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Multi Level Inverter THD minimization by Improved Particle Swarm Optimization

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ABSTRACT
In this paper, Improved Particle Swarm optimization is proposed to minimize the THD of a Multilevel Inverter. Particle swarm optimization is improved by adapting reproduction and elimination and dispersal of Bacteria Foraging algorithm. First, a 11 level cascaded H- bridge multilevel inverter is implemented in MATLAB simulink. Then an Improved Particle Swarm Optimization algorithm is developed in MATLAB to find the optimum switching angles which reduces the THD.

Keywords - Cascaded H-bridge Inverter, Multi Level Inverters, Particle Swarm Optimization and Bacterial Foraging algorithm

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I. INTRODUCTION

Numerous industrial applications have begun to require high power apparatus in recent years. To achieve high power applications Multilevel inverters have drawn increasing attention, especially in the distributed energy resources area, because several batteries, fuel cells, solar cells, or rectified wind turbines or micro-turbines can be connected through a multilevel inverter to feed a load or interconnect to the ac grid without voltage balancing problems. In addition, multilevel inverters have a lower switching frequency than standard PWM inverters and thus have reduced switching losses, higher efficiency, and electromagnetic compatibility.

The general function of the multilevel inverter is to synthesize a desired voltage from several levels of dc voltages. As the number of levels increases, the synthesized output waveform has more steps, which produces a staircase wave that approaches a desired waveform. Also, as more steps are added to the waveform, the harmonic distortion of the output wave decreases approaching zero as the number of levels increases.

The term “multilevel” starts from three levels. Subsequently, several multilevel converter topologies have been developed. However, the elementary concept of a multilevel converter to achieve high power is to use series of power semiconductor switches with several low voltage sources to perform the power conversion by synthesizing a stair case voltage waveform. Capacitors, batteries and renewable energy sources can be used as the multiple dc in order to achieve high voltage at the output; however, the rated voltage of the power semiconductor switches depends only upon the ratings of the DC voltage sources to which they are connected.

There are three topologies of multi level inverters are reported in the literature.: Diode-clamped converter, Flying-capacitors converter and Cascaded-inverters with separated dc sources.

Due to the great demand of medium voltage high power inverters, the cascaded inverter has drawn tremendous interest ever since. The output waveforms of multilevel inverters are in a stepped form resulting in reduced harmonics compared to a square-wave inverter. To reduce the harmonics further, different multilevel sinusoidal PWM and space-vector PWM schemes are suggested in the literature. However, PWM techniques increase the control complexity and the switching frequency. Another approach to reduce the harmonics is to calculate the switching angles in order to eliminate certain order harmonics or THD. The mathematical theory of resultants can be used to compute the optimum switching angles. These expressions were high order polynomials that could not be solved when the number of levels in the multilevel converter became large. In this paper, easy method of calculating optimum switching angles is proposed by Improved Particle Swarm Optimization method.

II. CASCADED H-BRIDGE INVERTER.

A cascaded H-Bridge inverter consists of a series of H-bridge (single phase, full bridge) inverter units. The general structure of multilevel inverter is to synthesize a desired voltage waveforms from several separate DC sources (SDCS)s which may be obtained from batteries, fuel cells or solar cells. Fig 1 shows the basic structure of a single phase cascaded H-bridge inverter with SDCSs. Each SDCS is connected to an H-bridge inverter. The AC terminal voltages of different level inverters are connected in series. Unlike Diode clamped or flying capacitors inverter, the cascaded inverter does not require voltage clamping diodes or voltage balancing capacitors.

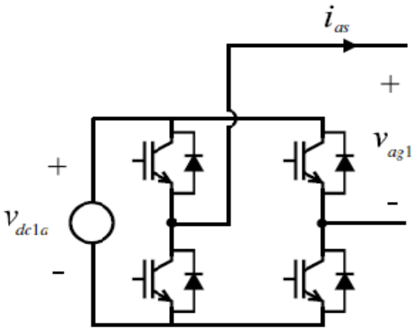
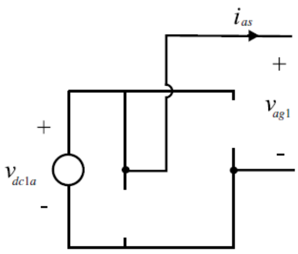
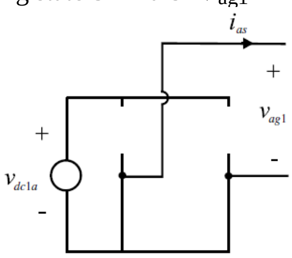


