International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 04 | April - 2023 Impact Factor: 8.176 ISSN: 2582-3930

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

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ABSTRACT-The reduction of harmonics in an 11-level cascaded H-bridge Multi Level Inverter (MLI) by applying the Bacterial Foraging Optimization Algorithm (BFOA) is reported in this study. The removal of lower order harmonics while maintaining satisfaction of fundamental component needs is the primary goal of the selective harmonic elimination pulse width modulation technique. The rod-shaped bacteria Escherichia coli, which belongs to the genus, is responsible for the collective foraging activity that drives BFOA. The fundamental biology that underpins Escherichia coli's approach to foraging is reproduced in a remarkable way and utilised as the basis for a straightforward optimisation technique. This approach possesses a greater degree of accuracy as well as a chance of convergence. In the MATLAB/SIMULINK program, the Bacterial Foraging optimisation technique is utilised for the purpose of optimising the switching angle of the Cascaded Multi Level inverter (CMLI). Simulations of an 11-level H-bridge inverter are used to validate the findings of theoretical calculations. The results of the simulation show that the proposed approach is effective in removing a large number of particular harmonics, and as a consequence, the output voltage achieves a low level of total harmonic distortion..

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

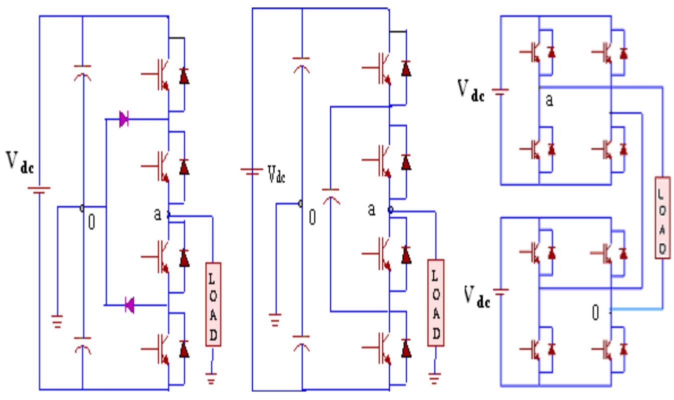
INTRODUCTION:

Electrical energy is an extremely valuable good, and several market studies show that the demand for electrical energy is consistently expanding at an exponential rate. Because there is not enough electrical energy available, there is an acute need for continuous improvements on the efficiency aspect in each and every one of the industrial and consumer applications [1]. The field of power electronics makes use of inverters, and several studies are now being conducted in an effort to improve output voltage while reducing total harmonic distortion [2]. Multilevel Voltage-Source Inverters (VSI) are an ideal architecture for achieving high power ratings and high quality output waveforms with minimal harmonic distortion in addition to adequate dynamic responses [3]. This may be accomplished through the use of a multilevel voltage source inverter. The cascaded multilevel inverter has established itself as a distinctive consideration among the many multilevel converter architectures due to its modularity and simplicity of control [4-6]. Sinusoidal Pulse Width Modulation (SPWM) and Space-Vector Pulse Width Modulation are two of the most popular types of modulation techniques that are used in multilevel converters with equal DC voltages [7,8]. These modulation techniques are chosen because they allow for regulated output voltage and minimised undesirable harmonics. The Selective Harmonic reduction (SHE) technique is yet another approach that has been suggested for the reduction of harmonics [9].

In [10], a method called the Genetic Algorithm (GA) is used to eliminate harmonics in multilevel converters that have equal DC sources. However, a large amount of processing time is required for this procedure. In [11], a method called Particle Swarm Optimization is broken down and analyzed in terms of its role in the harmonic removal of multilevel converters. In this study, a Bacterial Foraging Optimization method was utilised in order to assess the efficacy of the suggested algorithm by evaluating the harmonic optimization for 11 level converters that had equal DC sources. The results showed that the proposed algorithm was effective. When compared with previous iterative approaches, the computing time required to discover the best solution using the Bacterial Foraging Optimization Algorithm (BFOA) that was developed [12] is significantly less. The eleven level inverter is built using simulink blocks and is gated by BFOA switching angles that are optimised. Both the results and their analysis are published here.

