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Application of Optimization Technique in Grid Tied Inverter

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Abstract—*This paper proposes an application of ant colony optimization for harmonic elimination in single-phase seven level grid tied inverter for residential applications. Also the derived equation for total harmonic distortion (THD) of the output voltage of inverter is used as the objective function in the ACO algorithm. This proposed scheme consists of grid-tied H- bridge inverter along with Solar PV Cell and DC-DC boost converter. The fundamental switching method is used for inverter. With suggested current control technique grid synchronization condition (i.e. grid voltage and grid current) can be obtained. Harmonic elimination in inverter is a major issue which is solved by ant colony optimization (ACO) method. The switching angles for inverter are calculated using ACO optimization which will not only improve the harmonic profile but also reduce the size of filter inductor. The performance of the proposed system is simulated in MATLAB/Simulink environment and the results are validated through experimental results.*

1. INTRODUCTION

Recently power generation using photovoltaic is gaining much interest in the field of power sector as it is a source of clean and pollution free power. Also it is showing significant growth in grid-connected applications [1]. The solar energy cannot be directly interfaced with the utility grid due to economic constraints. Thus the power electronic devices are employed to interface the solar systems to the grid. The grid inverter plays very important role in PV system. The main characteristic of the grid inverter is that, it should deliver the current drawn from the inverter to the utility grid at unity power factor. Recently there are inverters having adjustable power factor. Most of the grid inverter technologies for PV applications are available such as centralized inverter, string inverter, multi-string inverter and modular inverter [2].In this paper, the work mainly focuses on the multilevel inverter modelling and its control. Multilevel inverters are increasingly used in grid tied application for distributed generation. Also, the other applications in field of chemical plant, oil, LNG plants, water plants, marine propulsion, power generation-transmission, power-quality devices, and FACTS devices are accountable [3]. Because of these advantages, power quality of the system, voltage capability can be enhanced with minimum switching losses [4]. Also it is applicable to transformer less system at the distribution side with lower cost. For synchronization of inverter to the grid closed loop current controlled method is mostly used. The limitation with this method is that the modulation index (M) is not certain and further, particular harmonics cannot be eliminated.

If modulation index, M, is fixed, then harmonic elimination with Ant colony optimization method, can be properly investigated in closed loop grid tied inverter system.

2. MATHEMATICAL MODELING OF HARMONIC EQUATIONS

In inverters, bipolar output voltage waveform is shown in Fig. 1. The output voltage obtained from fourier series is a set of nonlinear transcendental equations containing trigonometric terms given by equation (1).

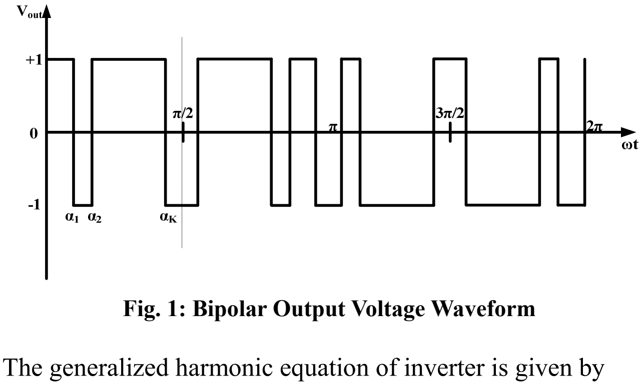


Fig. 1: Bipolar Output Voltage Waveform

The generalized harmonic equation of inverter is given by

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

where

V = Voltage output of inverter

Vdc = Magnitude of the DC input voltage

α = Switching (Notching) angle of the inverter

N = Number of Harmonic equations

K = Switching angle number (from 0 to N-1)

Number of harmonic equations (N) = Number of harmonics to be eliminated (N+1). The constraint to be satisfied by the waveform is that $0 \leq \alpha_1 \leq \alpha_2 \leq \alpha_3 \ldots \leq \alpha_{k-1} \leq \alpha_k \leq \frac{\pi}{2}$.

When equation (1) is expanded for N=3, the three equations can be given by

$$-1 + 2\cos\alpha_1 - 2\cos\alpha_2 + 2\cos\alpha_3 - \frac{\pi M}{4} = 0 \tag{2}$$

$$-1 + 2\cos 5\alpha_1 - 2\cos 5\alpha_2 + 2\cos 5\alpha_3 = 0 \tag{3}$$

$$-1 + 2\cos 7\alpha_1 - 2\cos 7\alpha_2 + 2\cos 7\alpha_3 = 0 \tag{4}$$

Total Harmonic Distortion (THD) is given by

$$THD = \frac{\sqrt{\sum_{n=2}\left(\frac{1}{n}\sum_{k=1}^{N}(-1)^{k+1}\cos(n\alpha_k)\right)^2}}{\sum_{k=1}^{N}\left((-1)^{k+1}\cos(\alpha_k)\right)} \tag{5}$$

