed method is its simplicity, for commercial system in particular. Therefore, this work can be an effective solution for the design and implementation of shunt active filters by employing this novel approach and this also reducing the overall computational time by means of modified PSO.

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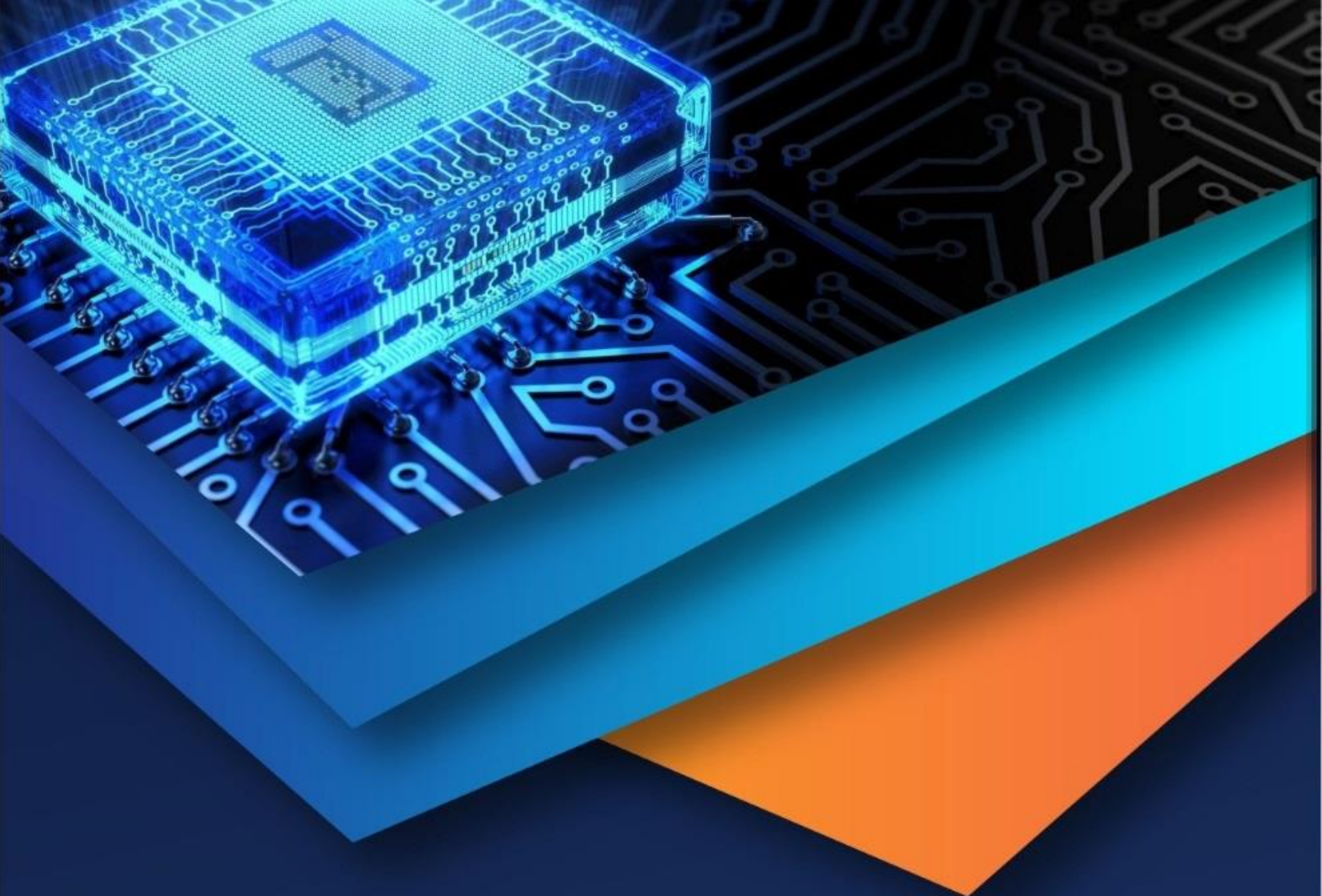

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