MULTILEVEL INVERTERS:

In high power and medium voltage situations, multilevel inverters have been implemented as an alternative. A multilayer inverter not only improves the overall system performance in terms of harmonics, dv/dt strains, and motor bearing stresses, but it can also achieve large power ratings. Diode clamped, flying capacitor, and cascaded or H-bridge are only some of the multilevel converter topologies that have been devised. Because of how the device voltage stresses are constrained in the multilayer structure, MLIs can easily create high-power, high-voltage output. Increasing the inverter's voltage levels is one way to boost the power output without upgrading any of the connected devices. Multilevel VSIs are unique in that they don't require transformers or synchronized series-connected switching devices to generate high voltages with little harmonics. With more voltage levels, the output voltage's harmonic content decreases noticeably [13]. In this study, an eleven-stage, single-phase, cascaded inverter is simulated using several DC sources.



(a) (b) (c)

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

CASCADED MULTILEVEL INVERTER:

Power circuit of N individual single-phase inverters in a cascaded multilayer inverter is shown in Figure 2. These inverters use a full-bridge topology and provide independent DC inputs. Fuel cells, solar cells, and batteries can all be linked in series to provide the sources. By connecting the DC supply to the AC load through varying combinations of the four switches, each complete bridge inverter unit may provide three distinct levels of output: +VDC, 0VDC, and -VDC.

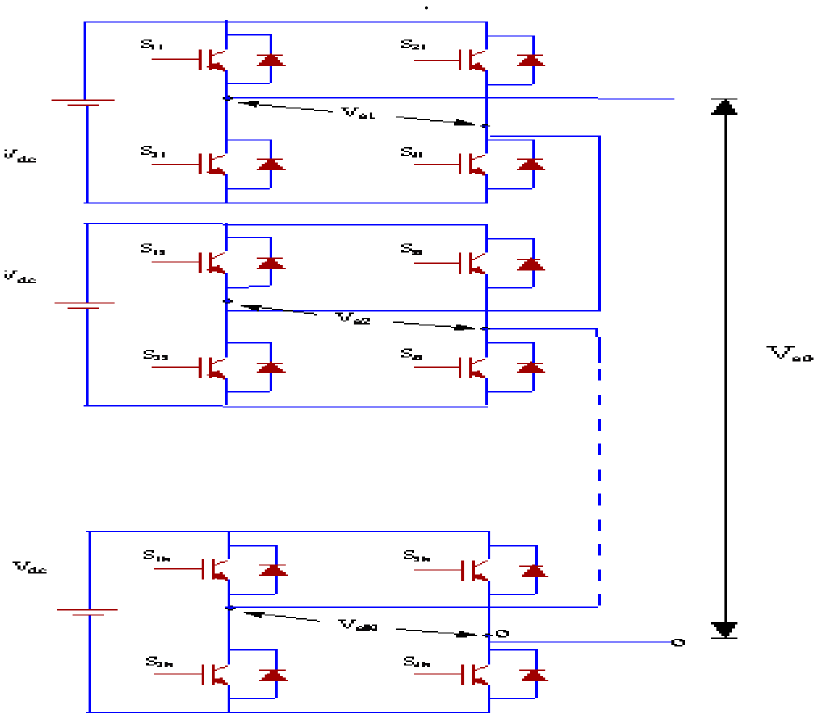


Figure.2 Cascaded Multilevel Inverter.

