Improved Ant Colony Optimization Algorithm for Selective Harmonic Elimination - A Novel Approach

[1]Sarika. D. Patil, [2]S. G. Kadwane, [3]Pratik Dhabe
[1,2]Yeshwantrao Chavan College of Engineering, Nagpur
[3]Shri Sant Gajanan Maharaj College of Engineering, Shegaon

Abstract
This paper presents new improved proposed algorithm over the basic Ant colony optimization algorithm to enhance the convergence speed, global ability for solution and to avoid from stucking into local optima. This (NEWACO) algorithm mainly aims at adaptive adjustment control of pheromone with active evaporation

factor for updation. The movement and pheromone deposition is improved and making it flexible for solving large scale problems. Hence this proposed (NEWACO) algorithm is applied for solving selective harmonic elimination equations which are non linear transcendental equation thereby providing optimized solution for switching angles and minimizing Total Harmonic Distortion (THD). The various simulated and experimental results show that this new proposed algorithm can be used for finding the global minima with high convergence performance. It proves its effectiveness over the other conventional methods too.

Keywords
Adaptive control pheromone, ant colony optimization, active evaporation factor, selective harmonic elimination, multilevel inverter, total harmonic distortion

Introduction

The ACO algorithm with its several advantages is widely used in solving many combinatorial optimization problems. It has positive feedback for obtaining rapid solution, dynamic applications, metahuristics search characteristics, robustness, Inherent parallelism implementation etc. Hence gradually it becomes the emerging field in solving optimization algorithms [1-3]. First it was used in problem of quadratic assignment [4], problem of job scheduling [5], to solve traveling salesman problem [6] and so on. Inspite of many advantages, it has shortcomings too i.e., maximum searching time, very slow speed of convergence, premature convergence for complex problems and so on. Many researchers proposed improved ACO algorithms to overcome these shortages. ACO with active pheromone updation and cell scheduling is proposed by Leng et al. for flexible manufacturing process to reduce cost and time [7]. Yang and Lai proposed improved ACO for p//T (p//T-ACO) for solving practical large scale problems [8]. Xu et al. suggested chaotic map for hybrid algorithm for enhancement of basic the ACO algorithm and to solve VRP problems [9]. Combination of ant colony algorithm with particle swarm algorithm is applied to solve traveling salesman problem (TSP) by Walid et al.[10]. Extended ant colony algorithm to implement regulation policy for controlling each type of ant during search process is presented by Escario et al.[11]. New GACO ant colony algorithm to compute Unified Device Architecture is presented by Li and Jin [12]. This paper presents, improved new ant colony optimization (NEWACO) algorithm which is an efficient and intelligent algorithm applied to solve nonlinear selective harmonic elimination equations which are transcendental in nature to obtain the optimized solution for switching angles in single phase H-Bridge 7 level multilevel inverter. With these solutions, Total Harmonic Distortion (THD) will also reduce to a great extent which proves the effectiveness of proposed algorithm.

1. Formulation of SHE Equations

Fig.1 shows bipolar output voltage waveform in inverters. From Fourier series, the output voltage equation can be obtained and is by equation (1). This equation is a nonlinear transcendental equation which contains trigonometric terms given by

$$V_{2k+1} = \frac{4V_{dc}}{(2k+1)\pi} \sum_{i=0}^{N} \cos(2k+1)\alpha_i \tag{1}$$

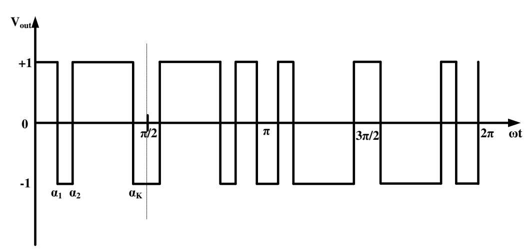

Fig. 1 Output voltage waveform

where,

V = Inverter output voltage

V_{dc} = Input voltage magnitude

α = Switching angles

N = Harmonic equations

$k =$ Number of switching angles (from 0 to N-1)

Total number of harmonic equations (N) can be given by

$N = (N+1)$ total number of harmonics to be eliminated.

