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Enhancing Multilevel Inverter Performance: A Novel Dung Beetle Optimizer-based Selective Harmonic Elimination Approach

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***Abstract*—This paper introduces a novel approach for enhancing the performance of multilevel inverters by applying a dung beetle optimizer (DBO)-based Selective Harmonic Elimination (SHE) technique. Focusing on a 3-phase multilevel inverter (MLI) with a non-H-bridge structure, the proposed method offers advantages such as cost-effective hardware implementation and eliminating the traditional H-bridge inverter requirement. To assess its efficacy, we compare the presented DBO-based SHE technique (DBOSHE) with Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), evaluating their ability to determine optimal switching angles for achieving low-distorted load voltage. Unlike methods reliant on time-consuming calculations or fixed solutions, DBO provides a flexible approach, considering multiple possibilities to yield accurate switching angles. Using Simulink, harmonic component values and Total Harmonic Distortion (THD) are obtained for each optimization technique, specifically emphasizing on 9-level and 11-level MLI topologies. Our study aims to identify the most effective optimization technique for achieving lower THD and THDe values while eliminating odd-order harmonics from the 3-phase load voltage. Finally, we demonstrate the effectiveness of employing DBO for THD and THDe optimization within the SHE technique.**

Keywords*—Multilevel Inverter; Selective Harmonic Elimination; Dung Beetle Optimizer; Total Harmonic Distortion; Non-H-Bridge Topology.

I. INTRODUCTION

With the advancement of semiconductor technology, power electronics has witnessed remarkable progress in terms of efficiency, durability, and versatility. Power conversion equipment plays a pivotal role in obtaining the desired output voltage waveform from either DC or AC input sources. However, as power and voltage requirements escalate, so does the voltage stress on power switches, particularly in systems necessitating high power rates and voltage levels. In such instances, the stress gradually rises and ends making high-cost semiconductor switches impossible to be used in medium voltage levels. In order to tackle this hindrance, multilevel inverters (MLIs) have turned out to be the most sought-after solution for medium-voltage purposes [1]-[5].

Over four decades have elapsed since the concept of multilevel inverters was initially introduced. The introduction of the cascaded H-bridge multilevel inverter in 1975, which was the first of its kind [6]-[12], marked the inception of multilevel inverter technology. Subsequently, these findings were utilized to establish DCMLI and CCMLI [13]–[18]. The cascaded H-bridge topology is the most straightforward and efficient design when working with high voltages, making it superior than other instances.

The MLI has several advantages, including reduced total harmonic distortion (THD), undistorted input current, and reduced switch stress. Although the load voltage exhibits a nearly sinusoidal waveform, it is interesting to note that the total harmonic distortion (THD) decreases as the current increases. Although power devices in MLIs result in higher system costs, their benefits are of utmost importance. Although significant efforts have been made to develop efficient MLI hardware for minimizing power fluctuations, the elimination of THD (Total Harmonic Distortion) is the highest priority and requires our whole attention. Therefore, it is necessary to have a certified load voltage that efficiently decreases or eliminates low order harmonics (THD) [19]–[26].

MLI structures can be equipped with a variety of switching methods. For instance, let's examine space vector PWM [27]–[34]. This method does not permit direct control over the harmonic order, modulation index, or total harmonic distortion (THD). Precise control calculations and comprehensive look-up tables are also required. The Space Vector PWM technique adds complexity to the top-level switching process. In DCMLI and CCMLI topologies, which are the main applications of the Space Vector PWM approach, the output voltage level cannot be raised because of the issue of DC-link capacitor imbalance. Another alternative is the Secure Hash Algorithm (SHE). She has exceptional proficiency in removing the specific harmonic order and modulation index. The findings indicate a reduction in Total Harmonic Distortion (THD) and Weighted Total Harmonic Distortion (WTHD) levels within the range of [35]-[45].

