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An Experimental Verification of Performance Improvement In Inverter Design By Using Accelerated Particle Swarm Optimization Technique

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***Abstract*:-This paper presents the harmonic reduction for three phase inverter, based on Selective Harmonic Elimination(SHE). This was implemented by using Accelerated Particle Swarm Optimization(APSO) Technique. The notch angles required for the SHE were determined by solving the non-linear equations using APSO. The results show that Accelerated Particle Swarm Optimization Technique applied to Selective Harmonic Elimination can give better result than those obtained by classical methods. Simulation and Hardware results are included in this paper, in order to confirm the effectiveness of the technique.**

***Key Words:-* Particle Swarm Optimization (PSO), Accelerated Particle Swarm Optimization (APSO), Selective Harmonic Elimination (SHE), Total Harmonic Distortion(THD), Inverter, Evolutionary Computing Techniques.**

I.INTRODUCTION

The problem of eliminating harmonics in Inverters has been the focus of research for last three decades. For maximizing efficiency of conversion, it is desirable to choose an optimum switching frequency, which will minimize switching losses. The most common method of eliminating lower order harmonics and voltage control is Sinusoidal Pulse Width Modulation(SPWM) technique [4]. Selective Harmonic Elimination (SHE) produces a fundamental wave form of magnitude higher than SPWM[1],[2]. The number of pulses per half cycle in SHE is likely to be less than SPWM, so that switching losses are lower. This feature is very important for high power applications in which power devices cannot be switched at higher frequencies due to high switching losses. The major problem faced by switch mode DC to AC conversion is that non sinusoidal output voltages are produced. The non sinusoidal waveforms of an inverter can be passed through filters to remove harmonics, but this may be costly at higher power levels. Selective Harmonic Elimination for inverters involves the solution of a number of transcendental equations with large number of possible solutions. These solutions will eliminate some specific harmonics. The aim of the current work is to pin point the best solution, that will result in the minimum Total Harmonic Distortion (THD). In this work, initially conventional techniques have been used and subsequently APSO has been used to get better results than conventional Methods. APSO was used to solve the transcendental equations with THD as an objective function and comparing the results with the conventional and PSO techniques. The paper [8] had shown that PSO gives better result than the classical techniques. The Augmented LaGrange Particle swarm Optimization technique (ALPSO) [4] is introduced to overcome the computation complexity of transcendental equations. In APSO algorithm complexity is reduced and the rate of convergence is very high. The switching angles obtained by this method is effective in removing of selected harmonics and minimizing Total Harmonic Distortion[5]. If THD of the output is minimized, the cost of filter equipment is reduced and this will benefit both the manufacturer and the end user of the equipment.

II.PARTICLE SWARM OPTIMIZATION TECHNIQUE

Particle Swarm Optimization (PSO) refers to a relatively new family of algorithms that may be used to find the optimal solutions to numerical and qualitative problems. It was introduced by Russell Eberhart and James Kennedy in 1995 [10]. It is easily implemented and has proven to be both very fast and effective. In PSO particles are flown through the problem space following the current optimum particles. Each Particle keeps the track of its co ordinates in the problem space, which are associated with the best solution that had been achieved so far. This implies that each particle has memory, which allows it to remember the best position on the feasible search space that it had ever visited. This value is commonly called P_{best}. Another best value that is tracked by the particle swarm optimizer is the best value obtained so far by any particle in the neighborhood of the particle. This location is commonly called as G_{best}. The basic concept behind the PSO technique consists of change in the velocity of each particle towards its P_{best} and G_{best} positions at each step. This means that each particle tries to modify its current position and velocity according to the distance between its current position and velocity according to the distance between its current position and P_{best}, and distance between its current position and $G_{best.}$ .The position and velocity vectors of the i^{th} particle of a N-dimensional search space can be represented as $X_i=(x_{i1,}x_{i2,,,,,,,}\ \ x_{id})$ and $V_i=(v_{i1,}v_{i2........}v_{id})$ respectively. In PSO, each potential solution to the problem is called *particle* and the population of particles is called *swarm[09]*. In this algorithm, each particle position x_i is updated each generation t by means of the next equation.