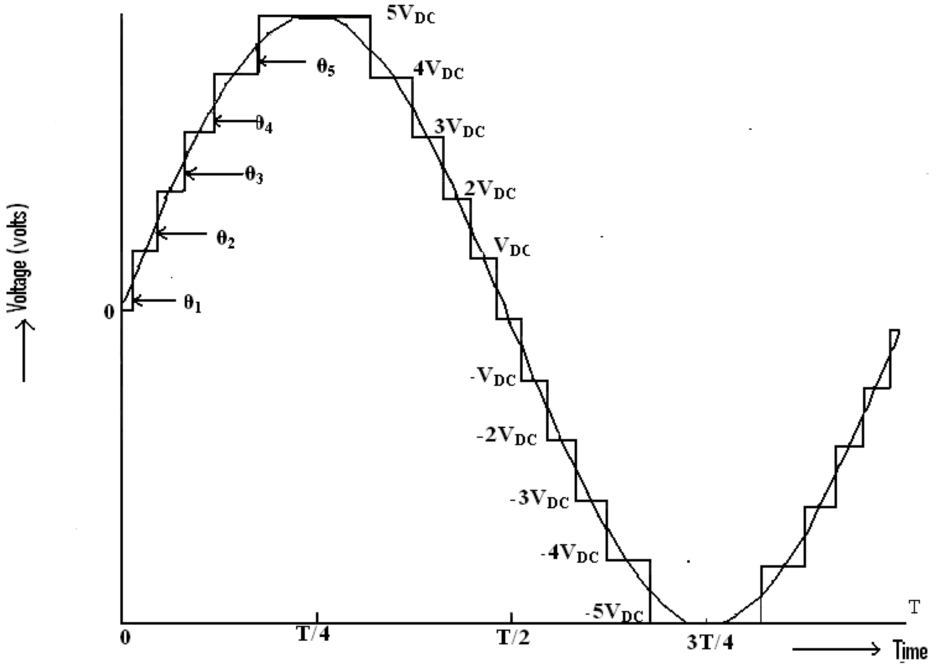


Figure.3 The output of a 11 level Cascaded Multilevel Inverter

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 includingthe zero levels also. Switching angles to eliminate 5th, 7th, 11th 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

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

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

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

Which gives the instantaneous output voltage V_{ao} as

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

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 $V_{a0\,(peak)}$ mustequal to the carrier peak voltage $V_{cr\,(peak)}$, $V_{cr\,(peak)} = (m-1)\,V_{DC}$.

Thus the modulation index M is

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

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 choosethe switching angles $0 \le \theta_1 < \theta_2 < \ldots < \theta_N \le \pi/2$ to make the first harmonic equal to the desired fundamental voltage V_1 (RMS) and specific higher harmonics of $V_{a0}(\omega t)$ equal to zero. The switching angles $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5$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, thefollowing 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 $\theta_1, \theta_2, \theta_3, \theta_4$ 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 minimizationusing 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 transcendentalequation 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 DCsources 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 aneleven 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 swarmingbehavior) 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 Δ_m (i),m=1,2….p, aRandom number on [-1,1].

[e] Move: Let θ^i (j+1,k,l) = θ^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) andlet θ^i (j+1,k,l) = θ^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 thebacteria is not over.

Step 6: Reproduction:

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

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

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 copiesthat 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

Bacterial foraging algorithm (BFOA) approach is used to solve the non-linear transcendental equation taking into account the equality of the DC sources. Globally optimal switching angles for the 11-level cascaded inverter are calculated by the BFOA method, which is written on the MATLAB platform. An FFT analysis is performed on the phase voltage at the output.

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.Two Hundred Bacteria. Iterations equal 100.
If a good solution is found or a maximum number of generations is reached, then the process will continue. The method is terminated in this study using the maximum number of iterations criteria. If the DC-side voltage is altered, the switching pattern must be recalculated or significant harmonic distortion will be introduced to the output voltage waveform..

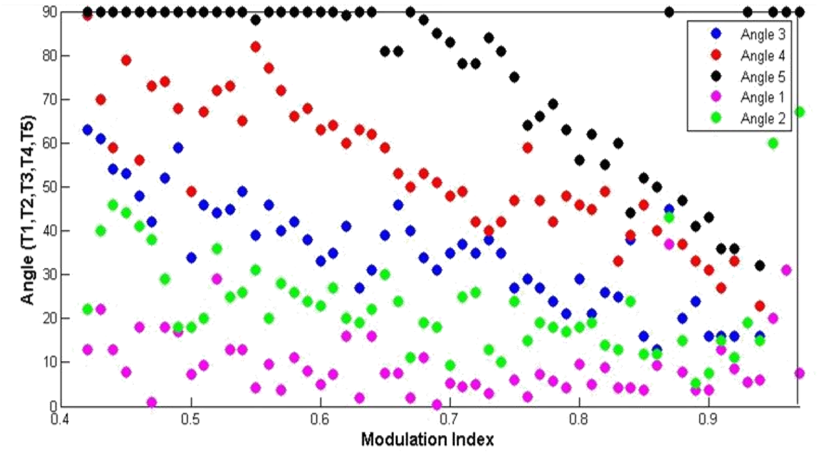


Figure.4 Modulation index (M) Vs Switching Angles

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.

