Implementing Selective Harmonic Elimination in Cascaded Multilevel Inverter Using Different Metaheuristic Optimization Methods and Comparing Their Effectiveness

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Abstract

During the process of designing a multilevel inverter significant effort is taken to reduce the harmonic content of the output. In recent years utilization of mathematical optimization algorithms for Selective harmonic elimination (SHE) in the multilevel inverter output has emerged as a much favored procedure among the engineering community. A special class of algorithms called metaheuristic algorithms is now being widely used for this purpose. This paper used four different metaheuristic methods for solving the nonlinear transcendental equation of SHE problem of a seven level cascaded H bridge inverter. A comparative study was carried out to measure the effectiveness of each method through rigorous simulation. The efficacious of each algorithm was assessed in terms of the total harmonic distortion in the optimized inverter output obtained after applying the algorithm. The four optimization used in this paper are simulated annealing, bacterial foraging, firefly and cuckoo algorithms. The following research concluded that cuckoo algorithm gave the lowest THD for the multilevel inverter.

Keywords *—Multilevel inverter; Selective harmonic elimination; Metaheuristic optimization algorithm.*

I. INTRODUCTION

A lot of research is currently focusing on developing high quality multilevel inverters for use in industrial applications currently dominated by the standard single level inverter technology.The general accord within the research community is that multilevel inverters will be extensively used in renewable energy applications, drives and high voltage transmission.

Multilevel inverters provide an alternative to using high power source for application requiring large input voltages. The advantages of MLI include availability of common node voltage, lower distortion in input currents and lower harmonic content in the output. MLI and designed in three conventional topologies: flying capacitor, diode clamped and cascaded [1, 2 and 3]. Apart from these various researches have proposed either new or modified topologies. This paper has used a cascaded H bridge topology which is constituted of several single phase full bridge inverters cascaded to construct a multilevel inverter. Within this topology the MLI can be further classified into ones using equal DC voltage sources and others with unequal DC voltage sources. For cascaded MLI using equal DC voltage sources such as the one considered in this paper the number of voltage levels in the output is given by (2S+1) where S is the number of single phase full bridge inverters used in the MLI.

II. CIRCUIT OPERATION

The 7 level MLI circuit is shown in fig .1 along with the output voltage waveform in fig. 2. The Fourier series analysis of the output waveform will yield an expression devoid of even harmonic terms as the output voltage waveform is symmetrical with respect to x axis. He Fourier series expansion is given by <eqn1>

$$V(\omega t) = \sum_{z=1}^{\infty} Vz\text{Sin}(z\omega t) \qquad (1)$$

Where Vn is the amplitude of the nth harmonic component. The selection of firing angles highlighted in the waveform as α1, α2, and α3 form the heart of the SHE method. The output equation in terms of firing angles are given by <eqn2>

$$f(z) = \begin{cases} \frac{4}{z\pi} Vdc \sum_{k=1}^{s} \text{Cos}(\text{za(k)}) & ,z = \text{odd} \\ 0 & ,z = \text{even} \end{cases}$$

(2)

Reduction of harmonic content of output waveform depends on how effectively the lower order harmonics such as the 3^{rd}, 5^{th}, 7^{th} are suppressed. The higher order harmonics can be easily filtered out using appropriate filters [4]. In the paper the optimization is done without taking into consideration the 3^{rd} harmonic component. We operate under the assumption that if MLI is connected in three phase manner the triple end harmonics are eliminated in the lines to line voltages. Therefore the work in this paper concentrates on the suppression of 5^{th}, 7^{th} and 9^{th} harmonic. The quality of the output waveform is analyzed in terms of the total harmonic distortion factor (THD) given by the equation

$$\% \text{ THD} = \left[\left(\frac{1}{{a^2}_1}\right) \sum_{z=5}^{\infty} {a_z}^2\right]^{1/2} * 100$$

THD is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. The equation for THD is a nonlinear transcendental equation THD factor gives the measure of harmonics present in the output in terms percentage. In SHE method we need to determine the values of α_1, α_2 and α_3 that will reduce THD value [5]. To obtain these values the optimization algorithms are utilized.