$x_i(t) = x_i(t-1) + v_i(t)$-------------------------------(1)

$v_i(t)$ is the velocity and is given by

$v_i(t) = v_i(t-1) * w + C1 * r1 * (x_{pbesti} - x_i) + C2 * r2 * (x_{gbesti} - x_i)$------------------------------------(2)

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x_{pbest} is the best solution, x_{gbest} is the best particle , w is the inertia weight of the particle, r1 and r2 are two uniformly distributed random numbers in the range [0, 1], and C1 and C2 are specific parameters which control the relative effect of the individual and global best particles. Individual Coefficient Factor C1 = **1.4**, Social Coefficient Factor C2 = **1.4**,Maximum Inertia Weigh w_{max} = **0.4**,Minimum Inertia Weigh w_{min} = **0.2.** After finding the two best values, the particle updates its velocity and positions with following equations (3) and (4).

$$v[\,] = v[\,] + c1 * rand(\,) * (P_{bset}[\,] - present[\,]) + c2 * rand() * (g_{best}[\,] - present[\,]) \text{-------------------------------} (3)$$
$$present[\,] = present[\,] + v[\,] \text{-----------------} \quad (4)$$

III. ACCELERATED PARTICLE SWARM OPTIMIZATION TECHNIQUE

There are many variants of PSO which extend the standard PSO algorithm, and the most noticeable improvement is probably to use inertia function $w_i(t)$. Here $V_i(t)$ is replaced by $w_i(t)*v_i(t)$ *in equation(2).*

$$V_i^{t+1}=g_i(t)+\alpha \epsilon_1[w_{i(t)}-x_{(t)}]+\beta*\epsilon_2[x_i-x_{i(t)}] \text{-------} (5)$$

where $w(t)$ takes the values between 0 and 1. In the normal case, the inertia function can be taken as a constant, probably 0.3 ~ 0.8[9]. This is equivalent to a virtual mass to stabilize the motion of the particles, and thus the algorithm is expected to converge more quickly. The standard particle swarm optimization uses both the current global best g_{best} and the individual best x_{best}. The main reason of using the individual best is to increase the diversity in the quality of solutions, but, this diversity can be simulated using some randomness. In APSO initially a random value is selected and this is used to find the G_{best} solution. This G_{best} is taken as the initial value and one more G_{best} is calculated. Thus there is no particular reason for using the individual best. Thus, in this algorithm, the velocity component is generated by a simple formula. Another advantage of reducing the randomness is, that lesser number of iterations are required, while the algorithm is processing. The solutions are reached like a monotonically exponential decay. These parameters are fine-tuned to suit the current optimization problem. The implementation of the APSO had been carried out using MATLAB. In APSO the convergence to the solution is faster than that using standard PSO.

IV. IMPLEMENTATION TO SELECTIVE HARMONIC ELIMINATION PROBLEM

The Harmonic elimination problem is formulated as a set of transcendental equations. These equations can be solved to determine the pattern of switching angles or notch angles for turning the switches ON and OFF in a bridge inverter [05]. The result of the switching will produce desired fundamental amplitude, and eliminate specified harmonics. In this work the notch angles for a three phase inverter has been determined by using the Accelerated particle swarm optimization technique and compared with other techniques and has been shown to give better results than previously reported work[8]. The harmonic elimination problem in PWM inverter is treated as an Optimization problem and solved using APSO. The THD of the output voltage of PWM inverter is used as the objective function. The switching angles are calculated by using APSO for Bipolar switching case and objective function is minimized to obtain in minimum THD. In Selective harmonic elimination the switching angles for a particular Modulation Index (MI) are calculated and then the pulse sequence and duration for the various gate pulses of the power semiconductor switches of the inverter are generated. In this work all simulations have been carried out for an inverter with output frequency of 50Hz and modulation index of 0.9. The number of nonlinear equations in terms of unknown switching angles depends on number of harmonic components to be eliminated. The equations have to be solved for each value of modulation index using numerical minimization approach or artificial intelligence techniques. The fundamental component is assigned a desired output value and other selected orders of harmonics are equated to zero to form the set of transcendental equations. The two types of switching techniques can be used to eliminate specific harmonics are Unipolar switching scheme and Bipolar switching scheme. In this work bipolar switching scheme has been considered. The fourier series of output voltage can be expressed as

$$V_o=\sum_{n=1,3,5}^{\infty} (B_n \sin n(wt)) \text{----------------} (5)$$

Where

$$B_n=\frac{4vi}{n\pi}\left[1+2\sum_{k=1}^{N}(-1)^k \cos(n\alpha_k)\right] \text{ for}$$

n=1,3,5…………..