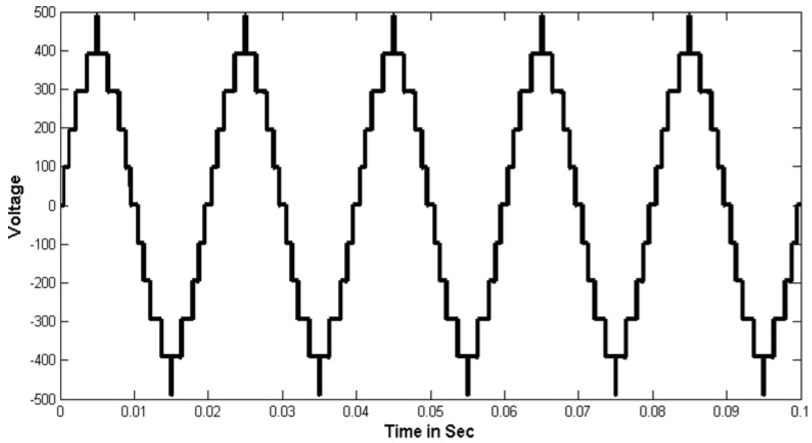


Figure.5 Output Phase Voltage (M=0.6)

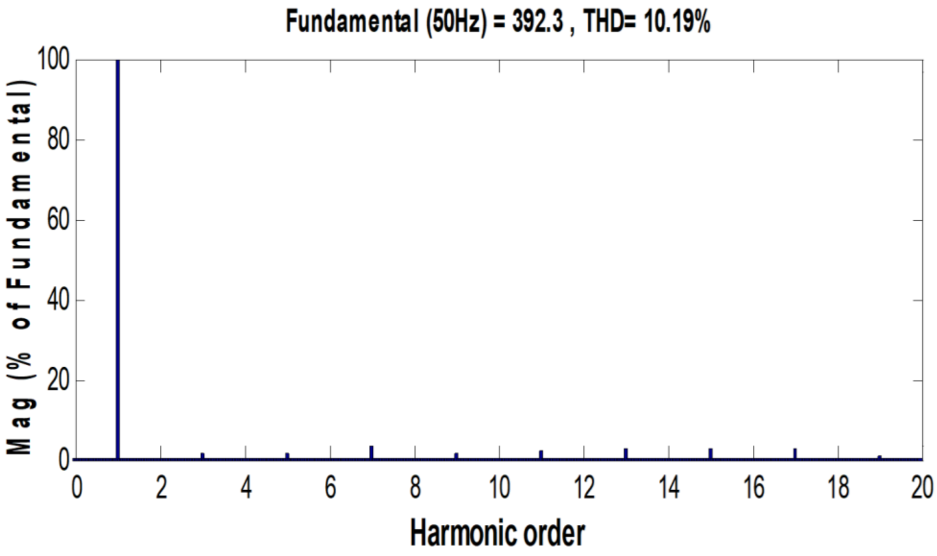


Figure.6 FFT Analysis for phase voltage (M=0.6)

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 areshown in Figure.7 and Figure.8 respectively.

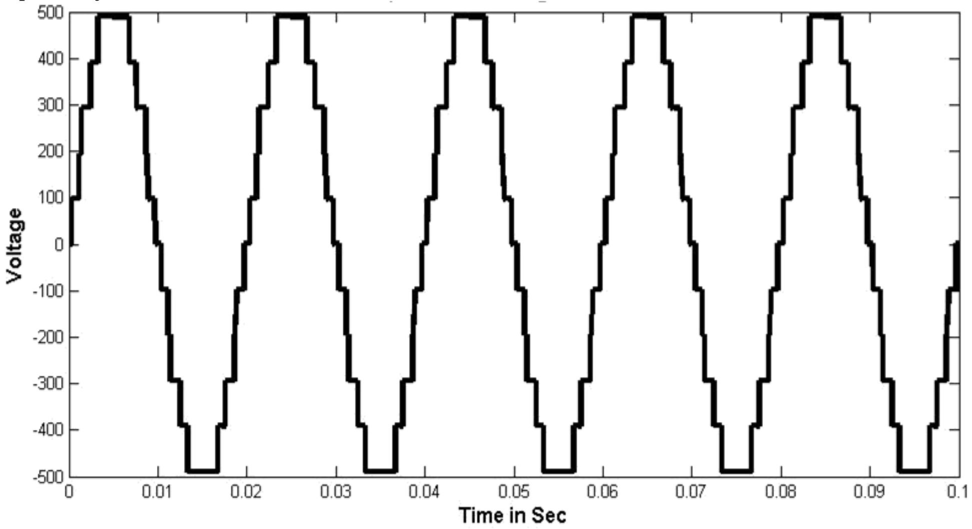


Figure.7 Output Phase Voltage (M=0.8)

