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Minimizing Harmonic Distortion In Multilevel Inverters Using Bacteria Foraging Algorithm

M.Praveen Reddy[1], K.Kartheek[2], M.Srinivas[3]
Assistant Professor[1, 2, 3]
Department of Electrical and Electronics Engineering
Matrusri Engineering College, Saidabad, Hyderabad, Telangana, India

Abstract:
Cascaded Multilevel Converters are very popular and have many applications in electric utility and for industrial drives. When these inverters are used for industrial drive directly, the THD contents in output voltage of inverters is very significant index as the performance of drive depends very much on the quality of voltage applied to drive. So it is important to reduce the harmonic distortion. Sinusoidal PWM and space vector PWM techniques are suggested in the literature. However, PWM techniques increase the control complexity and are also not effective in reducing the lower order harmonics. Another approach to eliminate specific harmonics is to find the optimal switching angles. In this paper, an evolutionary computation technique known as Bacteria Foraging Algorithm is used to find the optimum switching angles to reduce the Harmonic distortion. First, a cascaded H – Bridge Multi level inverter is developed in Simulink and a BFA program is developed in MATLAB to find out optimum switching angles with an objective of reducing the harmonic distortion considering the specific dominant lower order harmonics such as fifth, seventh, eleventh, thirteenth and seventeenth. The proposed algorithm is tested on 11-level multi level inverter and the simulation results are presented.

Keywords: MLI, BFA.

I.INTRODUCTION

The concept of multilevel converters has been introduced since 1975. The term multilevel began with the three-level converter. Subsequently, several multilevel converter topologies have been developed. However, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple dc voltage sources. multilevel inverters have attracted a great deal of attention in medium-voltage and high-power applications due to their lower switching losses, higher efficiency, and more electromagnetic compatibility than those of conventional two-level inverters [3]–[6]. The well-known multi level topologies are: 1) Cascaded H-bridge multi-level inverter, 2) Diode-clamped multi-level inverter, and 3) Flying capacitor multi-level inverter. Cascaded H-bridge multi-level inverter is superior to another multilevel topology and it requires the least number of components [2]-[6]. Also it is easily extensible for higher number of output voltage levels without increase in power circuit complexity. Due to the great demand of medium voltage high power inverters, the cascaded inverter has drawn tremendous interest ever since. To produce multilevel output ac voltage using different levels of dc inputs, the semiconductor devices must be switched on and off in such a way that the fundamental voltage is obtained as desired along with the elimination of certain number of higher order harmonics in order to have least harmonic distortion in the ac output voltage. For switching the semiconductor devices, proper selection of switching angles is must. 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. Once these solution sets are obtained, the switching angles producing minimum harmonic distortion in the output ac voltage are selected for switching of the power electronic devices. The main function of a multilevel inverter is to produce a desired ac voltage waveform from several levels of dc voltages and also minimizing the harmonics. Several algorithms have been suggested for this purpose Such as the Newton-Raphson method [8] is one of them. The disadvantage of this method, it is fast and exact but not for all modulation indices and it depends on initial guess. To reduce the harmonics further, different multilevel sinusoidal PWM, space-vector PWM and Sinusoidal pulse width modulation (SPWM) schemes are suggested in the literature [9]. However, PWM techniques increase the control complexity and the switching frequency. While Bacteria Foraging Algorithm [10]-[11] overcome these problems.

II. CASCADED H-BRIDGE MULTI-LEVEL INVERTER

The smallest number of voltage levels for a multilevel inverter using cascaded inverter with SDCSs is three. To achieve a three-level waveform, a single full-bridge inverter is employed. Basically, a full-bridge inverter is known as an H-bridge cell, which is illustrated in Figure 1.5. The inverter circuit consists of four main switches and four freewheeling diodes.