The set of to eliminate the 3rd ,5th ,7th ,9th ,11th Harmonics and to maintain fundamental magnitude control, are given by

$$1-2\cos(\alpha 1)+2\cos(\alpha 2)-2\cos(\alpha 3)+2\cos(\alpha 4)-2\cos(\alpha 5)=\pi\left(\frac{v_{01}}{v_i*4}\right)$$
$$1-2\cos(3\alpha 1)+2\cos(3\alpha 2)-2\cos(3\alpha 3)+2\cos(3\alpha 4)-2\cos(3\alpha 5)=0$$
$$1-2\cos(5\alpha 1)+2\cos(5\alpha 2)-2\cos(5\alpha 3)+2\cos(5\alpha 4)-2\cos(5\alpha 5)=0$$
$$1-2\cos(7\alpha 1)+2\cos(7\alpha 2)-2\cos(7\alpha 3)+2\cos(7\alpha 4)-2\cos(7\alpha 5)=0$$
$$1-2\cos(9\alpha 1)+2\cos(9\alpha 2)-2\cos(9\alpha 3)+2\cos(9\alpha 4)-2\cos(9\alpha 5)=0$$
$$1-2\cos(11\alpha 1)+2\cos(11\alpha 2)-2\cos(11\alpha 3)+2\cos(11\alpha 4)-2\cos(11\alpha 5)=0$$

with

If $V_{01}$is the Fundamental value, the equations to be solved to obtain α1, α2, α3,α4,α5.

Where the angles α1<α2<α3……………..<π/2 should satisfy the above criteria.

The above equation has been formulated to eliminate 3rd to 11th harmonics. However for 3phase inverter with star connected load and isolated neutral, the triplen harmonics are automatically eliminated. In this work all the examples are based on 3phase inverter with isolated neutral and the triplen harmonics i.e. 3rd and 9th have not been eliminated.

V.RESULTS AND DISCUSSIONS

The required notch angles for the best solution of the transcendental equations were obtained using MATLAB using various techniques (Newton Raphson method, PSO, APSO etc.) and the best results obtained were verified with hardware.

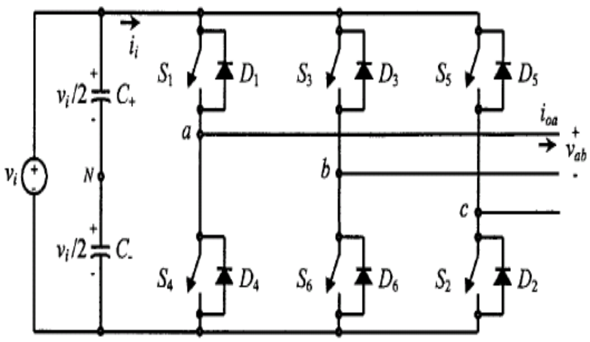

Fig 1. Basic Three Phase Voltage soucrce inverter.

In the Newton Raphson method, one can start with an initial guess which is reasonably close to the true root, then its function is approximated by its tangent line,and one can compute the x-intercept of the tangent line. The x-intercept is typically a better approximation to the function root than the original guess, the process is iterated.

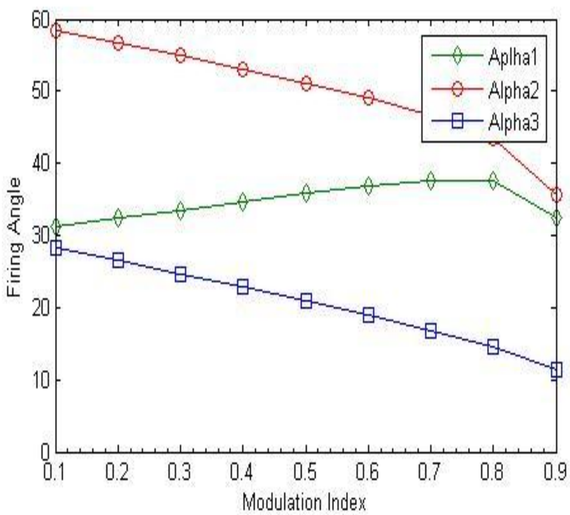

Fig 2.Variation of switching angles for three phase VSI obtained by Newton-Raphson Method.

