I J C T A, 9(14) 2016, pp. 6631-6637

An Analysis of Cuckoo Search Algorithm Based Selective Harmonic Elimination for Multilevel Inverter

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ABSTRACT

Multilevel Inverters (MLI) are widely used in many industrial application such as drives, inverters and static VAR compensation etc. MLI is the most preferable choice in comparison with conventional inverters due to its various advantages such as less EMI issues, voltage stress and switching losses. It is important that inverter must produce harmonic free output which is to be fed to the load. In two level inverter, Harmonics can be eliminated by using large size of filters due to the lower order harmonics. This leads to increase the overall size, volume and cost of an inverter. MLI has an advantage that the lower order harmonics can be eliminated by choosing the proper switching angles is called as Selective Harmonic Elimination (SHE) technique. In this work, the Cuckoo Search Algorithm (CSA) is applied to find the optimum switch angles to eliminate the lower order harmonics. CSA based optimization is applied for seven and nine level MLI provides better solution for eliminating lower order harmonics and reduction of Total Harmonic Distortion (THD). The simulation results are verified experimentally for seven level and nine level inverter. It is identified that the CSA is the best choice for nonlinear electrical problems.

Keywords: Multilevel inverter: Cascaded H bridge inverter: Cuckoo search: optimization: Selective Harmonic Elimination.

1. INTRODUCTION

The multilevel voltage source inverters are widely applied in many industrial applications in low power, medium power and high power application. Also it best choice of DC-AC power converter for solar cell or rectified wind turbines or micro turbine which can be connected through a multilevel inverter to feed a load or interconnect to the ac grid without voltage balancing problem [1].The significant advantages of multilevel configuration are: reduction THD in the output waveform[2]. Due to elimination of the bulky coupling transformers, reduction in size and volume is possible [3]. The most common MLI topologies classified into three types are Diode Clamped MLI (DC-MLI), Flying Capacitor MLI (FC-MLI), and Cascaded H-Bridge MLI (CHB-MLI) [3-4]. The cascaded inverters are preferable choice of MLI out of all due to the requirement of least number of components. The important is that the output produced by the inverter need to be free from harmonics. To produce the quality output from inverter, several modulation and control techniques are developed such as Sinusoidal PWM (SPWM), Space Vector Modulation PWM (SVM) and Selective Harmonic Elimination (SHE) [5]. Very effective method due to controllability is Selective Harmonic Elimination (SHE) technique. In this method the lower order harmonics can be eliminated by selection of appropriate switching angle. The various optimization algorithms used to eliminate harmonics [5-10]. In this proposed method, the CSA based optimization algorithm is used to eliminate the lower order THD for seven and nine level. The proposed method provides better solution for practical application due to robust and less number of tuning parameters. Organization of paper as follows: - Section I covers with introduction and the cascaded inverter is described in section II. Section III addresses the mathematical formulation and

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THD reduction using CSA for seven, nine level. Section IV is discussed with simulation and experimental results and section V gives the conclusion.

2. CASCADED H- BRIDGE MULTILEVEL INVERTER (CMLI)

The concept of the CHBMLI topology is that cascading the outputs of each module to get added stepped output. Each module consist of a DC source and four switches that is capable of producing +Vdc and –Vdc. One full bridge inverter produces a three level output. In Figure 1, seven level Cascaded Multilevel Inverter. The extension can be achieved by adding required number of modules.. Three modules are required to build seven level and four module to build for nine level MLI. The CHB multilevel inverters can be divided into two groups are symmetric and the asymmetric topology. In the symmetric topology, the values of all of the dc voltage sources are equal [11-13]. In order to increase the number of output voltage level, the values of the dc voltage sources are selected to be different, these topologies are called asymmetric [14]. The advantages of topology that requires the least number of components compared with other two topologies and higher reliability due to its modular topology. CHB MLI is applied in various application such as electric vehicle [15], direct torque control [16], static synchronous generator [17] and solar applications.