Iterative or analytical approaches commonly used to solve SHE equations include Groebner Bases Theory and Symmetric Polynomials [46]-[50]. Nevertheless, problems related to divergence and initial values are quite likely to arise. Pages 51 to 64. The AI techniques have been used to solve the SHE equations in [21], [24]-[26]. PSO and GA were utilised and contrasted in [24]. Alternatively, you may utilise the Colonial Competitive Algorithm to solve harmonic equations with the objective of reducing low-order harmonics [25]. An technique for Symbolic Execution (SHE) that use Neural Networks was introduced in reference [26]. It may be inferred from [21]-[26] that the eliminated harmonic component is very close to zero, albeit not exactly zero.

Novelties of this paper are as follows:

- Dung Beetle Optimizer (DBO) is proposed to solve SHE equations for the first time in the literature. DBO is a new meta-heuristic algorithm [27]. The DBO algorithm has the qualities of a quick convergence rate and a reasonable solution accuracy since it considers both local and global exploration [27], [28].
- The proposed MLI structure has several advantages, including a reduced number of switches, low-cost hardware implementation, and no need for an H-bridge inverter like traditional MLI. This design provides a range of output levels between 9 and 15 by using different connecting ports and isolated DC sources.
- While previous literature has achieved 9-level voltage using four-level modules [2], [7], [12]-[14], [17], the proposed structure stands out for its single-circuit with four-level modules, which can generate voltage levels from 9 to 15.

In this paper, DBO calculates switching angles for DBOSHE with the advantage of faster convergence speed concerning GA and PSO. The new 1-phase bridgeless MLI structure proposed in [29] is modified for 3-phase systems as in Fig. 1. In this way, simulation results of DBOSHE, GASHE, and PSOSHE methods including THD, and low-order harmonics, have been compared with each other to demonstrate which optimization-based SHE technique is more effective for 3-phase systems. Finally, with the comparison of results, it is demonstrated that DBO-based SHE generates lower THD with a modulation index closer to desired at the output, and DBO finds the solution faster and with a better fitness value than PSO and GA.

