APPLICATION OF BACTERIAL FORAGING OPTIMIZATION ALGORITHM FOR SELECTIVE HARMONIC ELIMINATION STRATEGY IN MULTILEVEL INVERTERS

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ABSTRACT-In this paper, harmonic elimination of an 11-level cascaded H-bridge Multi Level Inverter (MLI) using Bacterial Foraging Optimization Algorithm (BFOA) has been presented. The foremost objective of selective harmonic elimination pulse width modulation strategy is to eliminate the lower order harmonics, while the fundamental components are satisfied. BFOA is motivated by the collective foraging activity of Escherichia coli, rod shaped bacterium of the genus. The basic biology behind the foraging approach of Escherichia coli is imitated in an amazing way and used as an easy optimization algorithm. This method has higher precision and a probability of convergence. Bacterial Foraging optimization algorithm is used for optimization switching angle of the Cascaded Multi Level inverter (CMLI) in MATLAB/SIMULINK software. Theoretical results are verified by simulations for an 11-level H-bridge inverter. Simulation results illustrate that the projected method does efficiently eliminate a great number of specific harmonics and the corresponding output voltage is resulted with a low total harmonic distortion.

Keywords: **Bacterial Foraging optimization algorithm, Cascaded multilevel inverter, Total Harmonic elimination.**

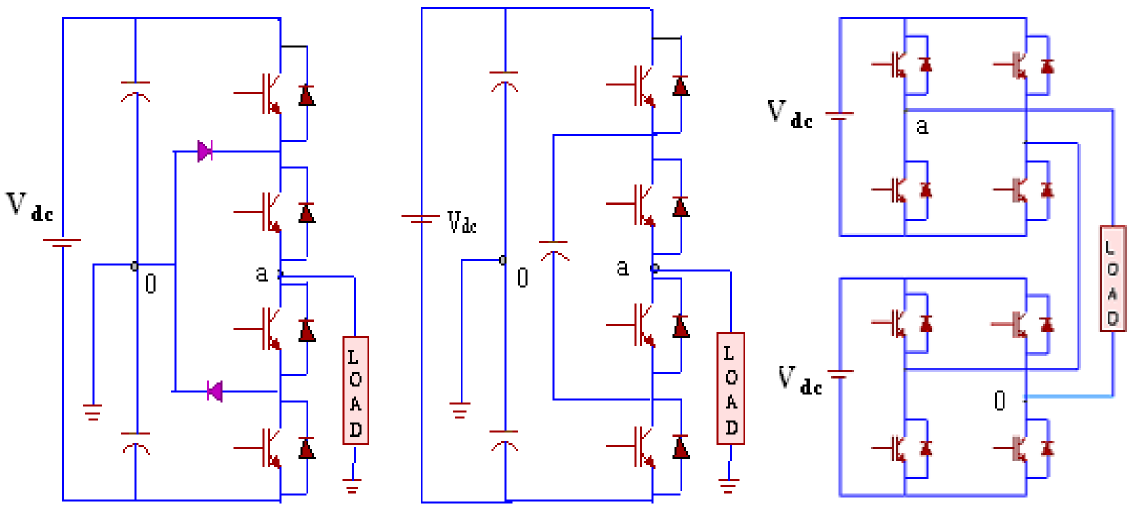
INTRODUCTION:

Electrical energy is an exceedingly priceless product and several market studies exhibit that the demand for electrical energy is repeatedly increasing exponentially. Due to the inadequate availability of electrical energy constant improvements are immediately required on the efficiency frontage in every one of the industrial and consumer applications [1]. Inverters are used in power electronics and numerous researches are going on to get better output voltage with low total harmonic distortion [2]. Multilevel Voltage-Source Inverters (VSI) are an appropriate configuration to attain high power ratings and high superiority output waveforms with low harmonic distortion in addition to acceptable dynamic responses [3]. Among the different multilevel converter configurations, the cascaded multilevel inverter has established unique consideration due to its modularity and ease of control [4-6]. For controlled output voltage and reduced unwanted harmonics in multilevel converters with equal DC voltages, different modulation techniques such as Sinusoidal Pulse Width Modulation (SPWM) and Space-Vector Pulse Width Modulation have been preferred [7,8]. Another method, popularly proposed for harmonic elimination is called the Selective Harmonic Elimination (SHE) [9].

The harmonic elimination for multilevel converters having equal DC sources using Genetic Algorithm (GA) approach is presented in [10]. However, this method requires significant computational time. The harmonic elimination of multilevel converters using Particle Swarm Optimization algorithm has been discussed in [11]. In this paper, to validate the effectiveness of the proposed algorithm the harmonic optimization for an 11 level converters having equal DC sources has been evaluated using a Bacterial Foraging Optimization algorithm. The proposed Bacterial Foraging Optimization Algorithm (BFOA) reduces the computational time to find the optimal solution compared with other iterative methods [12]. The eleven level inverter is constructed in simulink block is gated by BFOA optimized switching angles. The results are presented and analyzed.