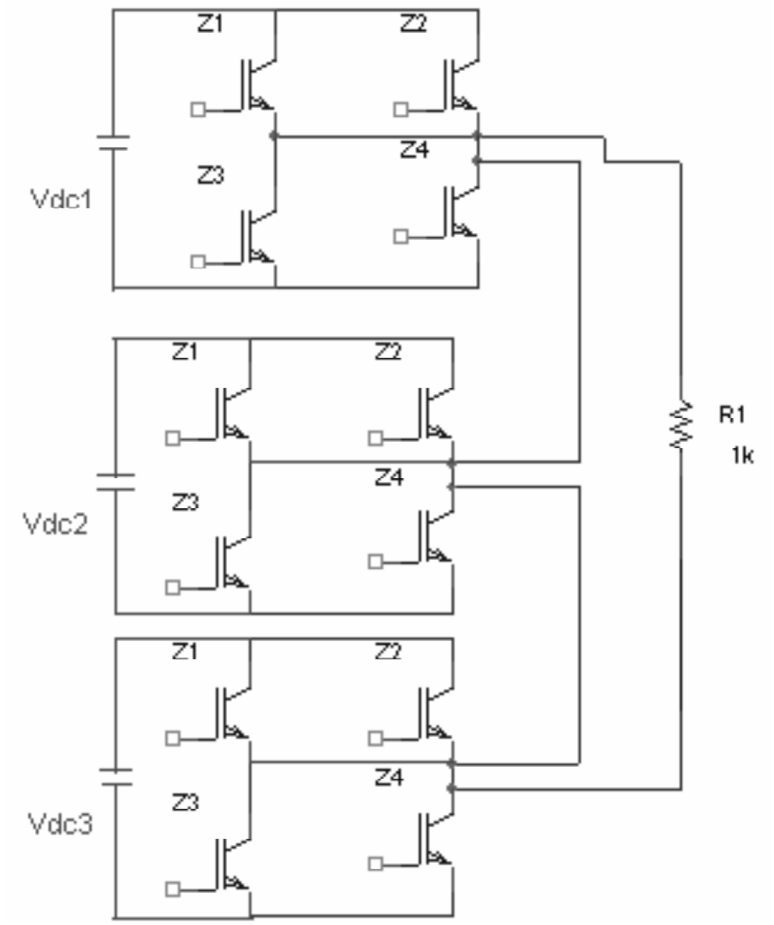


Figure 1: Seven level Cascaded H-Bridge MLI

3. FORMULATION OF FITNESS FUNCTION

The voltage sources (Vdc) are considered to be equal in amplitude and switching angle are lies between 0 to $\pi/2$. Odd harmonics only be present in the output and even harmonics are zero due to the symmetry. The Fourier series expansion for voltage output of stepped waveform is given in equation (1).

$$V(\omega t) = \begin{cases} 0 \\ \dfrac{4V_{dc}}{n\pi}\sum_{i=1}^{k}\cos(n\alpha_i) \end{cases} \quad \text{for n = even; for n = odd} \tag{1}$$

Where n is harmonic order and k is number of DC sources.

The Total harmonic distortion can be calculated for stepped waveform from the equation (2). The Vn is the nth harmonic amplitude can be calculated from equation (3) and V1 is the fundamental value α_k are the switching angles per quarter.

$$THD = \sqrt{\sum_{2}^{n} V_{n^2}} \Big/ V_1 \tag{2}$$

$$V_n = \left(\left(\frac{4V}{\pi}\right)\sum_{2}^{n}\sum_{1}^{k}\frac{Cos(n\alpha_k)}{n}\right) \tag{3}$$

$$V_1 = \left(\left(\frac{4V}{\pi}\right)\sum_{2}^{k} Cos(n\alpha_k)\right) \tag{4}$$

The objective of SHE PWM is to eliminate the selective harmonic order and the other harmonics will be filtered out through filter. Since the lower order harmonics are predominant which need to be eliminated. In seven level, the lower order are 5th and 7th. Similarly in the nine level are 5th, 7th and 11th and 5th, 7th and 11th. It not necessary to consider the Triple harmonics because it will be vanish in three phase system. The nonlinear equation to be solved for seven level and nine level an be written as equation (5-6). In equation seven the modulation index (M) is provided.

$$\begin{cases} (\text{Cos } \alpha_1 + \cos \alpha_2 + \cos \alpha_3)/\pi = M \\ (\text{Cos } 5\alpha_1 + \cos 5\alpha_2 + \cos 5\alpha_3) = 0 \\ (\text{Cos } 7\alpha_1 + \cos 7\alpha_2 + \cos 7\alpha_3) = 0 \end{cases} \tag{5}$$

$$\begin{cases} (\text{Cos } \alpha_1 + \cos \alpha_2 + \cos \alpha_3 + \cos \alpha_4)/\pi = M \\ (\text{Cos } 5\alpha_1 + \cos 5\alpha_2 + \cos 5\alpha_3 + \cos 5\alpha_4) = 0 \\ (\text{Cos } 7\alpha_1 + \cos 7\alpha_2 + \cos 7\alpha_3 + \cos 7\alpha_4) = 0 \\ (\text{Cos } 11\alpha_1 + \cos 11\alpha_2 + \cos 11\alpha_3 + \cos 11\alpha_4) = 0 \end{cases} \tag{6}$$