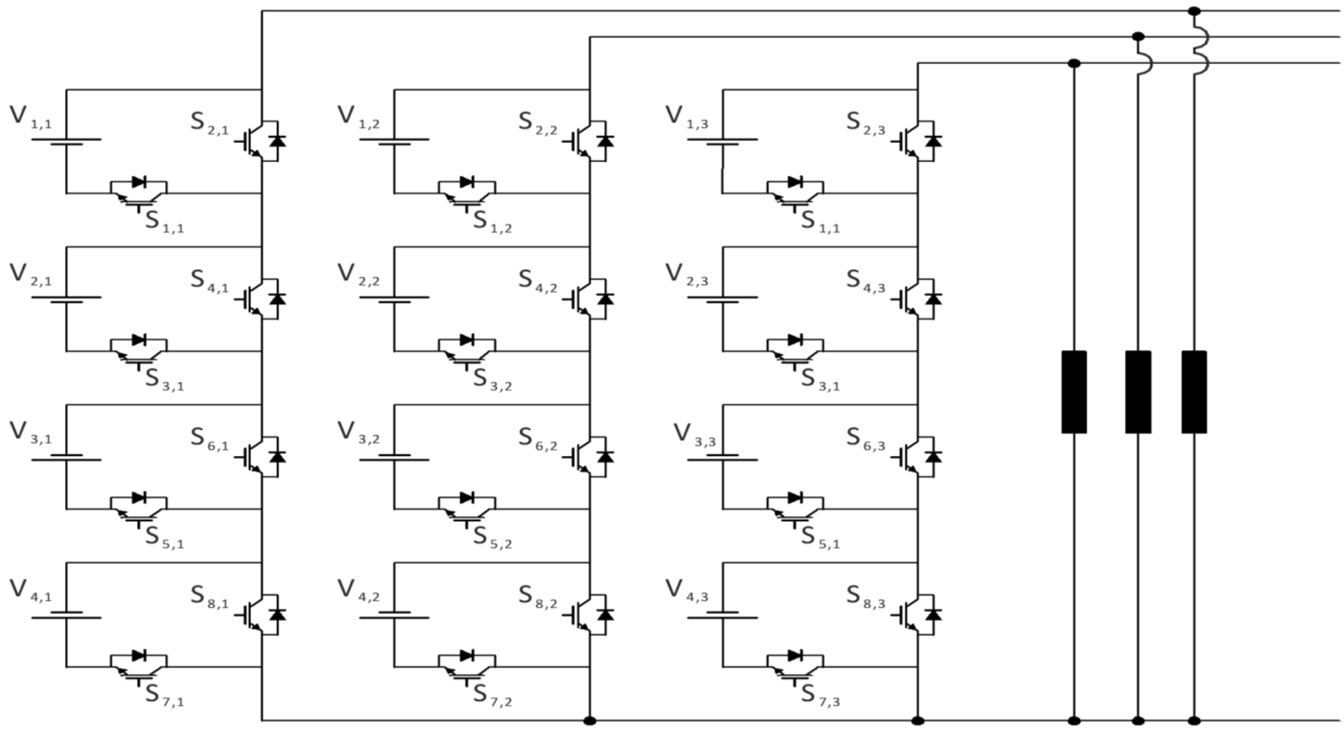


Fig. 1. Structure of proposed 3-phase bridgeless MLI [29]

II. SELECTIVE HARMONIC ELIMINATION

By resolving nonlinear equations generated from the Fourier expansion of the load voltage, the SHE method generates the switching angles not to minimize some harmonic components, particularly low-order harmonics [2]. These equations differ with the number of eliminated harmonics. Moreover, requires different solutions depending on each modulation index and the order of harmonics to be eliminated.

In (1) and (2), the Fourier expansion of load voltage per phase and first-order harmonic, in that fundamental waveform, are given for (2k+1)-level MLI. In addition, Fig. 2 illustrates the generalized (2k+1)-level output/load voltage.

$$V_L(\omega t) = \sum_{n=1}^{\infty} \frac{4kV_{DC}}{\pi n} (cos(n\alpha_1) + cos(n\alpha_2) + \cdots + cos(n\alpha_k)) \, sin(\omega t), n\ odd) \quad (1)$$

$$V_1(\omega t) \; \frac{4kV_{DC}}{\pi} (cos(\alpha_1) + \cdots cos(\alpha_k)) \, sin(\omega t) \quad (2)$$

where n is the order of harmonics. (1) is the general equation that can be derived for the desired harmonics order. The (2k+1)-level inverter's harmonic equations are included in the generalized mathematical representation of the SHE equations. In addition, the first harmonic must be included, and determines the modulation index to control the amplitude of the fundamental waveform. The modulation index is given as follows;

$$M = |V_{\ 1}|/(kV_{DC}) \quad (3)$$

This enables the creation of SHE equations and the removal of the k-1 harmonic. The absence of third, ninth, and fifteenth order harmonics in the load voltage of three phases, as well as the absence of six thousand and thirty-third order harmonics, is widely recognized. The reduction of harmonics in three-phase systems leads to a decrease in the total harmonic distortion (THD) of the load/output voltage. For instance, a three-phase system can be enhanced by employing a nine-level inverter to eliminate specific harmonics, namely the fifth, seventh, and eleventh. The inclusion of the harmonic order in the line voltage does not occur until the 13th harmonic, which happens at a frequency of 650 Hz for a 50 Hz load voltage.

To apply SHE equations to any optimization algorithm, these equations need to be formulated to resemble nonlinearly constrained optimization problems with objective and constraint functions. The simplification of SHE equations involves excluding certain constants, such as k, VDC, and π, from (2). For a 9-level inverter, nonlinear SHE equations are presented in (4) as follows:

$$\begin{gathered} cos(\alpha_1) + cos(\alpha_2) + cos(\alpha_3) + cos(\alpha_4) = M\pi \\ cos(5\alpha_1) + cos(5\alpha_2) + cos(5\alpha_3) + cos(5\alpha_4) = 0 \\ cos(7\alpha_1) + cos(7\alpha_2) + cos(7\alpha_3) + cos(7\alpha_4) = 0 \\ cos(11\alpha_1) + cos(11\alpha_2) + cos(11\alpha_3) + cos(11\alpha_4) = 0 \end{gathered} \quad (4)$$