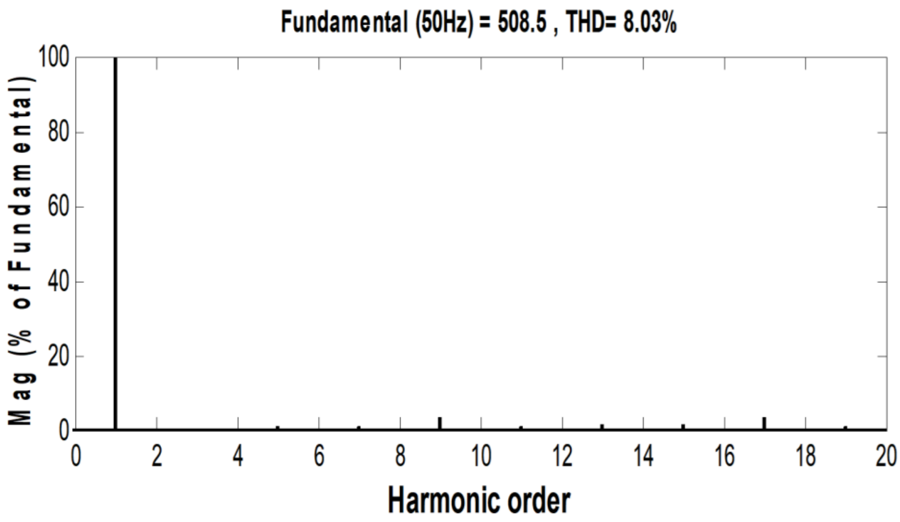


Figure.8 FFT Plot for Phase Voltage (M=0.8)

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 areshown in Figure.9 and 10 respectively.

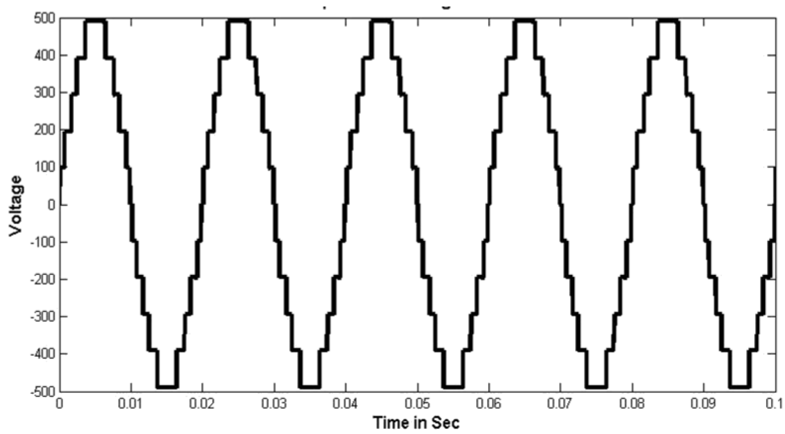


Figure.9 Output Phase Voltage (M=1)

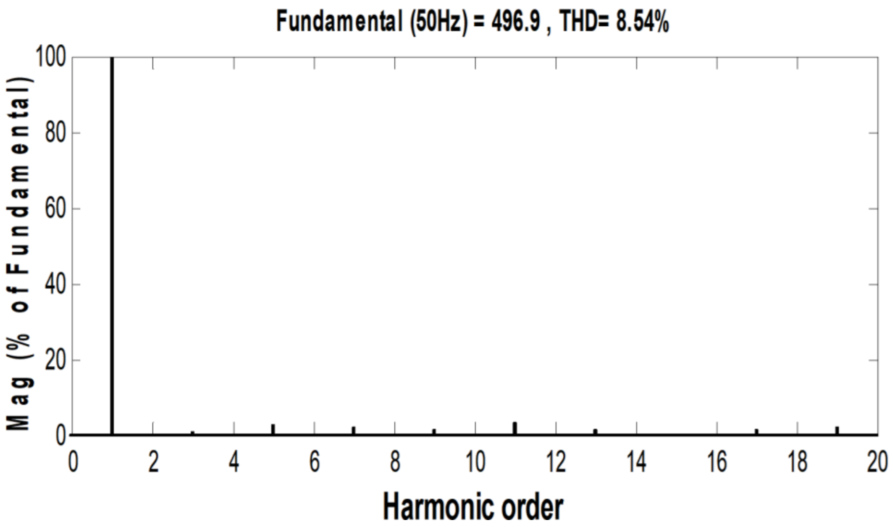


Figure.10 FFT Plot for Phase Voltage (M=1)

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%.