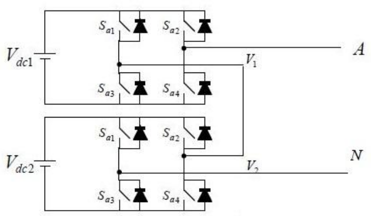

Figure. 1. an h-bridge cell.

The inverter circuit consists of four main switches and four freewheeling diodes.

The cascaded H-bridge multi level inverter is to use capacitors and switches and requires less number of components in each level. This topology consists of series of power conversion cells and power can be easily scaled. The combination of capacitors and switches pair is called an H-bridge and gives the separate input DC voltage for each H-bridge. It consists of H-bridge cells and each cell can provide the three different voltages like zero, positive DC and negative DC voltages. One of the advantages of this type of multi level inverter is that it needs less number of components compared with diode clamped and flying capacitor inverters. The price and weight of the inverter are less than those of the two inverters. Soft-switching is possible by the some of the new switching methods. Multilevel cascade inverters are used to eliminate the bulky transformer required in case of conventional multi phase inverters, clamping diodes required in case of diode clamped inverters and flying capacitors required in case of flying capacitor inverters. But these require large number of isolated voltages to supply the each cell. [4] To synthesize a multilevel waveform, the ac output of each of the different level H-bridge cells is connected in series. The synthesized voltage waveform is, therefore, the sum of the inverter outputs. The number of output phase voltage levels in a cascaded inverter is defined by

m=2s+1……1.1

Where's' is the number of dc sources.

For example, a nine-level output phase voltage waveform can be obtained with four-separated dc sources and four H-bridge cells.

Fig 1 shows a general single-phase m-level cascaded inverter. From Fig. 2, the phase voltage is the sum of each H-bridge outputs and is given as

$V_{AN} = V_{dc1} + V_{dc2} + +V_{dc}(s -1) + V_{dc}s$... (1.2)

Because zero voltage is common for all inverter outputs, the total level of output voltage waveform becomes 2s+1. An example phase voltage waveform for a nine-level cascaded inverter and all H-bridge cell output waveforms are shown in Fig.3. In this thesis, all dc voltages are assumed to be equal, i.e.

$V_{dc}1 = V_{dc}2 = = V_{dc}(S -1) = V_{dc}S = V_{dc}$…(1.3)

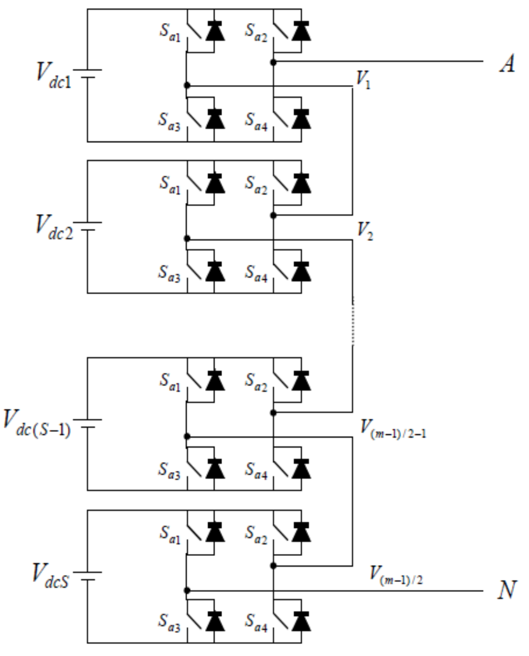

Figure.2. Single-phase configuration of an m-level cascaded inverter.

According to sinusoidal-liked waveform, each H-bridge output waveform must be quarter-symmetric as illustrated by V1 waveform in Figure2 Obviously, not even harmonic components are available in such a waveform.