MULTILEVEL INVERTERS:

Multilevel inverters have been introduced as a substitute in high power and medium voltage circumstances. A multilevel inverter can attain high power ratings and also enhances the performance of the whole system in terms of harmonics, dv/dt stresses and stresses in the bearings of a motor. Several multilevel converter topologies have been developed; i) diode clamped, ii) flying capacitors, and iii) cascaded or H-bridge. MLIs can effortlessly generate high-power, high-voltage output using the multilevel structure due to the way the device voltage stresses are restricted in the structure. The power rating can be increased by increasing the number of voltage levels in the inverter without involving higher ratings on individual devices. The exceptional structure of multilevel VSI enables them to attain high voltages with low harmonics with no use of transformers or series connected synchronized switching devices. The harmonic content of the output voltage reduces appreciably with increase in the number of voltage levels [13]. This paper deals with simulation of an eleven level single phase cascaded inverter with separate DC sources



(a) (b) (c)

Figure1. MLI topologies (a) Diode clamped MLI (b) Flying capacitor MLI (c) Cascaded MLI.

CASCADED MULTILEVEL INVERTER:

Figure 2 shows the power circuit of a cascaded multilevel inverter with N independent single-phase inverters. These inverters are of full-bridge configuration with separate DC sources. The sources can be fuel cells or solar cells, batteries and they are connected in series. Every full bridge inverter unit can produce three levels of output: $+V_{DC}$, 0 or $-V_{DC}$ by connecting the DC source to the AC load by dissimilar combinations of the four switches of each full bridge inverter. With the top full bridge inverter as the example, turning on of switches S_{11} and S_{41} gives in $+V_{DC}$ as output. Turning on off switches S_{21} and S_{31} produces $-V_{DC}$ as output. Turning off of all the switches gives in '0' volts as output. Similarly, the AC output voltage at other full bridge inverter can be obtained with the similar approach. The number of full bridge inverters in cascade is determined by the number of voltage levels at the load. The number of bridge inverter units or DC sources N is (m-1) /2 where m is the sum of zero level and the number of positive and negative levels of MLI output. Each switching component turns ON and OFF only once per cycle at the line frequency.

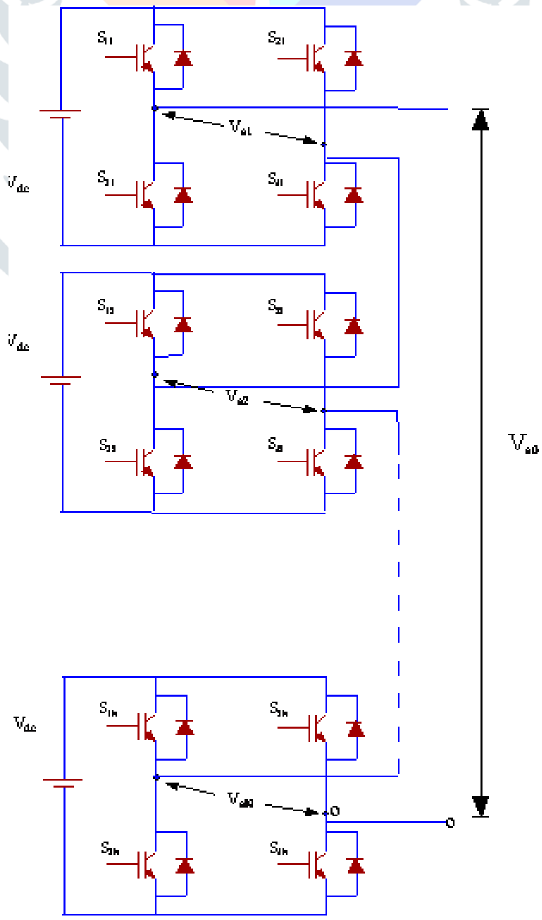


Figure.2 Cascaded Multilevel Inverter.