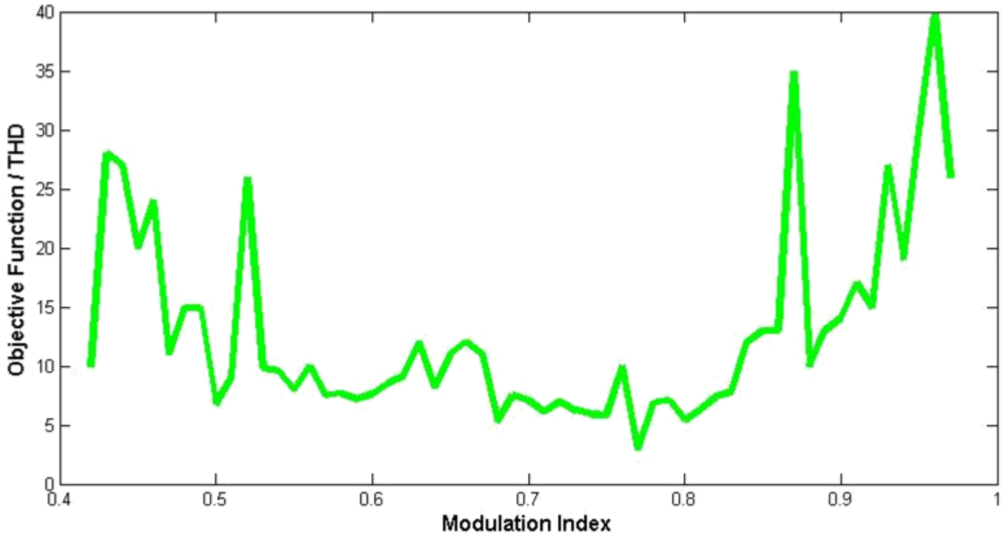


Figure.11 Modulation index (M) Vs Total Harmonic Distortion (THD)

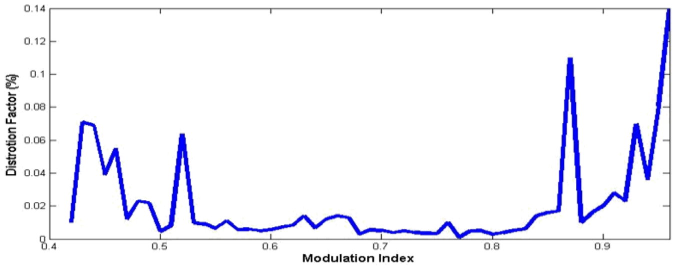


Figure.12 Modulation index (M) Vs Crest Factor

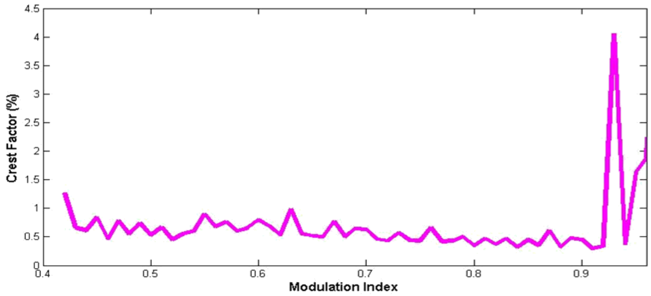


Figure.13 Modulation Index vs Distortion Factor

CONCLUSION:

In this research, we formulate the problem of harmonic removal in PWM inverter as an optimization assignment and show how it may be addressed with the help of the Bacterial Foraging Algorithm. The outcomes show that the Bacterial Foraging Algorithm is effective at regulating output voltage while also eliminating harmonics. For use in high-voltage electrical systems, MLI structures were created to compensate for the limitations of solid-state switching device ratings. The suggested method for voltage management and harmonic suppression removes all desirable harmonics..

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