$$M = \frac{V_1}{kV_{dc}} \tag{7}$$

3.1. Cuckoo Search Optimization Algorithm

Cuckoo search is a one of the heuristic algorithm where the imitation of bird breeding is taken. The bird called cuckoo during its breeding it lays eggs on the other birds nest called host birds nest. The first possibility is that the host bird identifies the cuckoo egg and abandon the egg. Second is that host bird will leave to the new location and starts a new nest. The productivity of cuckoo egg is increased because of confusion of the host bird due to similarity of host and cuckoo egg. Consequently the cuckoo gets more chance to become mature as the number of chicks in the nest is less. For simplicity, the three basic rules are considered. Each cuckoo laid egg randomly in host nest at a time. The best eggs are carried to the next iteration. Number of

host nest is fixed where the survival of egg could be found with the probability Pa between o and 1.That means the chances to identify cuckoo egg by the host egg. Once identified eggs are thrown away or abandon the nest. In this work, the objective or best survival egg is fitness function f(α). The best location of egg where the best survival is found for which switching angles (α1, α2, α3, ……., αk) . In cuckoo search, two controlling parameters are population size and probability (Pa). The cuckoo search is very effective and robust due to less number of tuning or controlling parameter. Pseudo code for cuckoo search is shown below [18]. The objective function is defied below in equation number (8) for seven level and (9) for nine level.

$$f(\alpha) = 100 * \left(\left| M - (V1/(K * Vdc)) \right| + \left| (V5 + V7)/(K * Vdc) \right| \right) \tag{8}$$

$$f(\alpha) = 100 * \left(\left| M - (V1/(K * Vdc)) \right| + \left| (V5 + V7 + V11)/(K * Vdc) \right| \right) \tag{9}$$

3.2. Pseudo code for CSA

Objective function f (α), where α = (α1, α2, α3, ……., αk);

Generate initial population of host nests (i = 1, 2, 3,…...n);

While (stop criterion)

Get a Cuckoo randomly;

Evaluate its fitness Fi;

Choose nest among n randomly Fj;

If Fi ≥ Fj

End

Kill worse nest with probability (Pa) and build a new nest;

Keep best;

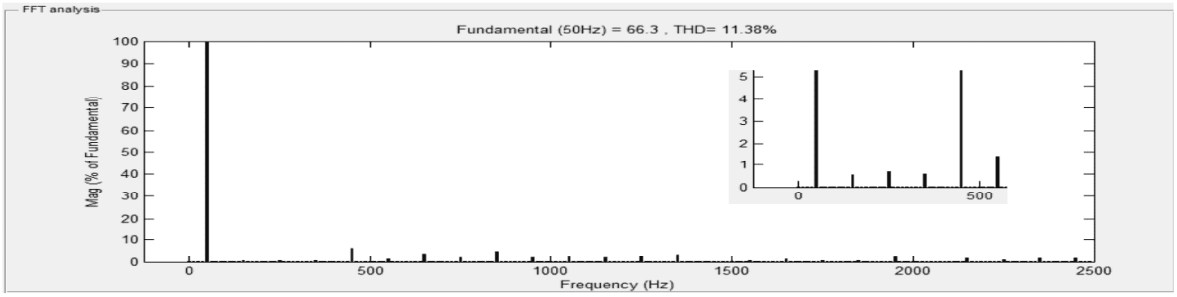
Find the Current Best;