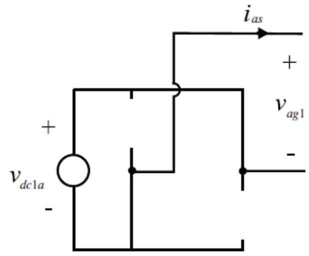
Fig 1. Single H-bridge cell topology.



Switching state S1 = 0 & $V_{ag1} = -V_{dcla}$



Switching state S2 = 1 & Vag1 = 0



Switching state S1 = 0 & $V_{ag1} = V_{dcla}$

Fig 2. switching states of H-bridge cell

Figure 2 illustrates the switching states of one cascaded H-bridge topology which produces three unique output voltages -Vdcla , 0 ,Vdcla . In accordance with the convention used here, the lowest switching state (S1 = 0) will be labelled state 0 and for the switching states S2 = 1, S3 = 2 produces output voltages Vag1 = 0, Vag1 = Vdcla respectively.

The Fig. 3 shows the staircase 2m+1 levels output voltage of inverter where m is the number of separated DC sources in the one leg of H-bridge inverter. Three phase configuration can be formed by connecting three number of inverters in Y or Δ. In the terms of eliminating undesired higher order harmonics, switching angels shown in Fig. 2.5 must be calculated such that the voltage total harmonic distortion reduces to minimum.

The AC output of each level's full-bridge inverter is connected in series such that the synthesized voltage waveform is the sum of all of the individual inverter outputs. The number of output phase voltage levels in a cascade multilevel inverter is then 2s + 1

Where S = number of dc sources

m = number of levels

For an 11-level cascaded multilevel inverter with five SDCSs and five full bridges is shown in Figure 4.With enough levels and an appropriate switching algorithm, the multilevel inverter results in an output voltage that is almost sinusoidal. Figure 4 also shows the synthesized phase voltage waveform of a 7 level cascaded inverter with three SDCSs.

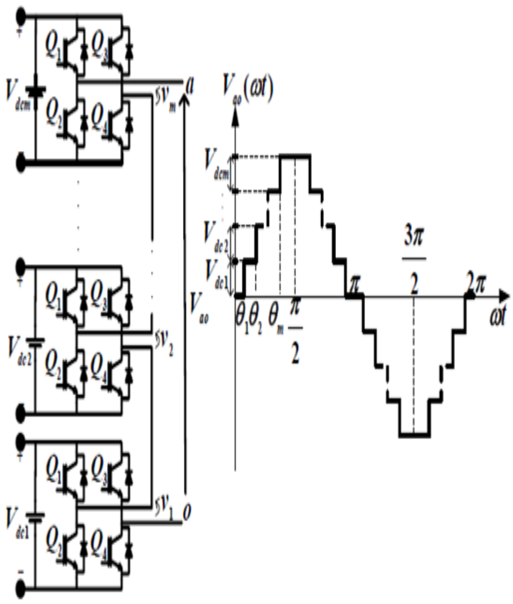


Figure 3. A 2m+1 levels H-bridge inverter structure with m separated dc sources and the stair case output phase voltage

The phase output voltage is synthesized by sum of five inverter output voltages Vao = V1+V2+V3+V4+V5. Each bridge could produce voltages of 0, +Vdc and –Vdc which depend on the state of four power switches, Q11, Q12, Q13 and Q14. Using the fig 2.6 turning on Q11 and Q13 yields Vdc, turning on Q12 and Q14 yields -Vdc turning on of any two switches of same leg yields 0 voltage which is represented in table 2.1. Similarly AC output voltage at each level can be obtained in the same manner.