The eliminated low-order harmonic components, as specified in (4), are defined as constraints within the context of the optimization algorithm. Other constraints encompass the magnitude relationship of the switching angles, as outlined in (5). In the SHE technique, the constraints encompass both (4) and (5).

$$0 < \alpha_1 < \ \alpha_2 < \alpha_3 < \alpha_4 \quad (5)$$

The equation for calculating THD is vital for the optimization algorithm's fitness function and is given in (6). The THD value is computed up to the 49th-order harmonics, and any other harmonic orders with an index of 51 or above are disregarded meeting IEEE-519 harmonic standard.

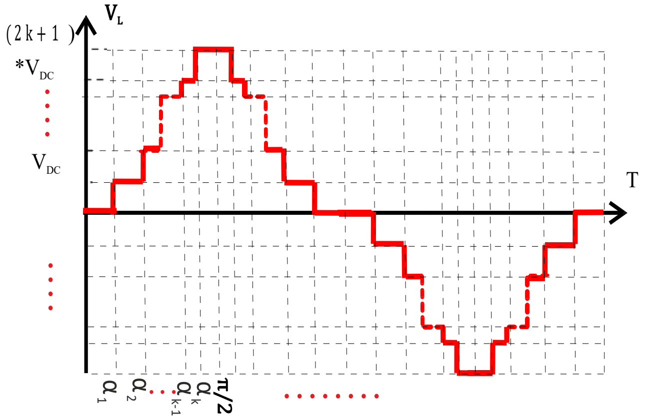


Fig. 2. Output/load voltage per phase of (2k+1)-level MLI

Section 4 explains this in more detail. In this paper, we have modified the fitness function of the Optimization-based SHE method for 9-level phase voltage as specified in (7). Fitness function (FF) must differ due to respective objectives. In the Optimization-based SHE method, the fitness function includes the calculation of THD for 5th, 7th, and 11th eliminated harmonics. In addition, the THDe value considers harmonics up to 11th harmonics for 3-phase load voltage. FF is derived from THDe and given in (8). The 3-phase system's 3rd and 9th harmonics are not taken into account in the calculations considering both are zero [2].

$$THD = \frac{\sqrt{V_3{}^2 + V_5{}^2 + V_7{}^2 + \ldots\ldots + V_{49}{}^2}}{|V_1|} \quad (6)$$

$$THD_e = \frac{\sqrt{V_3{}^2 + V_5{}^2 + V_7{}^2 + \ldots\ldots + V_{11}{}^2}}{|V_1|} \quad (7)$$

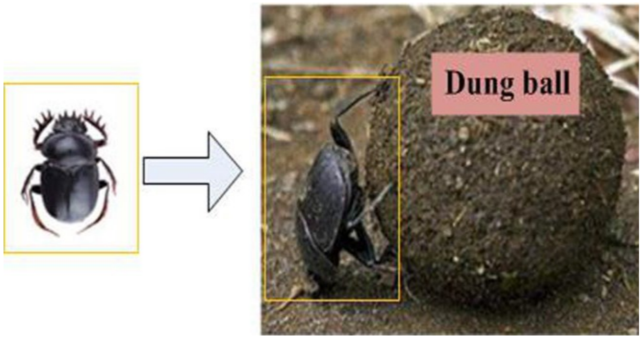
$$FF = \frac{\sqrt{\sum_{n=5,7,11}^{11} \left[\frac{1}{n} \sum_{k=1}^{4} (\cos(n\alpha_k))\right]^2}}{|\sum_{k=1}^{4} [\cos(\alpha_k)]|} \quad (8)$$

III. DETAIS OF DBO, GA, AND PSO

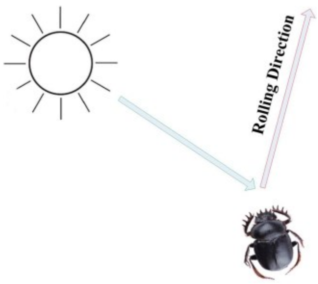
In this Section, details of proposed optimization algorithms are presented. A thorough explanation of the DBO algorithm's structure is provided. Particular attention is on the DBO method because it is an emerging optimization algorithm adapted to the SHE technique. Furthermore, the GA and PSO structure and steps are clarified.