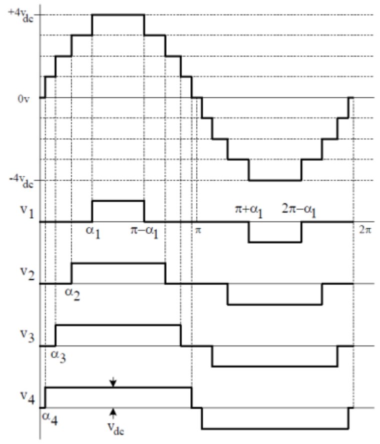

Figure.3. Waveform showing a nine-level output phase voltage and each H-bridge output voltage.

III. HARMONICS AND ITS EFFECTS

In an ideal power system, the voltage supplied to customer equipment, and the resulting loads current are perfect sine waves. In practice, however, conditions are never ideal, so these waveforms are often quite distorted. This deviation from perfect sinusoids is usually expressed in terms of harmonic distortion of the voltage and current waveforms. Power system harmonic distortion is not a new phenomenon - efforts to limit it to acceptable proportions have been a concern of power engineers from the early days of utility systems. At that time, the distortion was typically caused by the magnetic saturation of transformers or by certain industrial loads, such as arc furnaces or arc welders. The major concerns were the effects of harmonics on synchronous and induction machines, telephone interference, and power capacitor failures. In the past, harmonic problems could often be tolerated because equipment was of conservative design and grounded wye-delta transformer connections were used judiciously. Distortions of the fundamental sinusoid generally occur in multiples of the fundamental frequency.

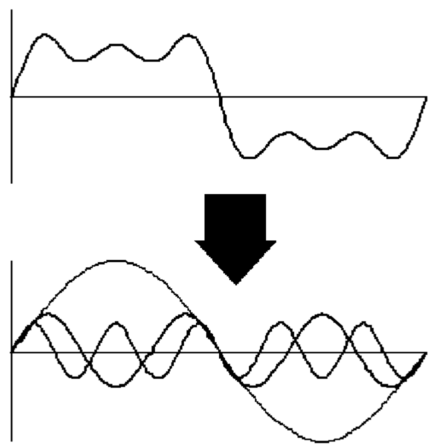

Figure.4. Distorted wave composed by the superposition of a 50 hz fundamental and smaller third harmonic and fifth harmonics.

Harmonics are often characterized by a harmonic distortion factor (DF) defined as:

$$DF = \frac{\sqrt{\text{sum of squares of harmonic amplitudes}}}{\text{amplitude of fundamental}}$$

The distortion factor can be used to characterize distortion in both current and voltage waves. Total harmonic distortion factors can be specified for a range of harmonics such as the second through the eleventh harmonic. A distortion factor can also be given for a single harmonic or small range of harmonics. The total harmonic distortion (THD) is the distortion factor including all relevant harmonics (typically taken as the second through the fiftieth).

3.1 Importance of understanding harmonics in today's systems:

As mentioned earlier, harmonic distortion problems are not new to utility and industrial power systems. In fact, such distortion was observed by utility operating personnel as early as the first decade of this century. Typically, the distortion was caused by nonlinear loads connected to utility distribution systems. Today, however, additional methods for dealing with harmonics are necessary for four main reasons:

a. The use of static power converters has recently proliferated.
b. Network resonances have increased.
c. Power system equipment and loads are more sensitive to harmonics.
d. Electricity costs are becoming more affected by increases populations of Non-linear equipment.

The introduction of reliable and cost-effective static power converters has caused a very large increase in the number of harmonic-generating devices and has resulted in their dispersion over the entire power system. The term "static power converter", as used in this text, refers to a semiconductor device that converts power of one frequency into power of another frequency. The types of converters most frequently used in industry are the rectifier, converting ac power to dc, and the inverter, converting dc power to ac. Moreover, the harmonic problem is often aggravated by the trend in recent years to install capacitors for power factor improvement or voltage control . Since the capacitor installation is in parallel with the inductance of the power system, as shown in Figure 3.2

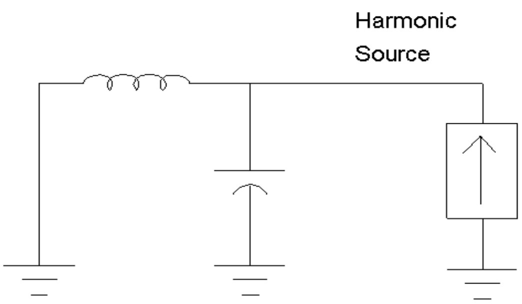

Figure.5. Excitation of a Parallel Resonant Circuit.