Magnitude of fundamental voltage is given by equation (2) whereas fifth harmonic voltage and seventh harmonic voltage is given by equation (3) and equation (4). Solution to these equations can be given by conventional methods like iterative methods. One of the iterative methods is Newton–Raphson (N–R) method [5]. But the major disadvantage of this method is dependency on initial guess along with divergence problems. Also, it is possible to find one set of solutions for feasible *M*. The initial guess should be exact close to the solution for obtaining the desired output. The theory of resultant polynomial is proposed in [6], [7]. This method is applicable only for finding all possible solutions with feasible Modulation index *M*. But when voltage level or input dc voltage level is changed, then this method becomes complicated and time-consuming. Also it requires new expression for new voltage level. These methods can not only find solutions, but they can also find solutions for infeasible *M* with optimum switching angles. These methods are simple and can be used for problems with any number of levels. They are derivative free. But the drawback of finding solutions by conventional method is that the process is complicated and time consuming.

In recent years, optimization techniques become very popular in many engineering applications. These methods are population based methods. The population is randomly generated in search space. The main advantage is that they do not require any suitable initial guess as compared to conventional methods. The computation time required is very less and convergence is very fast. Also probability of finding global minima is more. But these techniques have some constraints also. For example, for solving SHE-PWM problem with a differential evolution (DE) algorithm the constraint is that any two consecutive solutions are well separated [8]. Speed of finding solution of SHE problem is given by Genetic algorithms (GA)[9],[10]. Particle swarm optimization (PSO) is a evolutionary technique discovered through simplified social model viz. bird flocking, fish schooling, etc. [11], The ant colony algorithm is first proposed by Dorigo *et al.* [12]. It is a stochastic combinatorial optimization approach based on population with ants as cooperating artificial agents. The ants generally cooperate among themselves and get the optimum solution for the problem. The blind ants move randomly in search of food by selecting the shortest or optimized path, and it deposits pheromone trails on the edges. While the follower ant can detect the pheromone laid by first ant and follow the same path with high probability. More ants following the same trail path is the collective behaviour of all ants. The probability of selecting the same path increases with the number of ants that previously selected the same path. The flowchart for ACO algorithm is shown in Fig. 2. ACO algorithm is presently being used in many applications for optimization of nonlinear equations. On many applications ACO has been reported having better performance than GA, DE, PSO [13]. Moreover ACO is capable of producing the optimum solution with a very small population size.

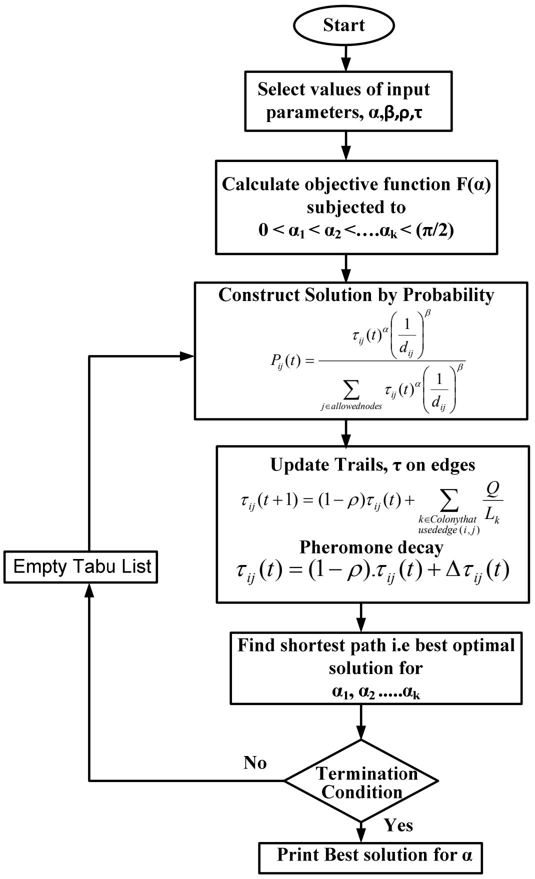


Fig. 2: Flow Chart of Ant Colony optimization Algorithm

3. HARMONIC ELIMINATION USING ANT COLONY OPTIMIZATION ALGORITHM

Following steps are involved for implementation of Ant colony optimization Algorithm

Step I : Initialization

While (termination not satisfied)

- Create ants
- Find solutions

The initial step is deploying the ants in a feasible solution space with the constraint $0 \le \alpha_1 \le \alpha_2 \le \alpha_3 \ldots \le \alpha_{k-1} \le \alpha_k \le \frac{\pi}{2}$. Here, the position of an ant refers to one complete solution set to the problem.