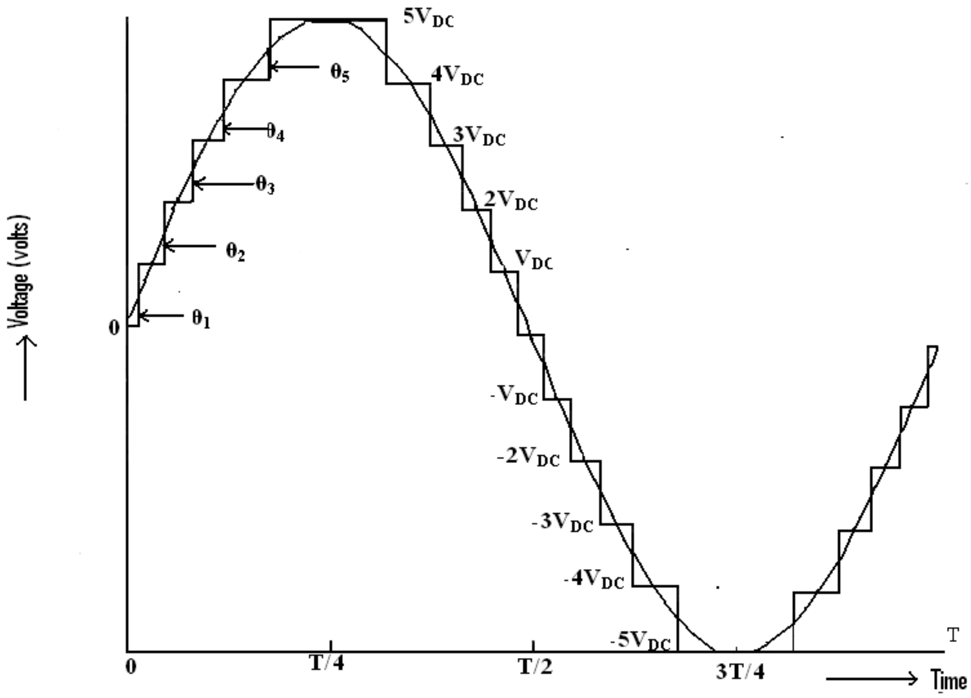


Figure.3 The output of a 11 level Cascaded Multilevel Inverter.

PROBLEM FORMULATION AND ANALYSIS FOR HARMONIC OPTIMIZATION

For the proposed eleven level inverter, m=11 where 'm' is the number of steps in the positive and negative side after including the zero levels also. Switching angles to eliminate 5^{th}, 7^{th}, 11^{th} and higher order harmonics are calculated generally assuming that the peak fundamental output voltage is a desired fraction of its maximum value. For any Cascaded Multilevel Inverter, the output voltage is given by

$$V_{a0} = V_{a1} + V_{a2} + \ldots\ldots + V_{aN} \qquad (1)$$

Where $N = \frac{(m-1)}{2}$

Due to the quarter wave symmetry along the x-axis in load voltage of Figure 3, both Fourier coefficients A_0 and A_n are zero. B_n is defined as

$$B_n = \frac{4V_{dc}}{\pi}\left[\int_{\theta_1}^{\frac{\pi}{2}} k_1 \sin(n\omega t)d(\omega t) + \int_{\theta_2}^{\frac{\pi}{2}} k_2 \sin(n\omega t)d(\omega t) + \ldots\ldots + \int_{\theta_N}^{\frac{\pi}{2}} k_N \sin(n\omega t)d(\omega t)\right]$$

$$= \frac{4Vdc}{n\pi}\left[\sum_{j=1}^{N} \cos(n\theta_j)\right] \qquad (2)$$

Which gives the instantaneous output voltage V_{ao} as

$$V_{a0}(\omega t) = \sum_{n=1}^{\infty} \frac{4V_{dc}}{n\pi}\left[\sum_{j=1}^{N} k_j \cos(n\theta_j)\right] \sin(n\omega t) \qquad (3)$$

Where $K_j = \frac{V_j}{V_{dc}}$

Equation (3) provides the generalized Fourier series expansion of the output voltage. If the peak output voltage $V_{a0\,(peak)}$ must equal to the carrier peak voltage $V_{cr\,(peak)}$, $V_{cr\,(peak)} = (m-1)\,V_{DC}$.

Thus the modulation index M is

$$M = \frac{V_{cr}(peak)}{V_{ac}(peak)} = \frac{V_{cr}(peak)}{(m-1)V_{dc}} \qquad (4)$$

The two principal techniques in choosing the switching angles $\theta_1, \theta_2, \ldots\ldots \theta_N$ are

(a). Eliminate the lower frequency dominant harmonics

(b). Minimize the THD.

Among the two techniques, the most accepted technique is to eliminate the lower dominant harmonics and filter the output to eliminate the higher residual frequencies. Here the preference is to remove the lower frequency harmonics. Here the aim is to choose the switching angles $0\leq\theta_1< \theta_2<\ldots<\theta_N\leq \pi/2$ to make the first harmonic equal to the desired fundamental voltage V_1 (RMS) and specific higher harmonics of V_{a0} (ωt) equal to zero. The switching angles θ_1, θ_2, θ_3, θ_4, $\theta_5$can be selected such that the THD of the output voltage is minimized. These angles are normally chosen so as to cancel some predominant lower frequency harmonics. To eliminate 5th, 7th, 11th and 13th harmonics assuming that the peak fundamental output voltage is the same as its maximum value, the following equations are solved for different modulation indices, m=11, N=5 and V_{DC}=100.