If a harmonic current is injected (from a static power converter, for example) at a frequency near the resonant frequency, a high oscillating current can flow that may in turn cause capacitor fuse blowing and high harmonic voltages. In addition to the increase in harmonic generators and network resonances, electric systems and loads have become no less, and in some cases even more, sensitive to harmonics. There are a number of areas of new and continuing concern:

IV. REDUCING THE EFFECTS OF HARMONICS

Because of the adverse effect of harmonics on power system components, the IEEE developed standard 519-1992 to define recommended practices for harmonic control. This standard also stipulates the maximum allowable harmonic distortion allowed in the voltage and current waveforms on various types of systems. Harmonic filters can be constructed by adding an inductance (L) in series with a power factor correction capacitor (C). The series L-C circuit can be tuned for a frequency close to that of the troublesome harmonic, which is often the 5th. By tuning the filter in this way, you can attenuate the unwanted harmonic. Since skin effect is responsible for the increased heating caused by harmonic currents, using conductors with larger surface areas will lessen the heating effects. This can be done by using finely stranded conductors, since the effective surface area of the conductor is the sum of the surface area of each strand. Specially designed transformers called k-factor transformers are also advantageous when harmonic currents are prevalent. They parallel small conductors in their windings to reduce skin effect and incorporate special core designs to reduce the saturation effects at the higher flux frequencies produced by the harmonics. Two approaches are available for mitigating the effects of excessive heating due to harmonics, and a combination of the two approaches is often implemented.

I. To reduce the magnitude of the harmonic waveforms, usually by filtering.
II. To use system components that can handle the harmonics more effectively, such as finely stranded conductors and k-factor transformers.

Filtering isn't the only means of reducing harmonics. The switching angles of an inverter can be preselected to eliminate some harmonics in the output voltage. This can be a very cost-effective means of reducing inverter-produced harmonics. This is the concept involved in this paper which is efficient method of reducing selected undesired harmonics.

V. BACTERIA FORAGING ALGORITHM

5.1 Introduction

Nature has been a source of inspiration for the design of several algorithms. One main principle behind nature inspired algorithms is the concept of efficiency, interpreted as the capability of an individual to obtain a sufficient energy source in the least amount of time. This procedure called foraging is crucial in natural selection, since the animals with poor foraging strategies are eliminated, and successful ones tend to propagate.

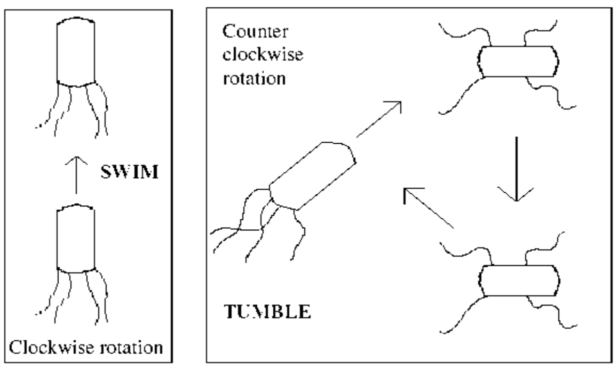

Figure .6. Swim and tumble of a bacterium.

Hence, to survive, an animal or a group of animals must develop an optimal foraging policy [10]. Some of the most successful foragers are bacteria like the E. Coli, which employs chemical sensing organs to detect the concentration of nutritive or noxious substances in its environment. The bacteria then moves through the environment by a series of tumbles and runs, avoiding the noxious substances and getting closer to food patch areas in a process called chemotaxis. Besides, the bacteria can secrete a chemical agent that attracts its peers, resulting in an indirect form of communication [11].