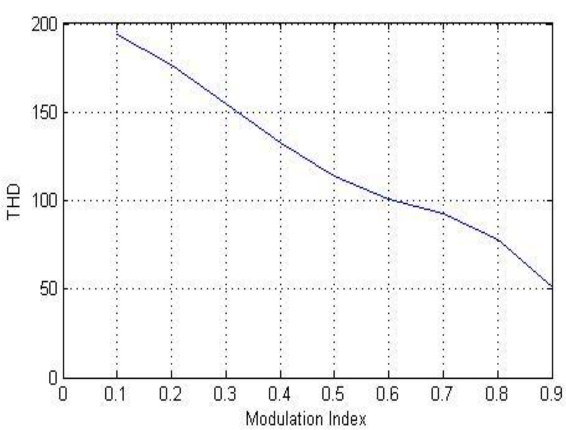

Fig 3.Variation of THD with modulation index
Newton Raphson Method

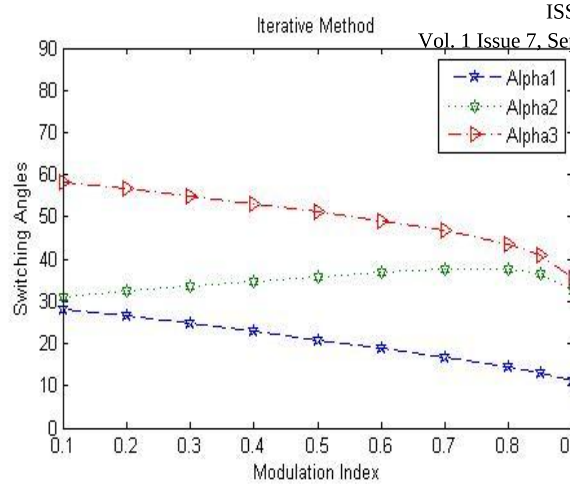

Fig 4.Variation of switching angles to the modulation index for VSI by Iterative method.

From the Fig 3 and Fig 4 it is observed that as the modulation idex increases the THD decreases. The minimum value of THD obtained by this method is 48.27% at Modulation Index 0.9.

The disadvantage of the conventional numerical methods discussed above is that the the convergence may be dependant on the accuracy of the initial guess. The THD of the output obtained from these solutions are likely to be high, as the best solutions may not be achieveable by these methods. These disadvantages are over come by particle swarm optimization techniques.

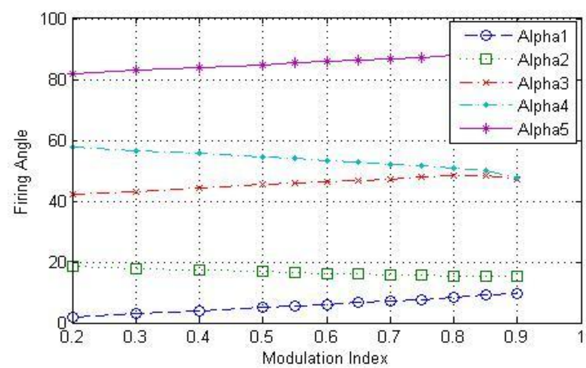

Fig 5.Variation Of modulation index with Firing angle by using PSO technique

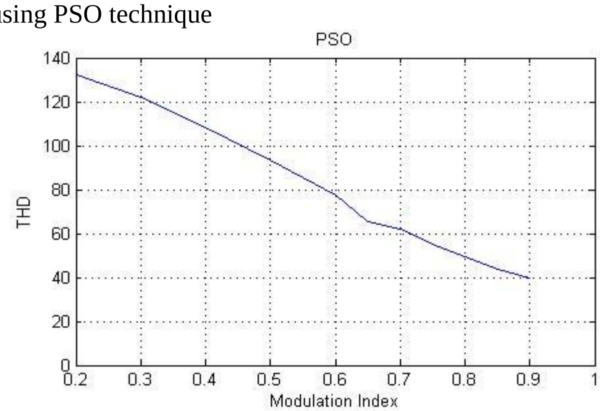

Fig 6. Variation of THD for three phase VSI by standard PSO

Fig 5 & 6 shows the results from conventional PSO technique. The maximum THD was 132.3% for modulation index 0.1,and

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minimum was 38.17% for modulation index 0.9 for five switching angles.