Table 2.1 Switching states of each cascaded H-bridge inverter

Q11	Q12	Q13	Q14	O/p Voltage
1	0	1	0	Vdc
1	1	0	0	0
0	0	1	1	0
0	1	0	1	-Vdc

Each cascaded H-bridge inverter generates a quasi square wave output by shifting its positive and negative leg switching timings. It should be noted that each switching device always conducts at 180 degrees (or half cycle).
Together, all cascaded H-bridge forms the output voltage waveform, as shown in Figure 4. For THD optimization, the switching angles θ1, θ2, θ3, θ4, θ5 must be selected so that THD is minimized.

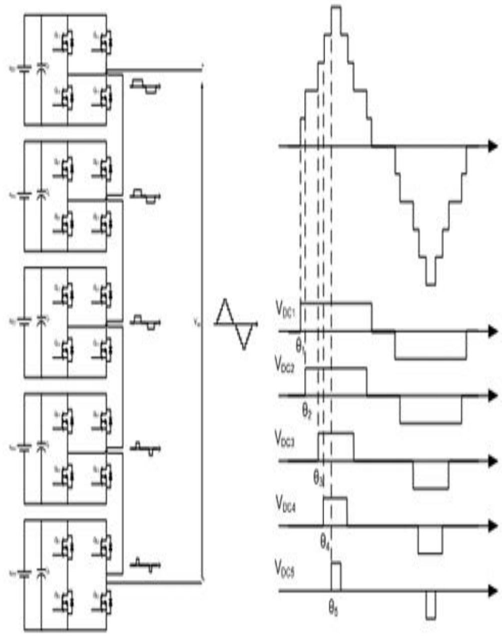


Figure 4: 11 level inverter and output waveforms

III. IMPROVED PARTICLE SWARM OPTIMIZATION ALGORITHM

3.1. Particle swarm Optimization

Particle swarm optimization (PSO) is one of the most popular evolutionary computation techniques developed by Dr. Eberhart and Dr. Kennedy in 1995. It is inspired by the bird flocking, where each bird adjusts it's velocity based on the bird which is near to the food. PSO algorithm begins with a population of particles, where each particle is potential solution. The initial population is improved by adding velocity, which is determined based on the difference between the particle and it's personal best (pbest) through iterations and also the difference between the particle and the overall best (gbest)[10]. In comparison to the other evolutionary computation techniques, PSO is simple because fewer parameters to control and it has faster convergence.

3.2. Improved PSO algorithm: Original PSO algorithm has the problem of stagnation of population too quickly. To overcome this, PSO is added with reproduction and elimination and dispersion of BFA. Elimination and dispersion gives new solutions, so this avoids stagnation problem. The tumble direction in chemotactic movement of BFA is calculated by using global best and each bacteria personal best as done in PSO. It avoids complex calculations and also randomness which delay the convergence. In reproduction step, all bacteria, which are gone through chemotactic step, are sorted and best half of bacteria are retained and worst half of bacteria die. To reduce the chance to trap in local minimum, which is the case in PSO algorithm, certain number of replicated bacteria is randomly dispersed in to the search space at a certain rate. This measure can increase the rate of achieving optimal solution and avoid premature convergence.

IV. PROPOSED APPROACH

Step 1: Develop simulink model for 11 level cascaded H-bridge inverter as shown in Figure 5. Set the parameters of the BFA and PSO.
Step 2: Choose initial population of bacteria randomly.
Step 3: Elimination dispersion loop, l=l+1, k=0.
Step 4: Reproduction loop: k=k+1, j=0.
Step 5: Chemotaxis loop: j=j+1, Check the bacteria for the constraints.
Step 6: Get the fitness value (THD) from 11 level Cascaded H-bridge inverter. Perform tumble by adding random vector to the bacteria. Calculate the fitness, if it is better than previous, perform swim for swim size otherwise use Differential Evolution to update position of bacteria. If the maximum number of chemotactic steps (Nc) is reached go to next step, otherwise go to step 5 and continue.
Step 7: Sort the bacteria according to their fitness. Remove the worst half of the population and replace them with the best half. If maximum number of reproduction steps(Nre) is reached go to nextstep otherwise go to step 4 and continue.
Step 8: Eliminate the bacteria with new one with the probability of Ped i.e if a random number is greater than Ped. If maximum number of elimination and dispersion steps is reached go to next step otherwise go to step 3 and continue.
Step 9: Print the results.