Step II : Transition probability

The ants are moving based on the level of pheromone content at its location. The *transition probability* P_{ij} of an ant at the *j*th location is computed using

$$P_{ij}(t) = \frac{\tau_{ij}(t)^{\alpha}\left(\frac{1}{d_{ij}}\right)^{\beta}}{\sum_{j \in allowednodes} \tau_{ij}(t)^{\alpha}\left(\frac{1}{d_{ij}}\right)^{\beta}} \qquad (6)$$

where τ_{ij} = Quantity of pheromone

d_{ij} = Heuristic distance

α, β = constant

Step III : <u>Pheromone update</u>

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{\substack{k \in Colonythat \\ usededge(i,j)}} \frac{Q}{L_k} \qquad (7)$$

where ρ = Evaporation constant

Q = Pheromone laid by each ant that uses edge (i,j)

L_k = tour length of the k^{th} ant.

$$\Delta\tau_{ij}^{k} = Q / L^{k}(t) \quad if\ (i,j) \in T^{k}(t)\ else\ 0. \qquad (8)$$

Where T is the tour done at time t by ant k.

Step IV : <u>Pheromone decay</u>

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

Where ρ is evaporation constant and it is assumed between 0 and 1. When all ants complete Steps I - IV, it is termed as one iteration.

Step VI : <u>Apply Stopping Criteria</u>

The stopping criterion can be applied when the objective functions' value reaches to reasonably low value after a finite number of iterations. In this paper, the program was stopped after 200 iterations.

4. PROPOSED METHODOLOGY APPLIED TO GRID TIED INVERTER

In this paper, seven levels Cascaded H Bridge (CHB) multilevel inverter is investigated for effective demonstration of the proposed scheme. Fig.3 shows the block diagram of application of proposed algorithm for grid connected household application. In grid tied inverter system, the sinusoidal output of the inverter must be synchronized with the grid frequency for unity power factor. PLL is mainly used for synchronization of Grid voltage (V_g) and Grid current (I_g). The voltage magnitude of the inverter output (V_{inv}) needs to exceed the grid voltage, (V_g) to enable the inverter current (I_{inv}) to be supplied to the grid.

Low Pass L-C Filter Design

To synchronise the grid voltage and current the output of the inverter should be sinusoidal. But practically this output voltage contains harmonics. According to the IEC 61727 standard (PV System, characteristics of the utility interface), the maximum allowed THD for the output current is 5 %. Therefore an LC filter plays very important role in achieving minimum THD value[14]. It should be able to generate a sinusoidal output current with THD less than 5 %. Table 1 shows specifications used for Grid connected system [15].

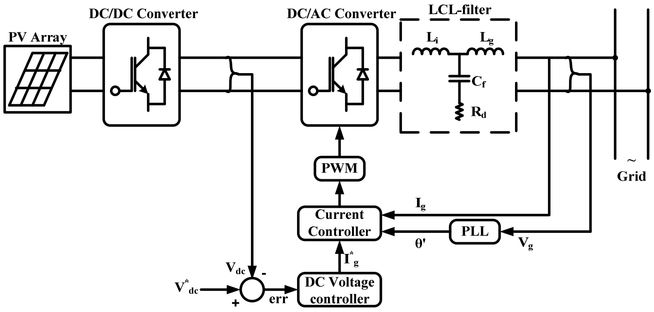
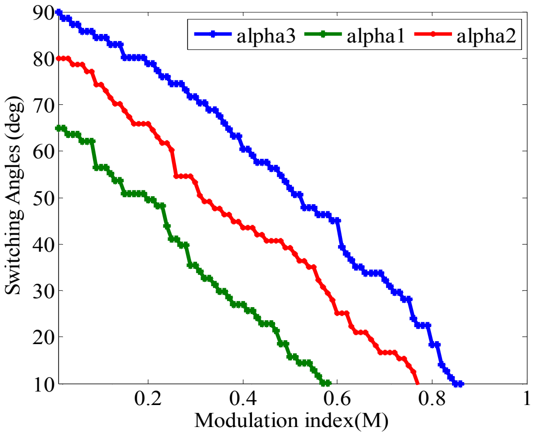


Fig. 3: Block diagram of grid tied system.