Futher improvement in results was obtained by the APSO technique as shown in Fig 7 & 8 .

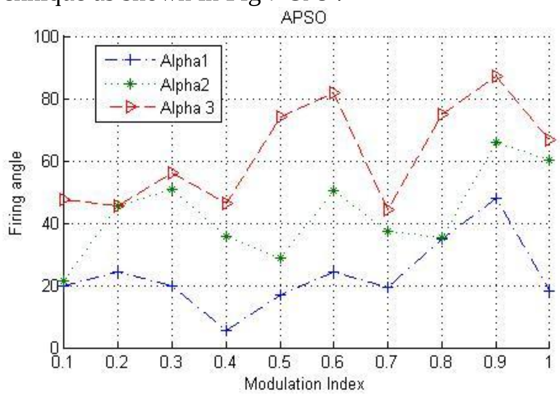

Fig 7.Variation of firing angles with modulation index by APSO technique.

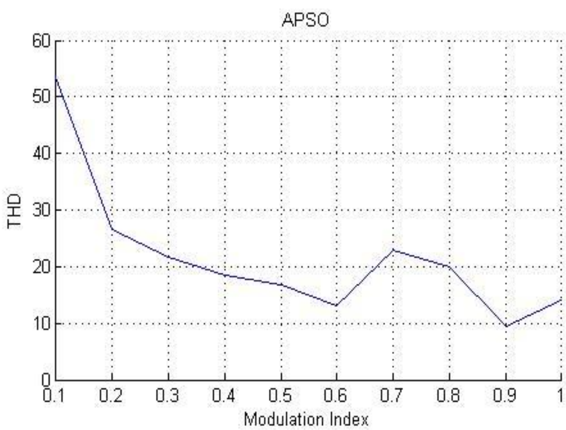

Fig 8. Variation of THD by changing the modulation Index

Where maximum value of THD obtained at MI 0.1 is 53.2% and minimum value of THD at 0.9 MI is 9.96%. Fig 9 shows the FFT analysis of the output obtained using APSO technique, this was obtained by using MATLAB/SIMULINK.

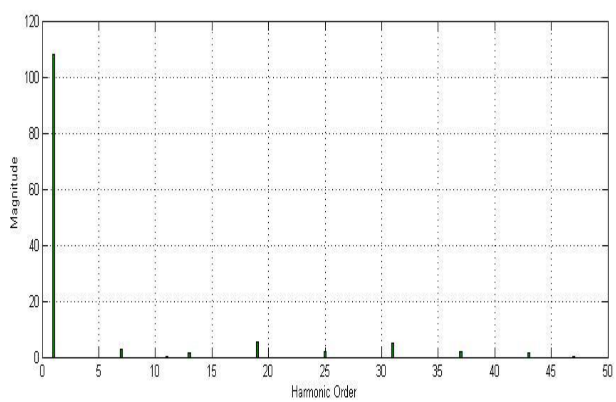

Fig 9.FFT analysis of three phase inverter with APSO technique.

V. HARDWARE VALIDATION OF SIMULATION RESULTS

The pulses at specific timings, required for three phase inverter had been generated by ATMEGA16 microcontroller.

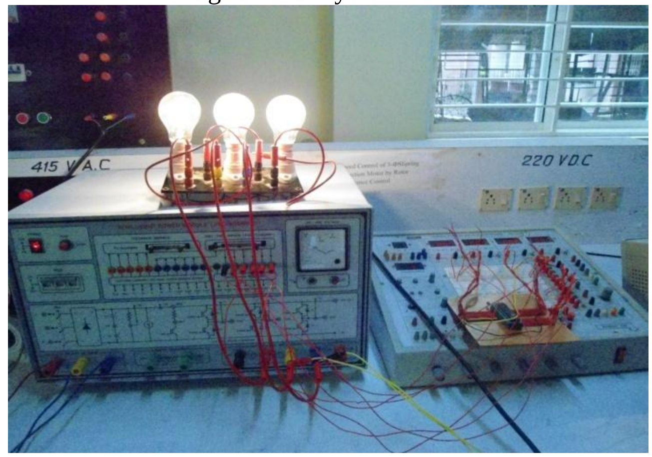

Fig 10.Experimental setup of three phase inverter

The input supply to the three phase inverter module was set at 100VDC by adjusting a three phase Auto transformer. Load was resistive balanced load. The switching pulses generated by the micro controller unit is given to the IGBT's through opto- isolators.