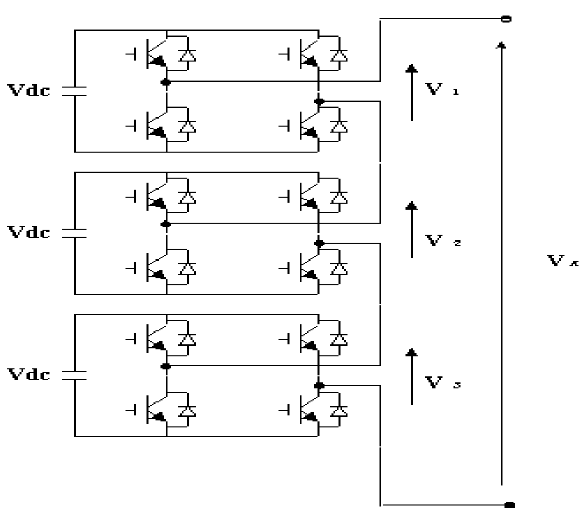

Fig 1: Single phase Cascaded 7- Level inverter

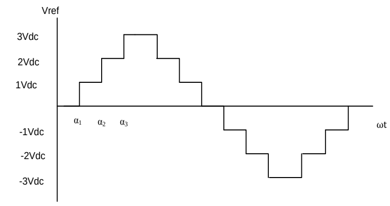

Fig 2: The full cycle of the Phase Voltage of 7- level Inverter

III. METAHEURISTIC ALGORITHM

Heuristics or metaheuristics are probability based trial and error method for solving a given optimization problem [6, 7, 8 and 9].The first step to optimization is formulating the objective function. The objective function used in this paper is:

$$\frac{(vh5^2 + vh7^2 + vh9^2)^{1/2}}{v1} * 100$$

Different algorithms are used to determine the three firing angles which will minimize the chosen objective function. α_1, α_2 and α_3 should be chosen such that they lie between o and 90 degree and also $\alpha_3 > \alpha_2 > \alpha_1$.These above condition should be incorporated in the algorithms. The search space is defined as 3 dimensional space in which each element is bound within 0 and 90 degrees. The optimization is constrained by the condition $\alpha_3 > \alpha_2 > \alpha_1$. Therefore the optimization problem is stated as:

Minimization of

$$\frac{(vh5^2+vh7^2+vh9^2)^{1/2}}{v1} * 100$$ $0 < \alpha_n < 90$ where n=1, 2, 3 Subject to constrains: $\alpha_3 > \alpha_2 > \alpha_1$

A. Simulated Annealing Algorithm

Simulated annealing (SA) is a trajectory-based, random search technique for global optimization. It mimics the annealing process in material processing when a metal cools and freezes into a crystalline statewith theminimum energy and larger crystal size so as to reduce the defects inmetallic structures. The annealing process involves the careful control oftemperature and its cooling rate. Each configuration of a solution in the search space represents a different internal energy of the system.

The heat increases the energy of the atoms allowing them to move freely, and the slow cooling schedule allows a new low-energy configuration to be discovered and exploited. Heating of the system results in a relaxation of the acceptance criteria of the samples taken from the search space. As the system is cooled, the acceptance criteria of samples are narrowed to focus on improving movements. Once the system has cooled, the configuration will represent a sample at or close to a global optimum.

B. Bacterial Foraging Algorithm

The Bacterial Foraging Optimization Algorithm (BFOA) is inspired by the group foraging behavior of bacteria. Specifically, the BFOA is inspired by the chemo taxis behavior of bacteria that will perceive chemical gradients in the environment and move toward or away from specific signals.

The information processing strategy of the algorithm is to allow cells to stochastically and collectively swarm toward optima. This is achieved through a series of three processes on a population of simulated cells: 1) 'Chemotaxis' where the cost of cells is derated by the proximity to other cells and cells move along the manipulated cost surface one at a time (the majority of the work of the algorithm), 2) 'Reproduction' where only those cells that performed well over their lifetime may contribute to the next generation, and 3) 'Elimination-dispersal' where cells are discarded and new random samples are inserted with a low probability.

C. Firefly Algorithm

The Firefly algorithm (FA) was inspired from the behaviour of fireflies. The flashing lights can be formulated in such a way that it is associated with the objective function to be minimized. We now use the following three idealized rules:

- All fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex
- Attractiveness is proportional to their brightness, thus for any two flashing fireflies, the less bright one will move towards the brighter one. The attractiveness is proportional to the brightness and they both decrease as their distance increases. If there is no brighter one than a particular firefly, it will move randomly
- The brightness of a firefly is affected or determined by the landscape of the objective function.

In the firefly algorithm, there are two important issues: the variation of light intensity and formulation of the attractiveness. For simplicity, we can always assume that the attractiveness of a firefly is determined by its brightness. This in turn is associated with the encoded objective function.

D. cuckoo algorithm (CA)

Cuckoo birds have a highly aggressive breeding strategy by which they lay their eggs in other birds nest. The survival of the eggs depends upon the host bird's ability to differentiate between its own eggs and the alien cuckoo egg. For simplicity in describing CA, we have used the following three idealized rules:

- Each cuckoo lays one egg at a time and dumps it on to a randomly chosen nest
- The best nests with high-quality eggs will be carried over to the next generation
- The number of available host nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability $pa \in [0, 1]$. In this case, the host bird can either get rid of the egg, or simply abandon the nest or built a new nest.