A. DBO

The rolling, dancing, breeding, foraging, and stealing actions of dung beetles in their natural environment serve as a basis for the dung beetle optimization method. In the first step, to replicate the rolling motion of a ball, dung beetles must go in a specific direction across the whole search area as stated in Fig. 3 [27]. The dung beetle may follow the direction of the moon or sun by rolling the dung ball backward, causing it to travel straight forward [28]. Given the assumption that the dung beetle's travel path will be influenced by the light source's intensity, the location update of the insect within the search space can be represented as follows.



(a)



(b)

Fig. 3. The behavior of dung beetle a) Rolling and b) Direction [27]

In (9) and (10), t is the number of iterations, $x_i(t)$ is the location of the dung beetle in the iteration i, k is deflection parameter, The natural parameter α has a value of either -1 or 1. X^w corresponds worst position, Δx is variation in the light intensity [27]. Dung beetles will dance to the top of the dung ball to reposition themselves and find a new path when they come across an obstruction that prevents them from moving as stated in Fig. 4. After figuring out its new orientation, the dung beetle is assumed to keep rolling the ball backward.

$$x_i(t+1) = x_i(t) + \alpha * k * x_i(t-1) + b * \Delta x \tag{9}$$

$$\Delta x = |x_i(t) - X^w| \tag{10}$$

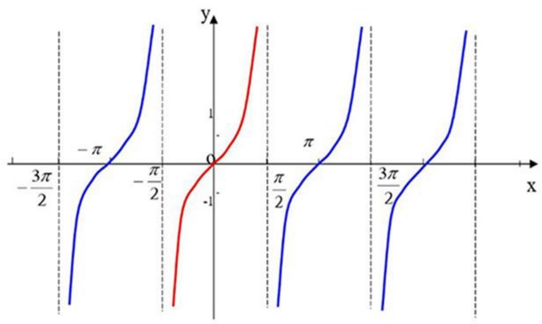
The female dung beetle will lay eggs in the dung ball after moving it to a secure area and hiding it. For dung beetles, selecting a good location to lay eggs is crucial. (11) and (12) are given for the definition of the region boundary selection approach used to mimic the spawning of dung beetles:

$$L_b^* = \max\left(X^* * (1-R), L_b\right) \tag{11}$$

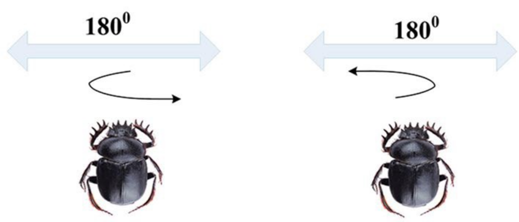
$$U_b^* = \max\left(X^* * (1+R), U_b\right) \tag{12}$$

where, X^* matches the ideal local position, L_b^* and U_b^* are the spawning area's lowest and upper bounds.

The female dung beetle will select the egg balls in this region for laying her eggs when the spawning area has been identified. Each female dung beetle only lays a single egg during each iteration of the DBO method. Then, location information of each egg in each iteration are determined.



(a)



(b)

Fig. 4. Finding new path, a) Model of path function and b) Dancing behavior [27]

During their quest for sustenance, a handful of mature tiny dung beetles will emerge from the soil and indicate ideal feeding locations. The ideal range for searching for food is determined. The stance of the little dung beetle has also been altered. Some dung beetles are referred to as "stealing dung beetles" due of their tendency to appropriate dung balls from other beetles. The location where the theft occurs is regarded as the optimal area for the DBO algorithm to search for targets. On each occurrence, the brood ball, the thief, the young dung beetle, and the ball-rolling dung beetle invariably wind up in separate locations. The population of the optimization algorithm consists of the four criteria that were previously described. The DBO strategy is aimed to provide significant accessibility by utilizing data from many periods to completely explore the search space and prevent becoming stuck at a local optimum [27], [28]. Fig. 5 depicts the DBO flowchart, illustrating the sequential updating of the population and optimal solution.