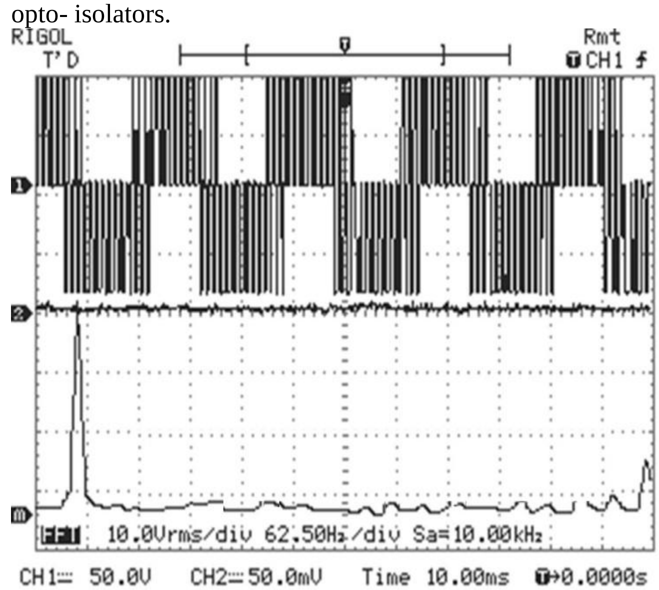

Fig 11.Voltage waveform of 3 phase inverter and its FFT analysis

As the load is resistive, the voltage and current wave form will be similar.

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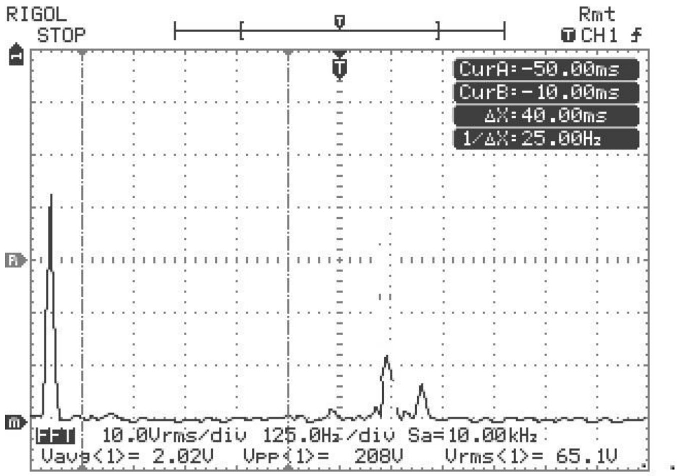

Fig 12.FFT analysis for APSO technique up to 41st harmonics

Table 1.Simulation and Experimental results

Harmonic	Simulation	Experimental
1	100%	100%
5	0%	0.002%
7	0%	0.01%
11	0%	0.004%
13	0%	0.002%
17	0.01%	0.901%
19	8.3%	9.40%
23	6.1%	7.01%
29	0.004%	0.008%
31	0.001%	0.003%
35	0.001%	0.003%
37	0.001%	0.003%

Table 1 shows the comparison between simulation and experimental results. It may be observed that there is a small deviation between the simulation and experimental results. This is mainly due to the 3 micro seconds blanking time introduced for the protection of the IGBT's in the experimental setup. Due to the effect of blanking time some additional harmonics are introduced in the system. THD obtained in simulation (up to 39th harmonic) is 10.5444% and in the experimental result THD was 12.3799%.

VI.CONCLUSION AND FUTURE SCOPE

The results obtained by using APSO technique have been shown to be better than those obtained by classical techniques and standard PSO technique. In the three phase inverter with the bipolar switching mode the THD was 10.544%. This work was limited to bipolar switching only. It can be predicted that better results can be obtained for unipolar switching. This method of harmonic elimination is recommended for low and medium power applications. Studies for further improvement of THD can be carried out, by using evolutionary computing and metaheuristic algorithms. Hybrid techniques, where the angles obtained by one optimization method are taken as the initial value of another optimization method, may be employed for obtaining better results.

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