$\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) = 0$

$\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3) = 0$

$\cos(11\theta_1) + \cos(11\theta_2) + \cos(11\theta_3) = 0$

$\cos(13\theta_1) + \cos(13\theta_2) + \cos(13\theta_3) = 0$

$\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) = (\pi/2) M$

This is a system of 5 transcendental equations with unknown θ_1, θ_2, θ_3, θ_4 and θ_5. Bacterial Foraging Optimization Algorithm (BFOA) technique is used to solve this set of non-linear transcendental equations. The proposed objective function for minimization using BFOA is given as,

$$f(\Theta_1,\Theta_2,\ldots,\Theta_s) = \left[\left|M-\frac{|V_1|}{sV_{dc}}\right| + \left(\frac{|V_5|+|V_7|+\cdots+|V_{3s-2\text{ or }3s-1}|}{sV_{dc}}\right)\right] \quad (5)$$

The conventional technique is derivative based and may result in local optima, nevertheless a cautious choice of initial values alone guarantees convergence. So optimization techniques like Bacterial Foraging Optimization Algorithm is employed for minimization of harmonics in order to decrease the computational burden related with the solution of the non-linear transcendental equation of the conventional SHE method. An accurate solution will be guaranteed with BFOA even for a higher number of switching angles than other techniques. Hence BFOA seems to be promising methods for applications when a large number of DC sources are required in order to eliminate lower-order harmonics to further eliminate the THD.

HARMONIC ELIMINATION USING BFOA

The following section explanations the steps involved in the implementation of BFOA approach for harmonic elimination in an eleven level inverter.

Pseudo code of the proposed BFOA Algorithm: [12]

Step 1: Initialize parameters p, S, Nc, Ns, Nre, Ned, Ped, C(i)(i=1,2…S), θ^i.

Step 2: Elimination-dispersal loop: l=l+1

Step 3: Reproduction loop: k=k+1

Step 4: Chemo taxis loop: j=j+1

[a] For I =1, 2… S takes a chemo tactic step for bacterium me as follows.

[b] Compute fitness function, J (I, j, k, l).

Let, J (i, j, k,l) J (i, j,k,l) + J_{cc} (θ^i (j,k,l), P(j, k,l))

(I.e. add on the cell-to cell attractant– repellant profile to simulate the swarming behavior) where, Jcc is defined in (2).

[c] Let J_{last}=J (i, j, k, l) to save this value since we may find a better cost via a run.

[d] Tumble: generate a random vector $\Delta(i) \in \Re^p$ with each element $\Delta_m(i)$,m=1,2….p, a Random number on [-1,1].

[e] Move: Let $\theta^i(j+1,k,l) = \theta^i(j,k,l) + c(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$

This results in a step of size C(i) in the direction of the tumble for bacterium i.

[f] Compute J (i, j +1, k,l) and let

J (i, j 1, k,l) = J (i, j,k,l) + J_{cc} (θ^i (j +1,k,l), P(j +1, k,l))

[g] Swim

i) Let m=0 (counter for swim length).

ii) While m< N_S (if have not climbed down too long).

Let m=m+1.

If J (i, j +1, k,l) < J_{last} (if doing better), let J_{last} = J (i, j +1, k,l) and

let $\theta^i(j+1,k,l) = \theta^i(j,k,l) + c(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$

and use this θ^i (j+1,k,l) to compute the new J (i, j +1, k, l) as we did in [f]

Else, let m = N_S . This is the end of the while statement.

[h] Go to next bacterium (i+1) if i ≠ S(i.e., go to [b] to process the next bacterium).

Step 5: If j < N_C , go to step 4. In this case continue chemo taxis since the life of the bacteria is not over.

Step 6: Reproduction:

[a] For the given k and l, and for each i = 1,2,..., S , let

$$J^i_{health} = \sum_{j=1}^{N_c+1} J(i,j,k,l) \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

be the health of the bacterium i (a measure of how many nutrients it got over its lifetime and how successful it was at avoiding noxious substances).
Sort bacteria and chemo tactic parameters C(i) in order of ascending cost J_{health} (higher cost means lower health).

[b] The S_r bacteria with the highest J_{health} values die and the remaining S_r Bacteria with the best values split (this process is performed by the copies that are made are placed at the same location as their parent).

Step 7: If $k < N_{re}$ go to step 3. In this case, we have not reached the number of Specified reproduction steps, so we start the next generation of the chemo tactic loop.