B. GA

One of the most notable artificial intelligence approaches in literature is the Genetic Algorithm, used for solving optimization problems (as referenced in [2], [24]). It's crucial to note that no artificial approaches can make harmonics equal to zero, but optimization methods reduce harmonic components to almost zero.

Inspired by the concepts of natural selection and genetics, the GA is a heuristic global evolutionary optimization algorithm. This algorithm was first created by John Holland at the beginning of the 1970s. GA uses biological evolution concepts to optimize a range of operations. One of the main differences between GA and other optimization methods is that GA uses a population-based strategy to explore the solution space instead of concentrating on single-point searches. It has been demonstrated that genetic algorithms work well for both constrained and unconstrained optimization problems.

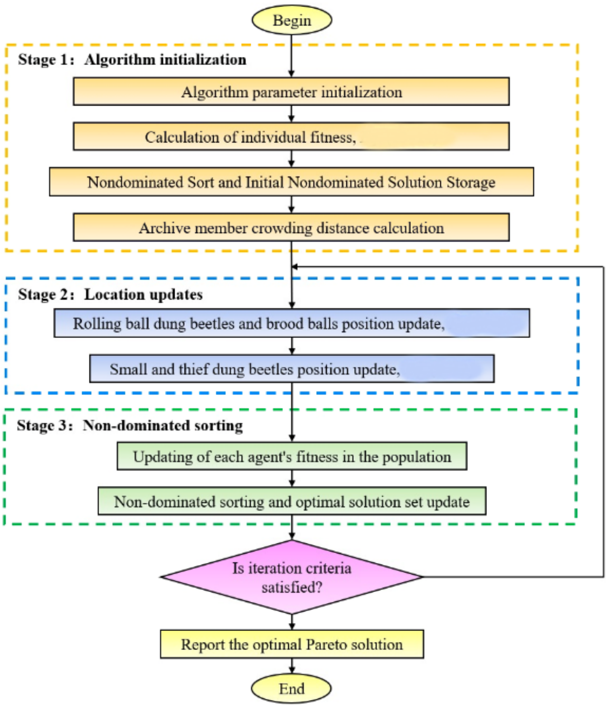


Fig. 5. Flowchart of DBO algorithm [28]

Since it doesn't involve complicated mathematical derivations or models, GA is noted for its simplicity and ease of application. As such, it is easily applicable to problems such as selective harmonic elimination [1], [30], [31].

Four basic steps are usually involved in the optimization procedure of a genetic algorithm. The optimization process is started with defining the initial population. And, the fitness function is calculated for each population. Subsequently, the selection step occurs. In this step, the penalty function is used to specify effective chromosomes in the next iteration, in that generation. With crossover and mutation, new genes are produced for the next iteration. Thereby, a new population is generated with the crossover and mutation process of selected chromosomes. The described technique is continued during each iteration until the optimized objective function falls below the intended value or the number of iterations reaches its limit. Thus, with a selection step equal to the number of repetitions, the most optimized solution is chosen from the newly generated population including the chosen effective chromosomes.

C. PSO

PSO is a metaheuristic optimization algorithm that uses a cooperative set of particles (often representing possible solutions) to move closer to optimizing an objective. PSO optimizes complicated problems by using a population-based methodology. To optimize an objective, the algorithm models the progress of feasible options throughout a search space. The main five steps can be summarized as follows;

- Throughout the solution space, a starting population of particles is produced. Each individual particle is a possible solution for the search optimization problem.
- Each individual particle is assessed according to its current position concerning the objective function, which quantifies the fitness or quality of a solution. The performance of every individual particle with the optimization target is measured in the Second step.
- Every particle keeps up with the greatest position and fitness value it has found to this point. The particle improves its personal best if the current position beats its previous best. The fitness values of every particle in the cluster are used to determine which particle is the best. The exact position of this particle is known as the best global.
- Based on their current velocities, personal bests, and global bests, the particles modify their velocities. The way the particles travel in the solution space is determined by their velocities. The locations of the particles are likewise modified once the velocities are updated.
- The algorithm ends if the number of iterations at Step 4 matches the maximum number. If not, the described process is continued with Step 2 [30 -35].