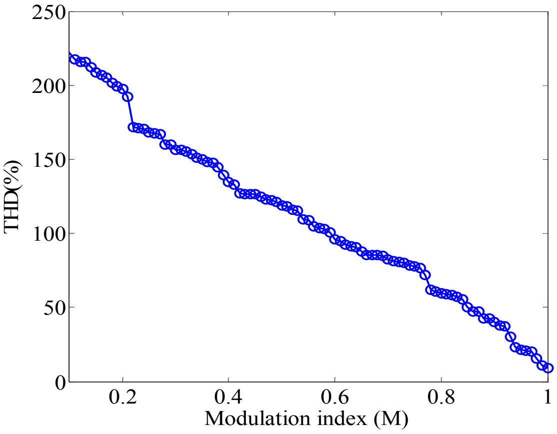
Table 1: Specifications

Parameters	Values
Grid voltage	$230V_{rms}$
Supply frequency	50Hz
Current limiting inductor	3mH
3 DC sources for inverter	100V each
Load	1000W

5. SIMULATION RESULTS



(a)



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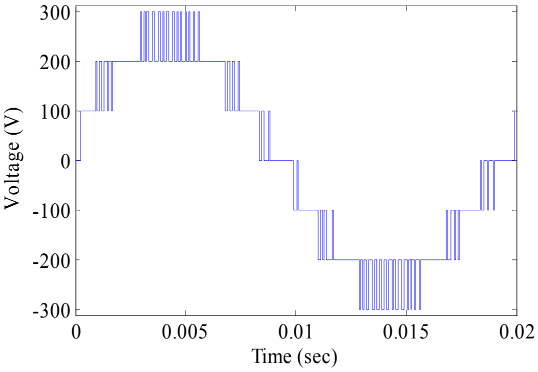
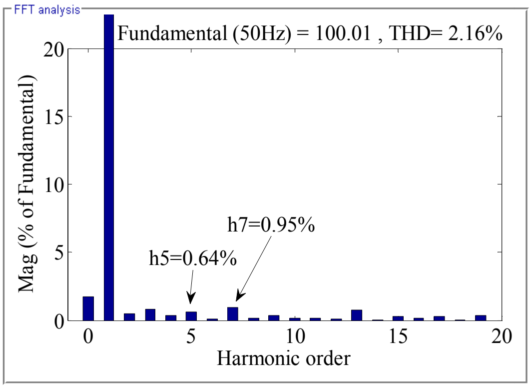


(c)



(d)

Fig. 4: Simulation results of (a) variation of switching angles with modulation index (b) % THD with modulation index (c) Output of the Inverter (d) FFT Analysis

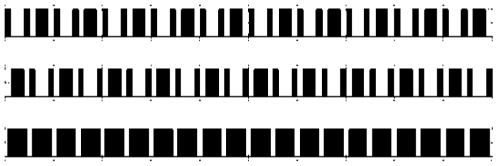
Fig. 4 (a) shows variation of switching angles with modulation index using ACO Algorithm. Fig. 4 (b) indicates variation of total harmonic distortion with respect to modulation index. Fig. 4 (c) shows output of inverter. Fig. 4 (d) indicates the bar graph for current waveform with THD of 2.16 % which is as per IEEE 519 standard. The grid current and voltage that is synchronized to the inverter output by using PLL circuit. Table 2 shows % harmonics (5th and 7th) as well as % THD of current waveform.

Table 2: Switching Angles for *M*=0.8

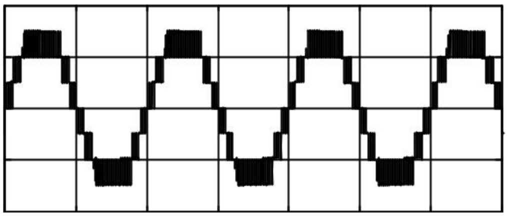
M	θ_1	θ_2	θ_3
0.8	14.32°	28.64°	41.25°

5th Harmonic	7th Harmonic	THD
0.64%	0.95%	2.16%

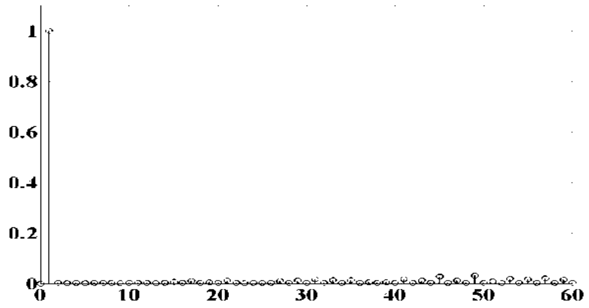
6. EXPERIMENTAL RESULTS



(a)



(b)



(c)

Fig. 5: Experimental results of (a) Gate Pulses (b) single phase 7-level inverter (c) FFT Analysis

7. CONCLUSION

This paper is an attempt to apply Ant Colony optimization algorithm for harmonic elimination in the grid tied inverter. Harmonic Elimination is an important aspect in power electronic inverters which is properly investigated through ACO algorithm. It is found that the proposed method has two important advantages in grid tied inverter based system. Firstly we can control the modulation index and thereafter the flow of active power to the grid side and secondly we can reduce the THD of current waveform at point of common coupling. Both the advantages are validated through simulation and experimental results. For modulation index = 0.8 the THD value of current is found to be 2.16% which is in accordance with IEEE 519 standards.

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