Step 8: Elimination-dispersal: For i = 1,2..., S with probability P_{ed} eliminate and disperse each bacterium (this keeps the number of bacteria in the population constant). To do this, if a bacterium is eliminated, simply disperse another one to a random location on the optimization domain. If $l < N_{ed}$, then go to step 2; otherwise end.

SIMULATION RESULTS

The non-linear transcendental equation considering the equality of the DC sources is solved by using Bacterial Foraging Algorithm (BFOA) technique. The BFOA algorithm is coded in MATLAB platform and gives the global optimum switching angles for the 11 level Cascaded Inverter. Fast Fourier Transform (FFT) of the output phase voltage is analyzed.

Table 1. Output Switching Angles and corresponding THD using BFOA

Modulation index (M)	SWITCHING ANGLES					THD %
	θ1	θ2	θ3	θ4	θ5	
0.6	8.9	22	38	65	89	10.19
0.8	5.6	20	25	44	59	8.03
1	2.3	13	30	44	65	8.54

The above results are obtained for the following BFOA parameters.

Number of Bacteria= 200. Number of Iterations = 100.

The number of generations that evolve depends on whether an acceptable solution is reached or a set number of iterations are exceeded. In this paper, the maximum number of iteration criterion is used to stop the algorithm. By changing the DC-side voltage, the switching pattern has to be recalculated if not, there will be considerable harmonics in the output voltage waveform.

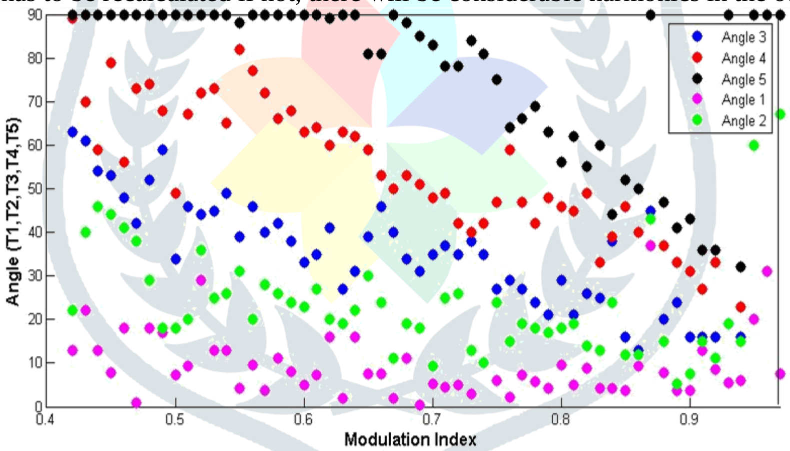


Figure.4 Modulation index (M) Vs Switching Angles

The output voltage waveform for Modulation Index M=0.6 and the corresponding Fast Fourier transform (FFT) analysis are shown in Figure.5 and Figure.6 respectively.

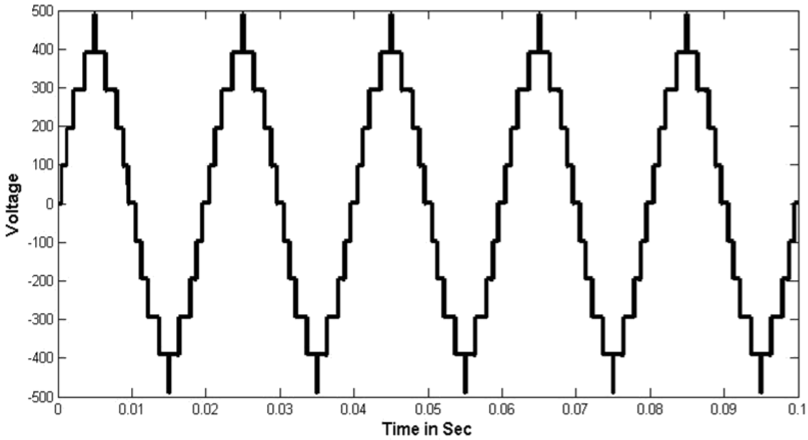


Figure.5 Output Phase Voltage (M=0.6)