IV. SIMULATION RESULTS

This study uses a bridgeless 3-phase multilevel inverter to implement optimization-based SHE techniques: DBO, GA, and PSO. The simulations have been conducted using the Simulink/MATLAB software platform (Fig. 6 to Fig. 9). In the developed simulations, each voltage level corresponds to 100 V, maintaining consistency between the first and third modules. Additionally, the second and fourth modules are configured with a voltage level of 300 V. Fig. 1 shows the necessary DC input voltage configuration structure.

Output voltages for each optimization-based SHE technique are obtained at a frequency of 50 Hz in a 3-phase configuration, and subsequent comparisons are made concerning Total Harmonic Distortion (THD), THDe values, and low-order harmonics. Each technique is meticulously fine-tuned to achieve the lowest possible THD value with eliminated 5th, 7th, and 11th eliminated harmonics.

In this study, each proposed optimization algorithm is applied to obtain 0.3, 0.6, and 1 modulation index at load voltage given in Fig. 6. The larger areas on the graph make it simple to examine the variations in angles computed in each modulation for all optimization methods. Fig. 7(a) to Fig. 7(f) show the FFT Analysis Tool Interface of Simulink for THD and THDe values separately at 1 modulation index. In addition, Table I and Table II illustrates to compare the effectiveness of the proposed DBOSHE technique.