For satisfying this, the main constraint is

$$0 \le \alpha_1 \le \alpha_2 \le \alpha_3 ... \le \alpha_{k-1} \le \alpha_k \le \pi / 2 \quad (2)$$

When N=3, the equation (1) can be expanded as

$$-1 + 2cos\alpha_1 - 2cos\alpha_2 + 2cos\alpha_3 - \frac{\pi m}{4} = 0 \quad (3)$$

$$-1 + 2cos5\alpha_1 - 2cos5\alpha_2 + 2cos5\alpha_3 = 0 \quad (4)$$

$$-1 + 2cos7\alpha_1 - 2cos7\alpha_2 + 2cos7\alpha_3 = 0 \quad (5)$$

and Total Harmonic Distortion (THD) is given by

$$THD = \frac{\sqrt{\sum_{n=2} \left(\frac{1}{n} \sum_{k=1}^{N} (-1)^{k+1} cos(n\alpha_k) \right)^2}}{\sum_{k=1}^{N} \left((-1)^{k+1} cos(\alpha_k) \right)} \quad (6)$$

Fundamental voltage is given by equation (2), whereas equation (3) and equation (4) give fifth and seventh harmonic voltage equations respectively. Here the main intention is to lower the objective function value by finding the optimum switching angles. It again reduces the lower order odd harmonics by maintaining desired fundamental voltage. This is treated as a optimization problem.

2. Ant Colony Optimization Algorithm

Ant colony optimization algorithm was first invented by Marco Dorigo [13] for solving the traveling salesman problem. Also, the various application of ACO in various fields has been introduced. Basically, ACO is a metahuristic combinatorial optimization algorithm. In this algorithm, the ants work as a artificial agents and correspond with each other for obtaining the particular solution. Generally ants move randomly in search of food. Every time they cross the edges by laying pheromone. The follower ants follow the similar path. This ensures the high probability of selection of the same path with maximum pheromone deposition [14].

Steps for ACO algorithm

Step 1 : Create initial ant population

Step 2:Defining objective function

Step 3:Definining probability by

$$P_{ij}(t) = \frac{\tau_{ij}(t)^{\alpha}\left(\frac{1}{d_{ij}}\right)^{\beta}}{\sum_{j \in \text{allowednodes}} \tau_{ij}(t)^{\alpha}\left(\frac{1}{d_{ij}}\right)^{\beta}} \quad (7)$$

where,

τ_{ij} = pheromone quantity of

d_{ij} = distance

α , β = parameter constants

Step 4: Updating Pheromone by

$$\tau_{ij}(t+1) = \tau_{ij}(t)x(1-\rho) + \sum_{\substack{k \in Colony\,that \\ used\,edge(i,j)}} \frac{Q}{L_k} \quad (8)$$

where,

Q = parameter constant

ρ= evaporation constant

L_k = Tour Length

Step 5 : Pheromone decay by

$$\tau_{ij}(t) = \tau_{ij}(t)x(1-\rho) + \Delta\tau_{ij}(t) \quad (9)$$

Step 6: End of Algorithm

3.NEW Improved Ant Colony Optimization (NEWACO) Algorithm

3.1Movement Rules for the Ants

Phenomenon Stagnation and evaporation is the main concern of basic ACO algorithm. To overcome this drawback of basic ACO algorithm, an appropriate probability rule is proposed which is based on combination of deterministic selection and random selection. Here quantity of pheromone deposition is more on the same visited path thereby increasing the chances of following the similar path. It ensures the global search potential of the proposed algorithm. The probability of visiting next node is given by

$$p_{ij}^{k}(t)=\begin{cases}\dfrac{\tau_{ij}(t)^{\alpha}\ x\ \eta_{ij}(t)^{\beta}\ x\ x_{ij}(t)}{\sum_{k\in allowed\ k}\tau_{ik}(t)^{\alpha}\ x\ \eta_{ik}(t)^{\beta}\ x\ x(t)} & if\ j\in allowed\ k\\ 0 & otherwise\end{cases} \quad (10)$$

$$x_{ij}=\frac{a\ x\ T_c}{a\ x\ T_c+\delta\ x\ Q_c(i,j)x\ \eta((i,j)/\eta_{max}} \quad (11)$$

where,

a = ant numbers

T_c = number of current iteration

η_{max} = maximum heuristic function

Q_c *(i,j)* = Total ants on path *(i,j)*

Here as the iterations are reaching to optimal solutions, the pheromone deposition is continuously increasing thereby decreasing the distance xij on the edge. If the same path is selected then chances of excessive deposition of pheromone is reduced which tends to premature convergence.

3.2 Updation for Pheromone

After each iteration, pheromone information must be updated and is given by

$$\tau(r,u)=\tau(r,s)\ \mathrm{x}\ (1-\rho)+\sum\Delta\tau_k\ (r,s) \quad (12)$$

In the above formula, the value of pheromone evaporating constant 'ρ' is generally kept as $(0<\rho<1)$. and $\Delta\tau_k\ (r,s)$ is pheromone amount on the edge (r,s) by ant *k* for the time period *(t<T<t+ Δt)*. This factor is

$$\Delta\tau_k(r,s)=\begin{cases}\dfrac{Q}{L_k} & (r,s)\in\pi_k\\ 0 & otherwise\end{cases} \quad (13)$$

where, Q = Quantity of pheromone

L_k = distance travelled by ant 'k' in time Δt.