End while

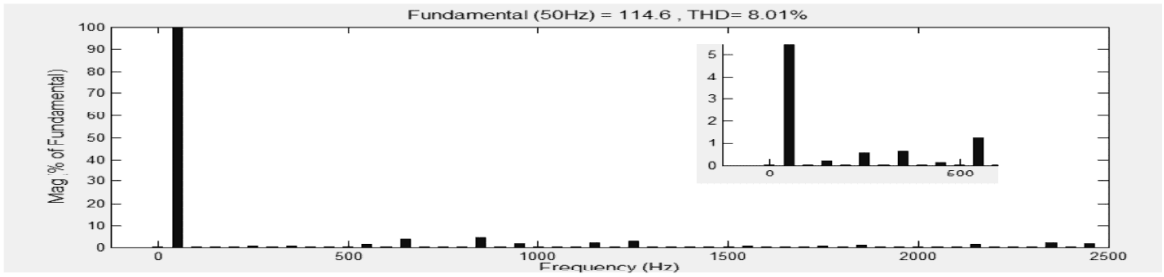
4. RESULT AND DISCUSSION

The matlab Simulink model is developed for seven and nine levels. In this, voltage sources are chosen equal in amplitude. The CSA code is developed using matlab programming. The fitness function f (á) is calculated by varying modulation index (M) from 0.4 to 1.2 where the aim is to eliminate fifth and seventh harmonics for seven level voltage waveform. Similarly, fifth, seventh and eleventh are to be eliminated for nine level. The figure 2 shows the FFT analysis of phase voltage waveform and line to line voltage waveform for seven level. From the figure, it can be noted that the harmonics of fifth and seventh is near to zero and it is eliminated almost. The THD measured about 12.51 for phase voltage waveform and 8.01 for line-line voltage waveform. In line-line voltage waveform the triplen harmonics are vanished. Figure 3a shows the FFT analysis of phase voltage waveform and figure 3b shows line- line voltage waveform of nine level inverter. From the figure, it can be noted that after increasing the two level of output, line voltage waveform THD is reduced to 6.64% whereas phase voltage THD is about 9.99%. Further the individual harmonics upto 13th harmonics are suppressed. So that the effect of the lowest harmonics are eliminated. This shall improve the performance of the inverter and reduce the filtering requirements. The unwanted higher order harmonics can be filtered out through a filter.

In figure 5, the modulation index with respect to THD is shown. The THD is reduced for the modulation index between 9 and 1.1. The lowest THD is achieved for the modulation index at 0.98 and 0.99 for nine



(a)



(b)

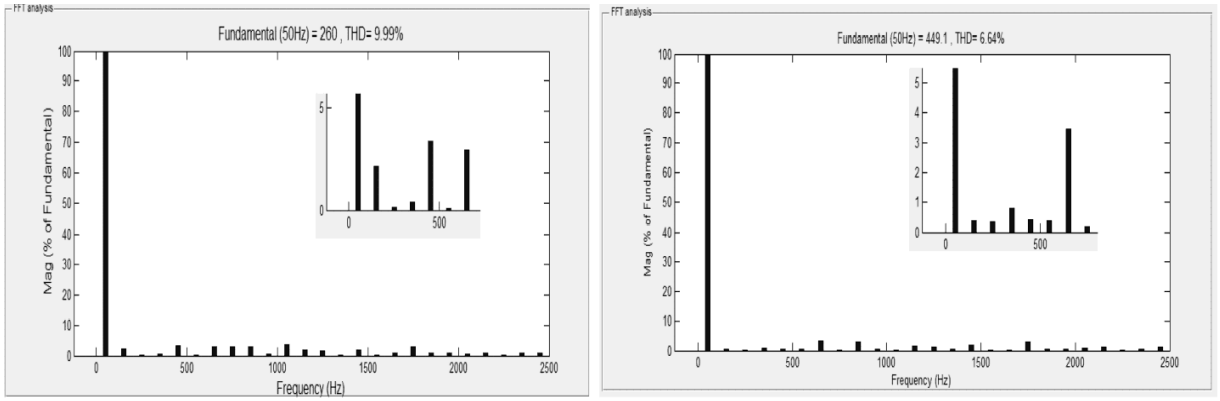
Figure 2: FFT analysis for seven level using CSA a) Phase Voltage b) Line-Line voltage

level and seven level respectively. To address the performance of any algorithm it is necessary to compare with the existing work. In this connection, the results of seven level are compared with BA which is best similar work proposed recently. The comparison of results are shown in table1.This comparison clearly addresses that the proposed algorithm is providing better result at modulation. Phase THD about 12.51%, line THD is about 8.8% and the 5th and 7th harmonics are 0.01% and 0.13%. The results are similar with bee algorithm, but slightly better. But it provides better solution for line THD which is about 7.83% at Modulation index 0.98. Best solution of THD for nine level inverter at switching angles 10.0267, 22.122,40.210,61.765 at modulation index .99. The better solution can be achieved with respect to probability (Pa) between 0.15 to 0.4. The second controlling parameter is population size. In this problem the population size is selected as 40 as the constraints and the variables are less. The large nonlinear problems the population size can be higher to achieve the better solution. On other hand, increasing population size will increase the simulation time.