5.2 Description of algorithm

During foraging of the real bacteria, locomotion is achieved by a set of tensile flagella. Flagella help an E.coli bacterium to tumble or swim, which are two basic operations performed by a bacterium at the time of foraging [10, 11]. When they rotate the flagella in the clockwise direction, each flagellum pulls on the cell. That results in the moving of flagella independently and finally the bacterium tumbles with lesser number of tumbling whereas in a harmful place it tumbles frequently to find a nutrient gradient. Moving the flagella in the counter clockwise direction helps the bacterium to swim at a very fast rate. In the above-mentioned algorithm the bacteria undergoes chemotaxis, where they like to move towards a nutrient gradient and avoid noxious environment.

Generally the bacteria move for a longer distance in a friendly environment. Figure 1 depicts how clockwise and counter clockwise movement of a bacterium take place in a nutrient solution. When they get food in sufficient, they are increased in length and in presence of suitable temperature they break in the middle to from an exact replica of itself. This phenomenon inspired Passino to introduce an event of reproduction in BFOA. Due to the occurrence of sudden environmental changes or attack, the chemotactic progress may be destroyed and a group of bacteria may move to some other places or some other may be introduced in the swarm of concern. This constitutes the event of elimination-dispersal in the real bacterial population, where all the bacteria in a region are killed or a group is dispersed into a new part of the environment.

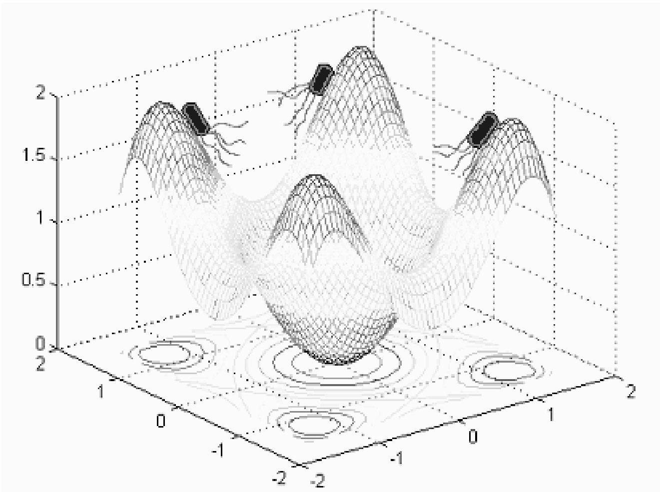

Figure.7. a bacterial swarm on a multi-modal objective function surface.

5.3 Explanation of the parameters

The bacterial foraging optimization system consists of three principal mechanisms, namely, chemotaxis, reproduction, and elimination-dispersal. We briefly describe each of these processes as follows:

5.3.1 Chemotaxis:

In the bacterial foraging algorithm, a unit walk with random direction represents a "tumble" and a unit walk with the same direction in the last step indicates a "run". Suppose θi (j+1, k, l) represents the bacterium at j^{th} chemotactic, k^{th} reproductive, and l^{th} *elimination*-dispersal step. C(i), namely, the run-length unit parameter, is the chemotactic step size during each run or tumble. Then, in each computational chemotactic step, the movement of the *i*th bacterium can be represented as:

$$\theta^i(j+1,k,l)=\theta^i(j,k,l)+c(i)*[\Delta(i)/[\Delta^T(i)*\Delta(i)]^{0.5}] \quad .... (5.1)$$

Where Δ(i) is the direction vector of the jth chemotactic step. When the bacterial movement is run, Δ(i) is the same with the last chemotactic step; otherwise, Δ(i) is a random vector whose elements lie in [−1, 1]. With the activity of run or tumble taken at each step of the chemotaxis process, a step fitness, denoted as j (i, j, k, l), will be evaluated.