The last assumption can be approximated by a fraction pa of the n nests being replaced by new nests (with new random solutions at new locations). The test variable is updated using a concept called levy flight governed by the equation

$X(t+1)_i = x(t)_i + \alpha \oplus \text{Levy}(\lambda)$, where α is the step size.

IV. SIMULATION RESULTS

Using the Matlab Simulink software simulation were carried out on a 7 level H-bridge inverter with three equal DC source voltages of 100 V each. Each algorithm was used to determine an optimal value for the firing angles and the THD in the output obtained by substituting the determined angles was measured. The results have been quantized into two parts

- The optimized result given by each algorithm is tabulated along with the various algorithm parameters
- To determine the effectiveness of each algorithm in comparison to the restsimulationwere carried out for a fixed number of iteration and the convergence rate of each algorithm was measured in terms of THD value it gave for those fixed iteration.

Table 1: BFOA Parameters

Boltzman's constant	**1**
Initial temperature	1
Maximum number of runs	150

Table 4: Obtained Results (FA)

Table 2: Obtained Results (BFOA)

THD Phase (%)	**α_1**	**α_2**	**α_3**
14.47	7.8782	17.7896	42.9854

Table 3: FA Parameters

Table 6:Obtained Results(SA)

Randomization of parameter	**0.5**
Attractiveness of firefly	0.2
Light absorption coefficient	1

THD Phase (%)	**α_1**	**α_2**	**α_3**
13.73	3.349	23.205	47.699

Dimension of search space	3
Number of bacteria	26
Number of chromatic steps	50
Number of reproduction	4

Table 5: SA Parameters

Number of nests	**25**
Discovery rate of alien eggs	0.25
Step size for levy flights	0.01

Table 7: COA Parameters

THD Phase (%)	**α_1**	**α_2**	**α_3**
13.29	3.568	23.286	47.911

Table 8:Obtained Results(COA)

THD Phase (%)	**α_1**	**α_2**	**α_3**
13.12	3.598	24.0912	54.233

S.NO	ALGORITHM	NO. OF ITERATIONS	FIRING ANGLES			THD (%)
			α-1	α-2	α-3	
1	BFOA	500	7.748625468	17.4938253	42.836491	14.43
2	FIREFLY	500	8.872825621	30.7896541	54.9854932	16.06
3	SIMULATED ANNEALING	500	3.349505851	23.2054638	47.6992814	20.3
4	CUCKOO	500	3.59883751	24.0912172	54.233024	13.12

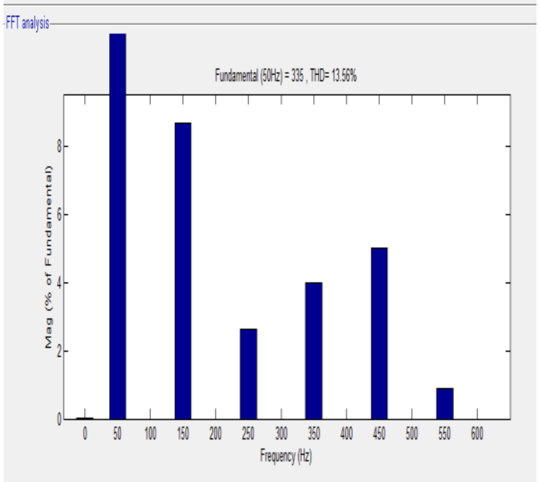

Fig3: Harmonic Order of Inverter Output by Using Cuckoo Algorithm

The cuckoo algorithm gave the lowest THD value at 13.12% (table 8) followed by the FA, giving a THD of 13.29% (table 4) and next lowest THD given by SA at 13.73% (table 6). BFOA gave the highest THD at 14.47% (table 2). The THD level and the corresponding algorithm parameters used have been tabulated for each algorithm and presented below.

To perform a comparative study, each algorithm was simulated for 500 iteration to compare their convergence rate. Table 9 shows the THD obtained by using each algorithm with a constant number of iteration of 500. Cuckoo gave the least THD for 500 iterations.

V. CONCLUSION

This paper has used four metaheuristic algorithms to solve the SHE problem of a 7 level cascaded MLI. Through simulations the effectiveness of each algorithm to eliminate lower level harmonics was measured in terms of THD. A comparison was done between all algorithms in terms of their respective convergence rate to arrive at the optimum firing angles. This study has concluded that cuckoo algorithm is most efficient in this matter. Furthermore cuckoo uses lower number of variables compared to the other algorithms and its output is not overly dependent on fine tuning of algorithm parameters. Nature inspired algorithms such as CA, FA, BFOA which have a machine learning component incorporated in them which is absent in SA therefore give higher optimization.

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