Table 1
Comparison of CSA Vs BA for seven level

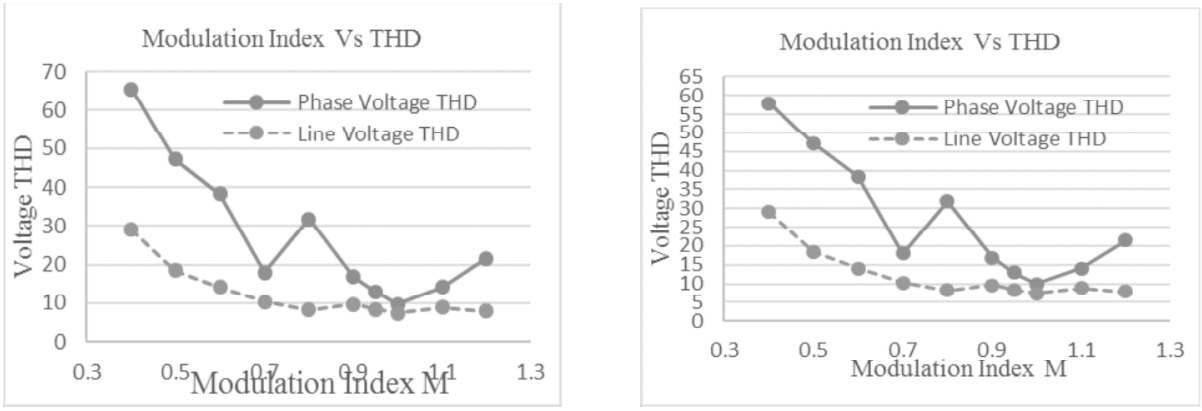
Optimization techniques used	*M*	*α 1 in degree*	*α 2 in degree*	*α 3 in degree*	*Phase voltage THD in %*	*Line Voltage THD in %*
Proposed Cuckoo search	0.98	12.3248	33.6668	60.0764	13.63	7.83
	1.0	11.6874	31.1939	58.6088	12.51	8.01
BA	0.8	11.5042	28.7170	57.1061	12.52	8.99

The experimental setup and voltage waveform for seven level and nine level is shown in figure 6. The THD measured and analysed where the performance is similar to the simulation result for seven level. The amplitude of each voltage sources are selected as 48V peak and the IRF 540N MOSFET are used as power switches and the drivers are used is IRS2104.



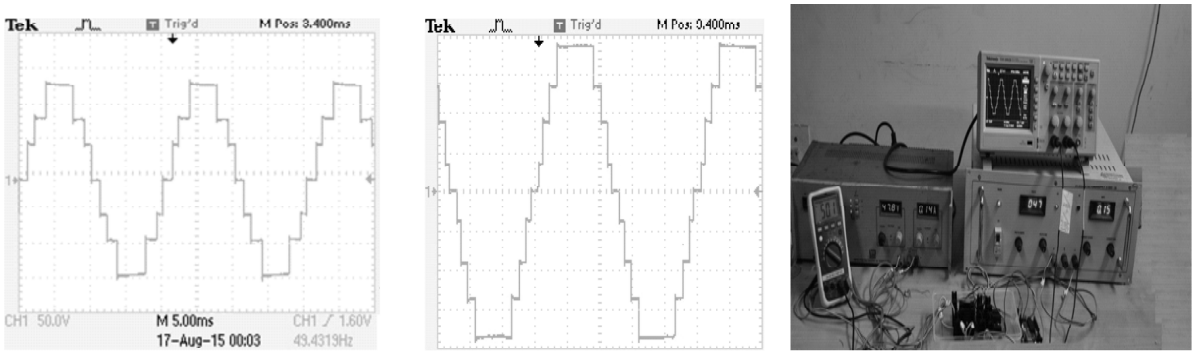
(a) (b)

Figure 3: FFT analysis for voltage waveform for nine level using CSA



(a) (b)

Figure 5: Modulation index Vs Voltage Waveform THD a) seven level b) nine level



(a) Seven level waveform (b) Nine level (c) experimental setup

Figure 6: Experimental result for voltage waveform and setup

5. CONCLUSION

In this paper, the quality of inverter output is improved by optimizing switching angle to eliminate the lower order harmonics using Cuckoo Search. The algorithm shows better performance such as converge to global optima, controlling parameter and satisfying constraints. The lower order harmonics are eliminated for seven and nine level which can reduce the requirement of filter circuit. The overall performance of the inverter model with optimized values of switching angles is verified with experimental results. It is much

closed to the simulation results. The author strongly believes that the CSA is best choice for the electrical nonlinear problem.

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