5.3.2 Reproduction:

The health status of each bacterium is calculated as the sum of the step fitness during its life, namely, ∑ J (i, j, k, l), where Nc is the maximum step in a chemotaxis process. All bacteria are sorted in reverse order according to health status. In the reproduction step, only the first half of population survives, and a surviving bacterium splits into two identical ones, which are then placed in the same locations. Thus, the population of bacteria keeps constant.

5.3.3 Elimination and Dispersal:

The chemotaxis provides a basis for local search, and the reproduction process speeds up the convergence which has been simulated by the bacterial foraging algorithm, while; to a large extent, only chemotaxis and reproduction are not enough for global optima searching. Since bacteria may get stuck around the initial positions or local optima, it is possible for the diversity of bacterial foraging algorithm to change either gradually or suddenly to eliminate the accidents of being trapped into the local optima. In bacterial foraging algorithm, the dispersion event happens after a certain number of reproduction processes. Then, some bacteria are chosen, according to a preset probability *P*ed, to be killed and moved to another position within the environment.

VI.FLOW CHART OF BACTERIA FORAGING ALGORITHM

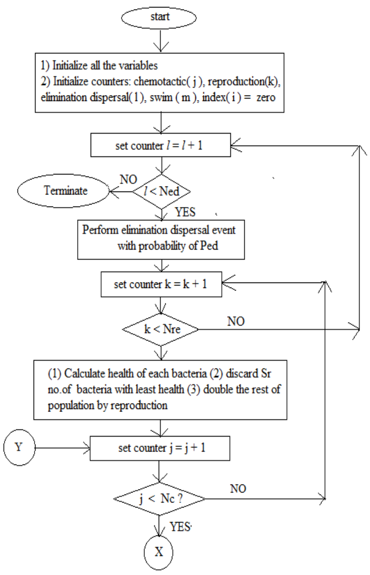

Figure.8.Flow chart part (a) of bacteria foraging algorithm.

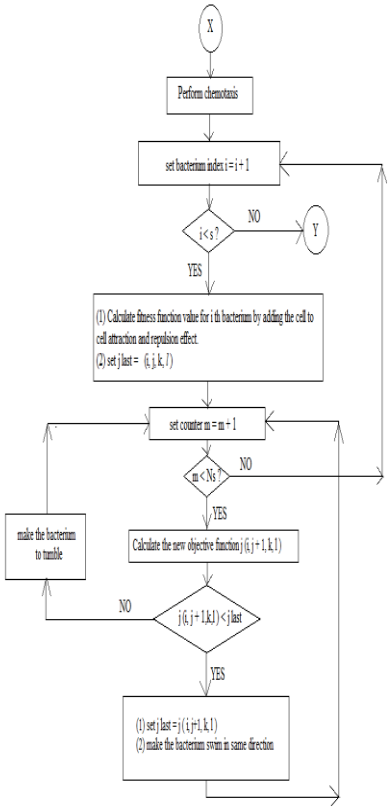

Figure.9.flow chart part (b) of bacteria foraging algorithm.

VII.MODELLING OF MULTILEVEL INVERTER

The modelling of the following eleven level inverter using bacteria foraging algorithm is done using MATLAB/ SIMULINK.