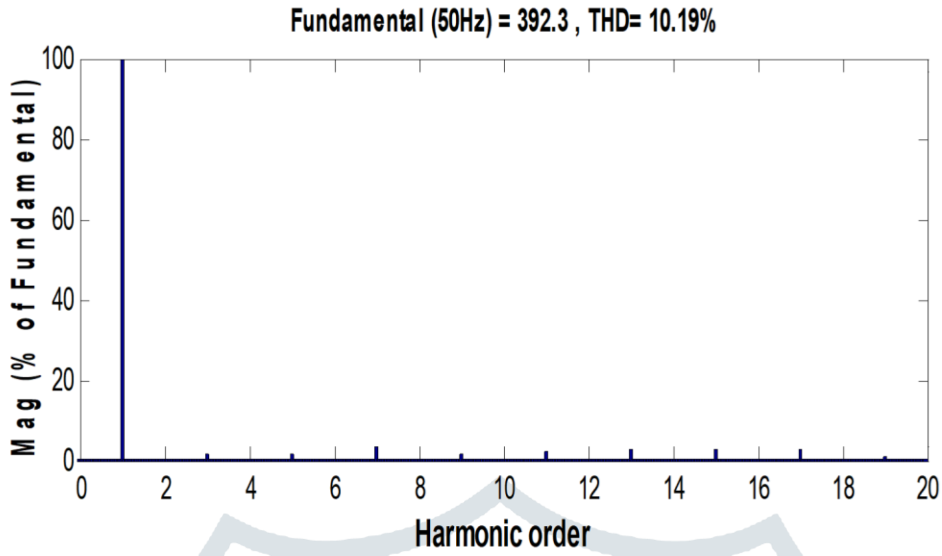


Figure.6 FFT Analysis for phase voltage (M=0.6)

From the FFT plot of the phase voltage, it is observed that the 5th, 7th, 11th, 13th order harmonics are effectively minimized. THD is 10.19% with 1st order harmonic dominating more than 80% of fundamental.

The output voltage waveform for Modulation Index M=0.8 and the corresponding Fast Fourier Transform (FFT) analysis are shown in Figure.7 and Figure.8 respectively.

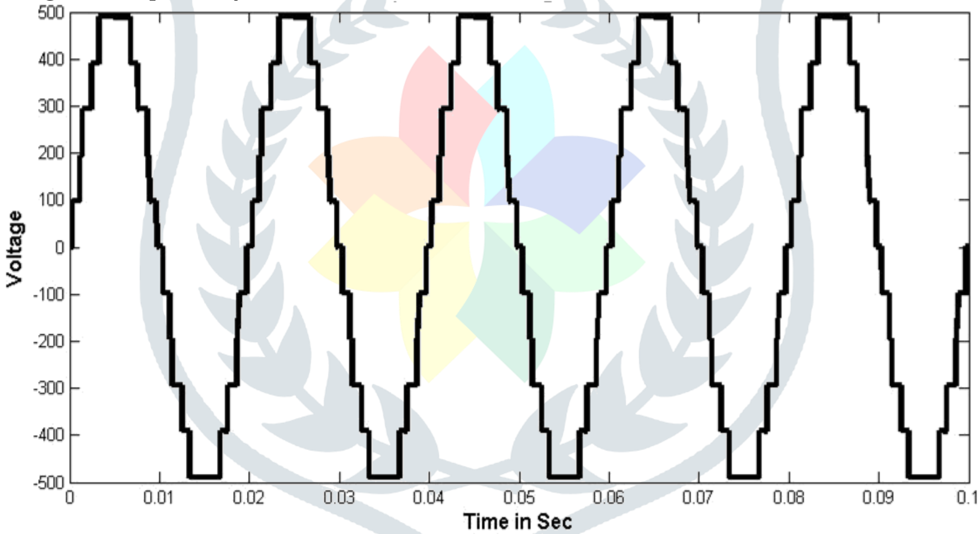


Figure.7 Output Phase Voltage (M=0.8)

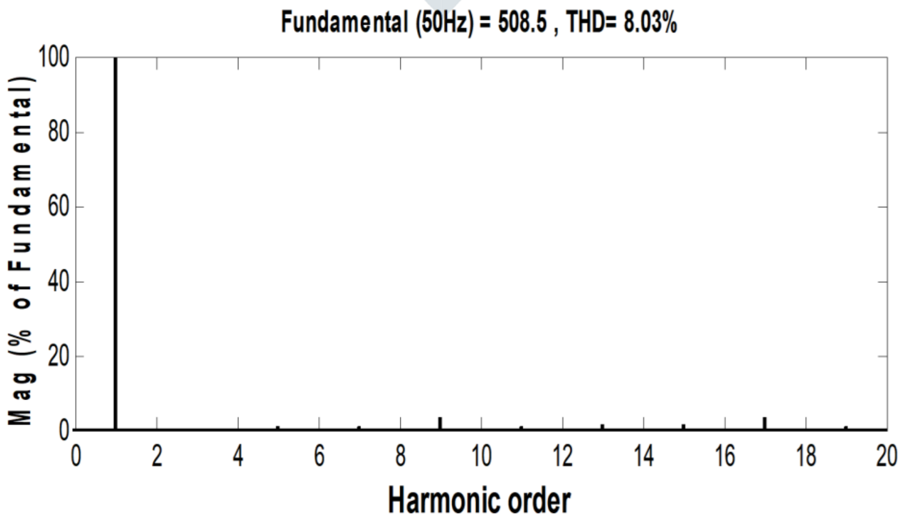


Figure.8 FFT Plot for Phase Voltage (M=0.8)

From the FFT plot of the phase voltage, it is observed that the 5th, 7th, 11th, 13th order harmonics are effectively minimized. THD is 8.03%

The output voltage waveform for Modulation Index M = 1 and the corresponding Fast Fourier Transform (FFT) analysis are shown in Figure.9 and 10 respectively.