In this new improved ACO (NEWACO) algorithm, this pheromone updation is given by

$$\tau_{ij}(t+1)=\rho\,\mathrm{x}\,\tau_{ij}(t)+\Delta\tau_{ij}+\Delta\tau_{ij}^{*} \quad (14)$$

$$\Delta\tau_{ij}^{*} = \sum_{k=1}^{m} \Delta\tau_{ij}^{*} \quad (15)$$

3.3 Adaptive Adjustment Control of Pheromone

In basic Ant Colony algorithm, use of a constant quantity of pheromone for updation purpose leads to the ignorance of uniform distribution of pheromone deposition. This further leads to stagnation and poor convergence causing falling into local optima. In this paper, adaptive adjustment control of quantity of pheromone is introduced where constant term Q is replaced by real time variable function Q(t) for maintaining the balance between random search and evaporation constant.

$$\Delta\tau_{ij}^{k}(t) = \frac{Q(t)}{L_k} \quad (16)$$

$$Q(t) = \begin{cases} Q_1 & t \le T_1 \quad \text{for time period } T_1 \\ Q_2 & T_1 \le t \le T_2 \quad \text{upto time period } T_2 \\ Q_3 & T_2 \le t \le T_3 \quad \text{upto time period } T_3 \end{cases} \quad (17)$$

For expanding the scope of search and finding the optimal solution, a positive feedback in the algorithm is introduced. This ensures the reducing of the probability of selecting worst path by any ant in search process. If the obtained optimal solution remained unchanged within time limit, it shows that probability of finding optimum solution is maximum.

3.4 Active Evaporation Policy

The value of pheromone evaporation factor ‘ρ’ in basic ant algorithm is always a constant term. Generally it lies between 0 &1. If its value is 1 then it shows maximum deposition of pheromone which ensures the probability of visited path/node is being selected. If its value is 0, then it shows no deposition and all pheromone gets evaporated. Here concept of active evaporation policy is introduced where initially the value of ρ is kept maximum so that global search capability is improved. Also its rate continues to decay which converges to the optimal solution quickly within the time limit. It is implemented with the number of sets and is given by

$$\rho(t) = \frac{\text{T x } (\tau_{\max} - \tau_{\min}) \text{ x } t}{\text{T} - 1} + \frac{\text{T x } (\tau_{\min} - \tau_{\max})}{\text{T} - 1} \quad (18)$$

where,

τ_{max}= Upper limit of Pheromone

τ_{max}= Lower limit of Pheromone

t= time at current iteration

T= time at maximum

4 Steps for Proposed NEWACO Algorithm

for solving Selective Harmonic Eequations, following steps are used:

Step 1. Parameter's initialization.

All the parameters of NEWACO algorithm are initialized properly. It mainly consist of ant size(a), Time for maximum iteration (T_{max}) heuristic constant term (β), pheromone constant term (α), , evaporation constant term (ρ), pheromone quantity (Q), initial pheromone deposition(τ_ij), initial probability(q_0),and so on. Initially all the nodes are equally divided for successfully running proposed NEWACO algorithm.

Step 2. All the ants (a) are randomly distributed over 'n' nodes, and the same data is stored in the Tabu list.

Step 3. Until and unless the Tabu list is empty, probability of selection of next node is calculated and this information is again added to existing Tabu list. Then pheromone is updated locally.

Step 4. When all the ants completed one iteration, then the tour length is calculated and accordingly Tabu list is updated. Repeat step 3 until all the iterations gets completed. This current optimal tour length is saved and updates for the global optimal tour length.

Step 5. Pheromone Updation

Update the pheromone according to the equation 14 for selecting globally updating pheromone

Step 6. Stopping Criteria

Set incremental time as t = t+1 until it reaches to $t < Tmax$, repeat step 3, otherwise NEWACO algorithm is terminated and print the optimal solution.

Table 1: Parameters for NEWACO Algorithm

Ants Population size (a)	Pheromone constant (α)	Evaporation constant (ρ)	Initial Pheromone deposition (τ_{ij})
100	1.0	0.05	1.0
Iteration Time (T_{max})	Heuristic constant(β)	Pheromone Quantity (Q)	Initial probability(q_0)
500	1.0	100	0.5

5. Simulation and Experimental Results and Analysis

MATLAB/Simulink environment is used for the simulation of a single phase 7-level multilevel inverter. Table 2 shows the parameters considered for simulation. In this, switching frequency is maintained at fundamental frequency which ensures the minimum switching losses.