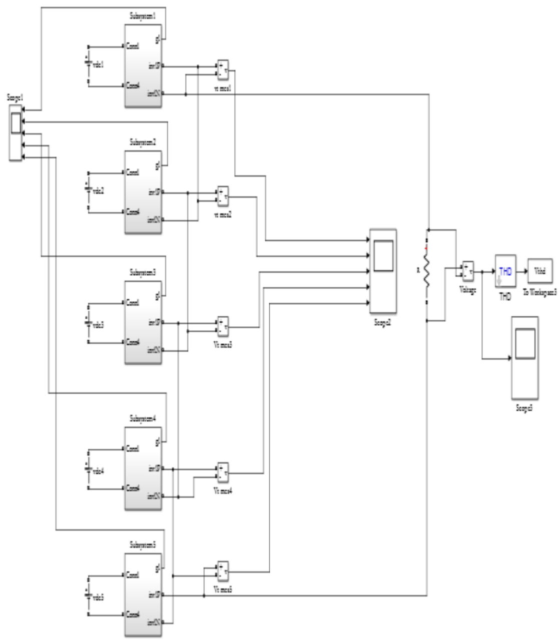


Figure 5: Simulink model of Cascaded H-bridge 11 level inverter.

V. RESULTS AND DISCUSSION:

The simulations are done in MATLAB 2016a. Population size is taken as 20. the algorithm is run for 100 iterations.

Table 1: Optimum switching angles obtained by PSO

θ_1	θ_2	θ_3	θ_4	θ_5
5.4916	16.6844	28.5874	42.0592	59.4625

The optimum switching angles provided by the proposed algorithm are shown in Table 1.
The voltage waveforms of the multi level inverter are shown in Figure 6. The THD by FFT analysis is shown in Figure 7. Each Vdc value is taken as 50V. Fundamental voltage is 259.6 and THD of the voltage is 7.5%. The convergence characteristics are shown in Figure 8.

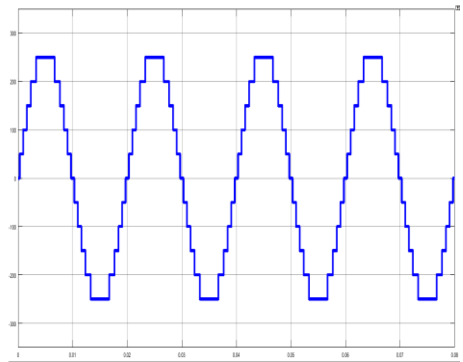


Figure 6 : Output Voltage Wave forms after THD minimization by PSO

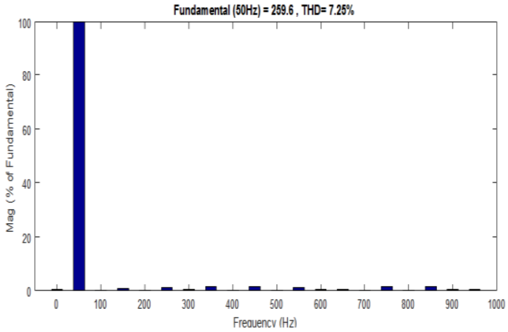


Figure 7: FFT analysis of 11 Level inverter

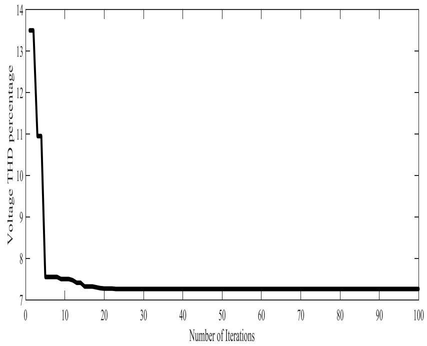


Figure 8: Convergence characteristics of PSO

VI. CONCLUSIONS

Hybrid Bacterial Foraging Particle swarm optimization algorithm is proposed to find optimum switching angles for 11 level cascaded H-Bridge multi level inverter. The simulation results show that Proposed method is effective in reducing the THD. The convergence characteristics show the better performance of the improved PSO algorithm.

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