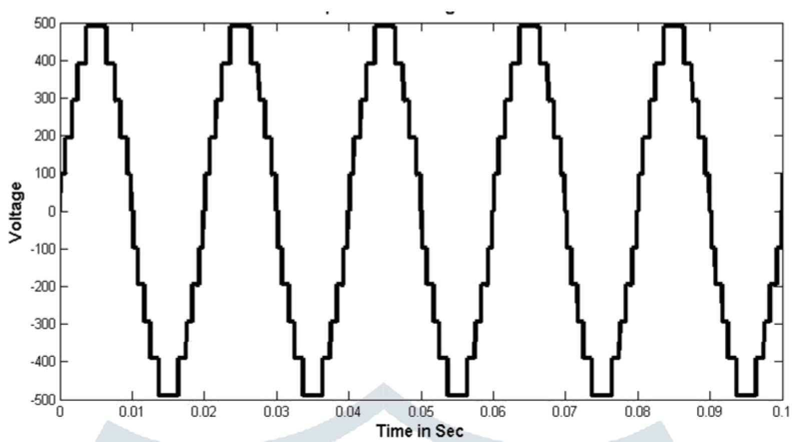


Figure.9 Output Phase Voltage (M=1)

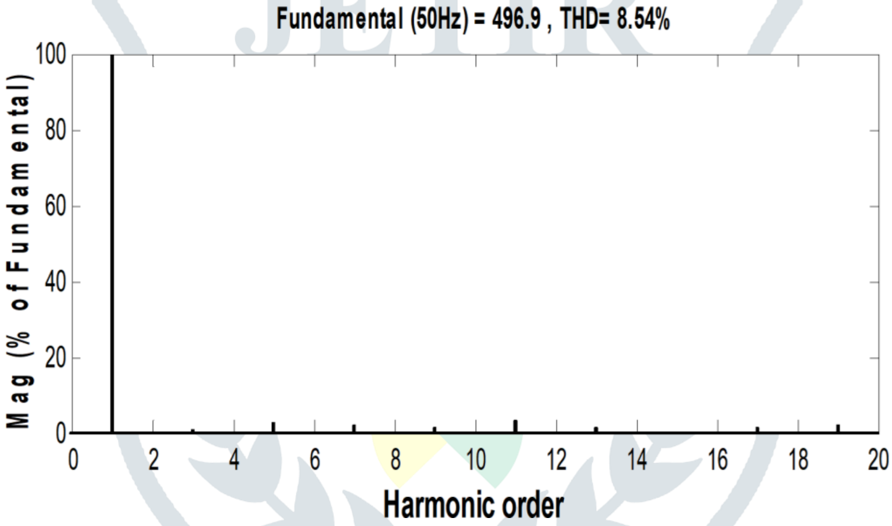


Figure.10 FFT Plot for Phase Voltage (M=1)

From the FFT plot of the phase voltage, it is observed that the 5th, 7th, 11th, 13th order harmonics are effectively minimized. THD is 8.54%.

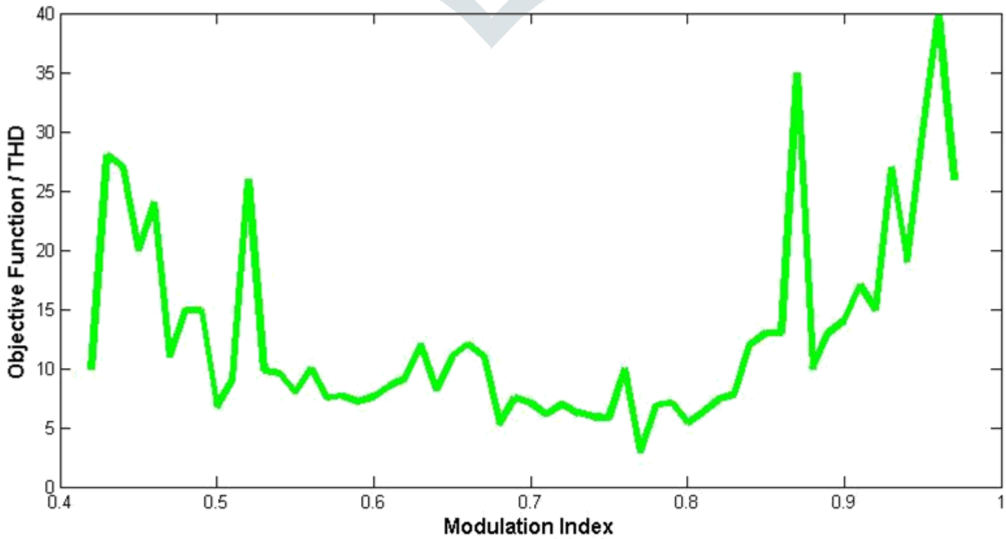


Figure.11 Modulation index (M) Vs Total Harmonic Distortion (THD)