Table 2: Simulation parameters

Parameters	Values
DC sources	12V each
Switching frequency	50 Hz
Fundamental frequency	50 Hz

To obtain solution for SHE equations the proposed algorithm is applied. From this algorithm the optimum switching angles are obtained as α_1 = 14.32˚, α_2 = 28.64˚, α_3 = 41.25˚ for modulation index, m_a = 0.8. This obtained solution set provides optimized switching angles. Also it minimizes the lower order harmonics and Total Harmonic Distortion (THD). The 5th and 7th harmonic is reduced to a great extent. The variation of these angles with modulation index m_a is shown in Figure 2. The variation of objective function with iterations is shown in Figure 3 which is minimum as desired. The output of single phase 7-level inverter is shown in Figure 4. Figure 5 shows the FFT analysis. Figure 6 shows the contour graph of objective function. Harmonic profile shows lower odd harmonics are actually less i.e. h_5 = 0.02% and h_7 = 0.01% and THD = 2.66%. Hence from all these results the effectiveness of proposed algorithm is proved which also improves the harmonic profile of the inverter.

Simulation Results

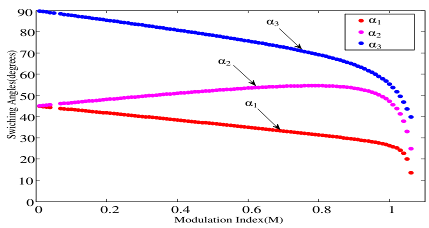

Fig. 2 Variation of switching angles

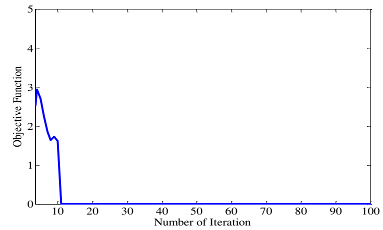

Fig. 3 Variation of objective function

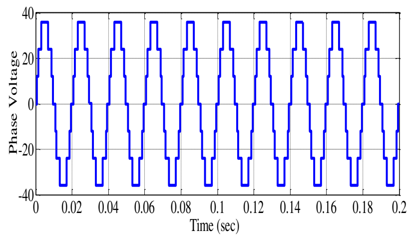

Fig. 3 Output phase voltage

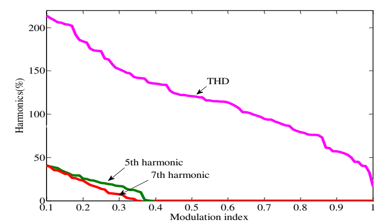

Fig. 4 Harmonic Profile

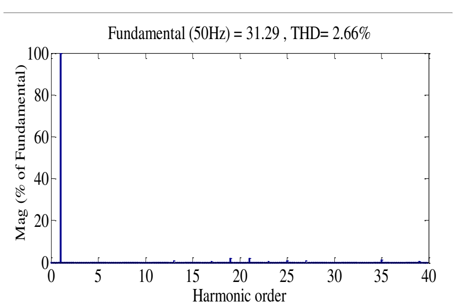

Fig. 5 FFT Analysis

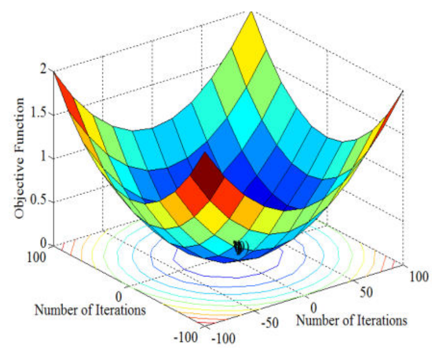

Fig. 6 3-D graph of objective function

Experimental Results

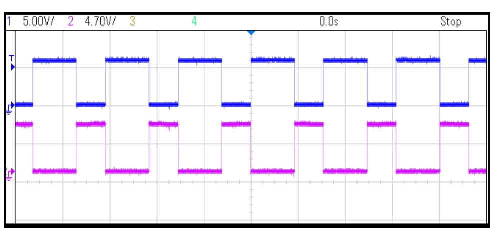

Fig. 7 Switching Pattern

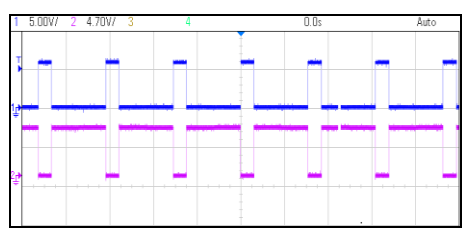

Fig. 8 Complementary Switching Pattern

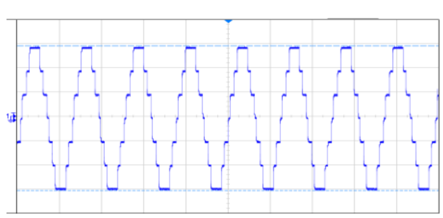

Fig. 9 Experimental Result of Phase output

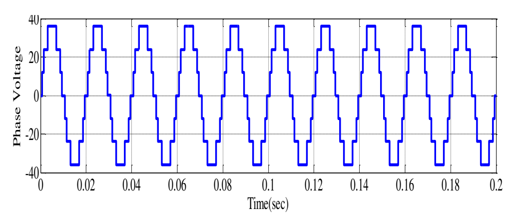

Fig. 10 Simulation Result of Phase output

6. Conclusion

This paper proposes an intelligent and efficient new improved (NEWACO) optimization algorithm. Based on adaptive adjustment control of pheromones and updation for active evaporation factor are the key for obtaining global optimum solution along with fast convergence speed. These rules are also used for solving large scale problems. Here NEWACO algorithm is used to find the optimal solution of switching angles of single phase seven level multilevel inverter and to reduce the lower odd order harmonics and THD. All the simulation and experimental results show the effectiveness of proposed algorithm.

References