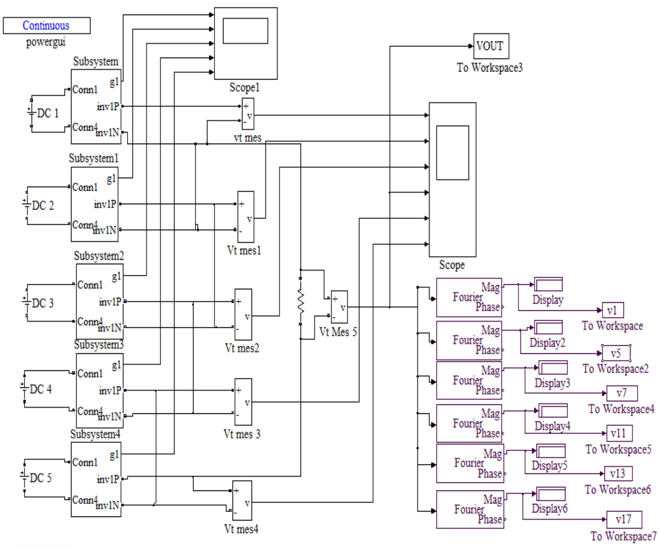

Figure.10.simulink diagram for eleven level cascaded multilevel inverter.

The simulink implementation of a eleven multilevel inverter is shown in fig 5.2 It consists of five bridges, the ideal input voltage source V_{dc1} = 100volts for cascaded H-bridge1, similarly $V_{dc2} = V_{dc3} = V_{dc4} = V_{dc5}$ = 100volts for cascaded H-bridge2, cascaded H-bridge3, cascaded H-bridge4, cascaded H-bridge5 inverters, the positive terminal is represented by plus (+) sign on one port and minus '-'on other port, this voltage source can modify voltage at any time during the simulation.

The Load is R of 10Ω, the voltage measurement1, voltage measurement2, voltage measurement3, voltage measurement4, voltage measurement5 are used to measure individual instantaneous voltages of each cascaded H-bridge inverters, total voltage measurement is used to measure the total output voltage of cascaded H-bridges. 'To work space' block writes data to MATLAB work space. It inputs a signal and writes the signal data to the MATLAB workspace. The Fourier block can be programmed to calculate the magnitude and phase of DC component where in the harmonic component is specified to perform the fourier analysis, enter a number in the Fourier block corresponding to desired harmonics. The harmonics considered for elimination are 5^{th}, 7^{th}, 11^{th}, 13^{th} and 17^{th}.

7.1 Parameters of the simulated model

Table .1.

Input voltage in each bridge	100volts
Total input voltage of five bridges	500volts
R-load	10Ω
Switching device	IGBT/ Diode
Internal resistance	1mΩ
Snubber resistance	1e5
Snubber capacitance	Inf

VIII.RESULTS AND DISCUSSION

8.1 Optimization of lower order harmonics in 11-level inverter

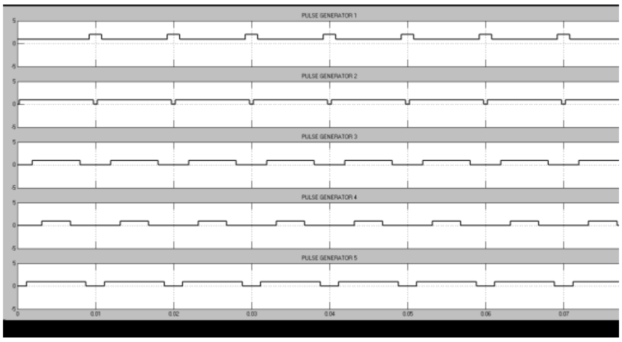

Figure.11. Simulated Results of Gating Pulses Generated for H-Bridge Inverter for elimination of lower order harmonics in 11-level inverter

The above figure 8.1 shows the simulated gate pulses at subsequent intervals of each cascaded H-bridge1, cascaded H-bridge2, cascaded H-bridge3, cascaded H-bridge4, cascaded H-bridge5 using pulse generators of their H-bridges.