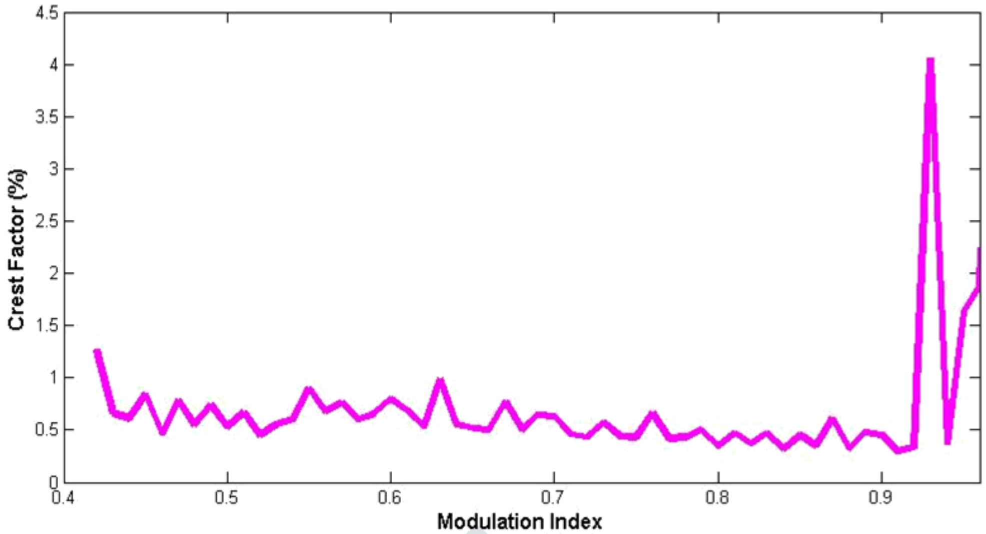


Figure.12 Modulation index (M) Vs Crest Factor

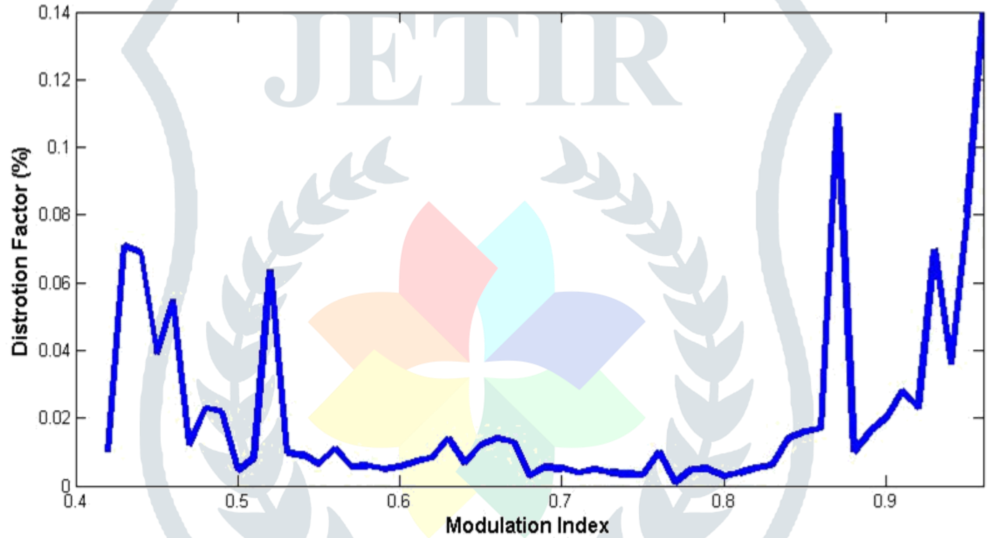


Figure.13 Modulation Index vs Distortion Factor

CONCLUSION:

The problem of harmonic elimination in PWM inverter is drafted as an optimization task and the same is solved using Bacterial Foraging Algorithm and the results are presented in this paper. From the results, it is observed that Bacterial Foraging Algorithm works efficiently well for output voltage regulation together with harmonic elimination. MLI structures have been developed to overcome shortcomings in solid-state switching device ratings, so that they can be applied to high voltage electrical systems. The proposed algorithm completely eliminates desired harmonics together voltage regulation.

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