[1] M. Dorigo and G. D. Caro, "ant algorithms for discrete optimization", *Artificial Life,* vol. 5, no. 3, (1999), pp. 137-172.

[2] T. Stutzle and H. H. Hoos, "MAX-MIN ant system", *Future Generation Computer Systems,* vol. 16, no. 8, (2000), pp. 889-914.

[3] J. Dero and P. Siarry, "Continuous interacting ant colony algorithm based on dense hierarchy", *Future Generation Computer Systems,* vol. 20, no. 5, (2004), pp. 841-856.

[4] M. Dorigo and L. M. Gambardella, "Ant colony system: a cooperative learning approach to the traveling salesman problem", *IEEE Transactions on Evolutionary Computation,* vol. 1, no. 1, (1997), pp. 53-66.

[5] L. M. Gambardella, E. Taillard and M. Dorigo, "Ant colonies for the quadratic assignment problem", *Journal of the Operational Research Society,* vol. 50, no. 1, (1999), pp. 167-176.

[6] A. Colorni, M. Dorigo and V. Maniezzo, "Ant system for job-shop scheduling", *Belgian Journal of Operations Research, Statistics and Computer-Science*, vol. 34, no. 1, (1994), pp. 39-54.

[7] S. Leng, X. B. Wei and W. Y. Zhang, "Improved ACO scheduling algorithm based on flexible process", *Transactions of Nanjing University of Aeronautics and Astronautics,* vol. 23, no. 2, (2006), pp. 154-160.

[8] Y. Yi, Yang and J. L. Lai, "Computation model and improved ACO algorithm for p//T", *Journal of Systems Engineering and Electronics*, vol. 20, no. 6, (2009), pp. 1336-1343.

[9] H. L. Xu, X. Qian and L. Zhang, "Study of ACO algorithm optimization based on improved tent chaotic mapping", *Journal of Information and Computational Science*, vol. 9, no. 6, (2012), pp. 1653-1660.

[10] E. Walid, E. A. Haikal, A. Ajith and A. M. Alimi, "A comparative study of the improvement of performance using a PSO modified by ACO applied to TSP. *Applied Soft Computing Journal",* vol. 25, no. 12, (2014), pp. 234-241.

[11] J. B. Escario, J. F. Jimenez and J. M. Giron-Sierra, "Ant colony extended: Experiments on the travelling salesman problem", *Expert Systems with Applications,* vol. 42, no. 1, (2015), pp. 390-410.

[12] F. Li and M. L. Jin, "GACO: a GPU-based high performance parallel multi-ant Colony Optimization algorithm", *Journal of Information and Computational Science,*

vol. 11, no. 6, (2014), pp. 1775-1784.

[13] M. Dorigo and L. M. Gambardella, "Ant colonies for the travelling salesman problem", Biosystems, vol.43, no. 2, (1997), pp. 73-81.

[14] S. Patil, and S. Kadwane, "Hybrid optimization algorithm applied for selective harmonic elimination in multilevel inverter with reduced switch topology," Microsystem Technologies- springer, vol.24, issue 2, pp.1-7, 2018.