8.2 Simulated results of output Voltages for elimination of lower order harmonics in 11-level inverter

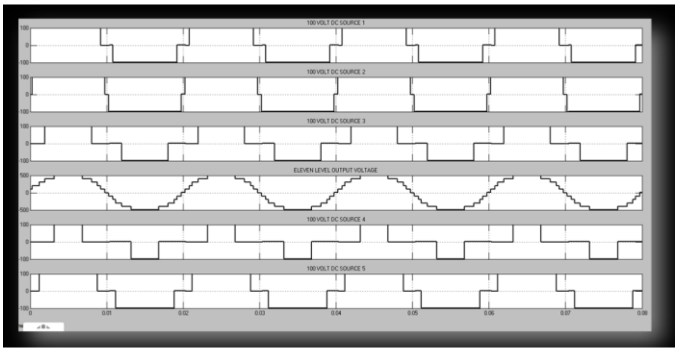

Figure.12. Represents the Individual output voltages for each H-bridge and the overall output voltage with elimination of lower order harmonics in 11-level inverter.

8.3 FFT analysis output of 11-level cascaded H-bridge inverter

In FFT analysis the total harmonic distortion for the case minimizing harmonics 5th, 7th, 11th, 13th and 17th, the powergui FFT of MATLAB analyses the total harmonic distortion which is 10.11%. Here the fundamental voltage is 542.4 volts and this voltage is only used for power conversion i.e. to mechanical power all other predominant lower order harmonic components are wasted in the form of heat energy and disturbance, from above even harmonic components gets eliminated because of symmetry shape and In three-phase power system, triplen harmonic components are absent in line-to-line voltage, as a result, only non-triplen odd harmonic components are present in line-to-line voltage like 5, 7, 11, 13, etc.

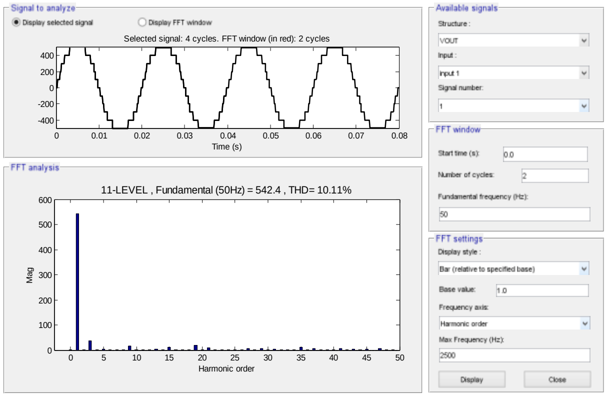

Figure.13. FFT analysis for minimization of harmonic distortion in11-level cascaded H-bridge inverter.

8.4 THD values in eleven level converter with variation in chemotactic steps R-load

Table.2.

	Without 4 chemotactic steps	With 35 chemotactic steps
THD percentage	29.76 %	**10.11 %**
Fundamental voltage	v1 = 619.0225 volts	v1 = 541.2411 volts
Switching angle values	θ_1 = 0.178600355859953 θ_2 = 0.276057620392530 θ_3 =5.734170500418645 θ_4 =16.27314966560449 θ_5 =24.25347383887088	θ_1= 4.50975 θ_2 = 14.43669 θ_3 = 21.1358 θ_4 =35.2787 θ_5 = 57.2660
Lower order harmonic voltages	v5 = 63.8037 v7 = 24.9710 v11 = 16.1302 v13 = 20.7651 v17 = 19.3948	v5 = 6.1673 v7 = 3.2241 v11 = 0.1394 v13 = 3.6494 v17 = 0.2024
Total number of bacteria in the population	i = 26	i = 26
The number of chemotactic steps	j = 4	j = 35
The number of reproduction steps	k = 2	k = 3
The number of elimination-dispersal events	e11=1	e11= 3

IX.CONCLUSIONS

Bacteria foraging algorithm is developed in MATLAB to find the optimum switching angles for a seven level and eleven level cascaded H-bridge multilevel inverter to minimize the harmonic distortion by considering the specific dominant harmonics such as fifth, seventh, eleventh, thirteenth and seventeenth while maintaining the fundamental voltage. The simulation result shows that this algorithm is reducing the dominant harmonics resulting in lower THD. As the level increased THD is further reduced. The proposed algorithm can be applicable even for higher level inverters

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