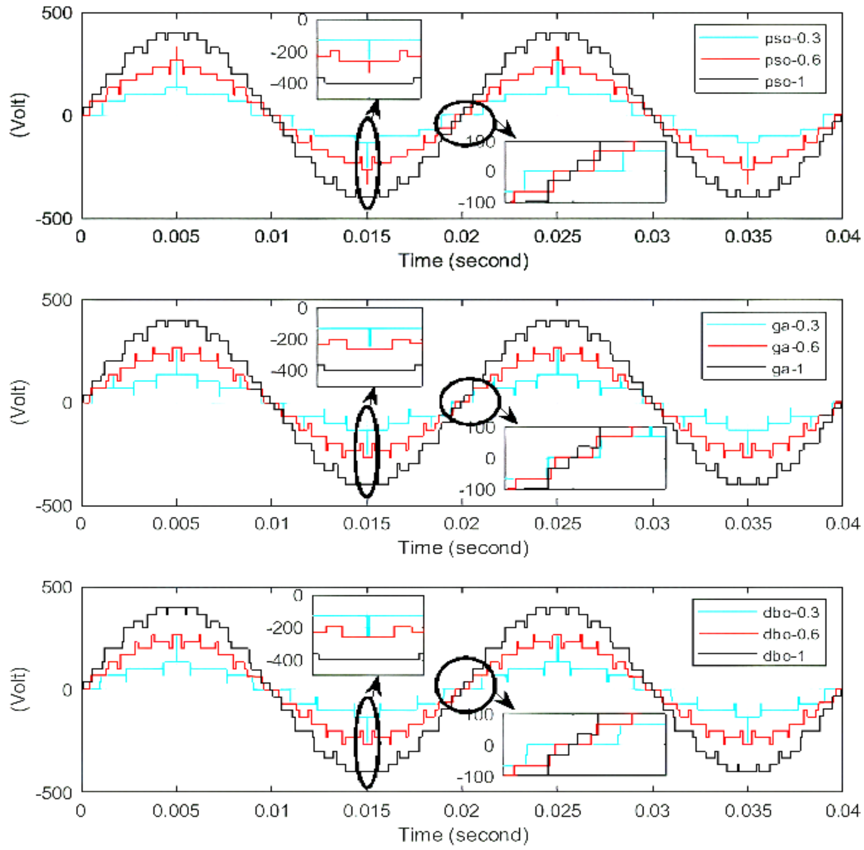


Fig. 6. Load voltages of 9-level inverter for all modulation and each technique

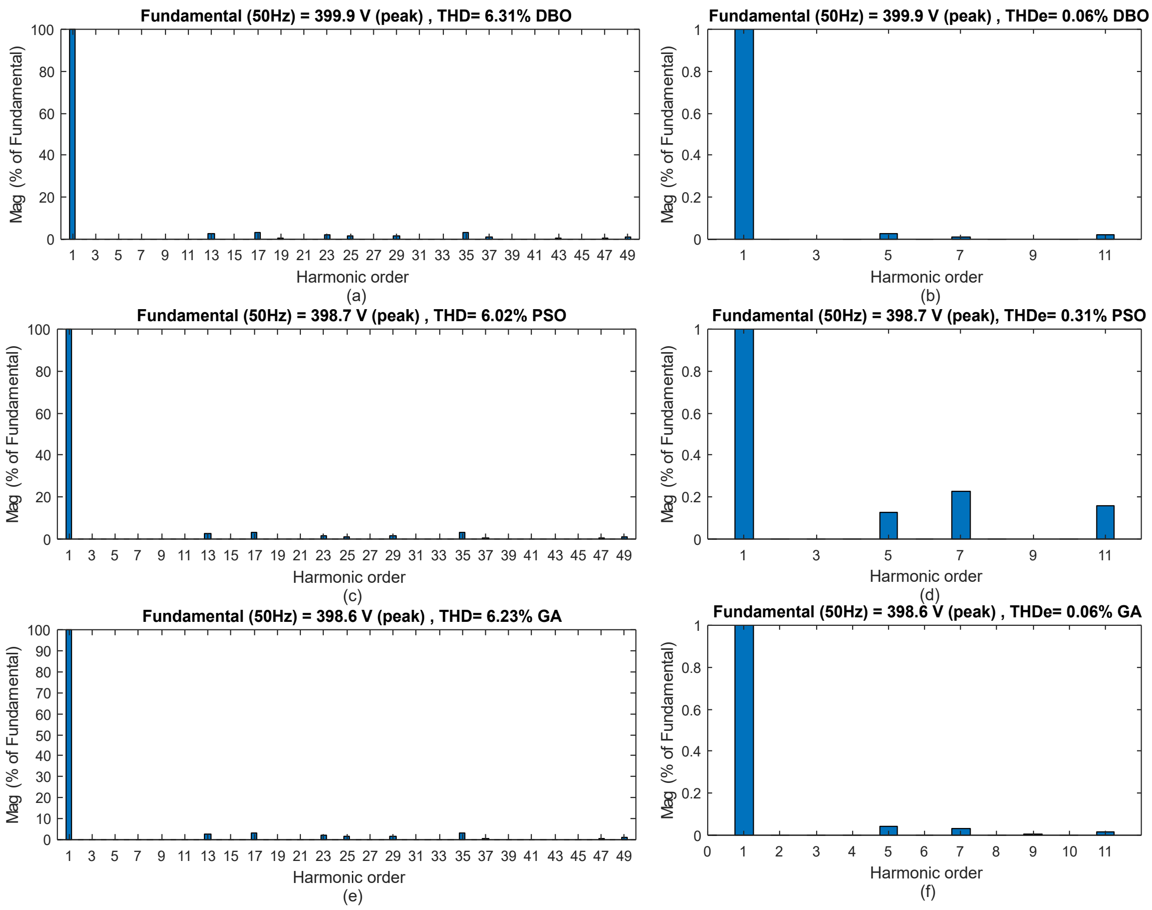


Fig. 7. FFT analysis tool for 1 modulation index with THD and THDe a-b) DBO c-d) PSO and e-f) GA

The main purpose of the SHE technique is to eliminate the desired harmonics at the desired modulation index. In Table I, V1 represents the first harmonic, that is, the desired load voltage at the output. Regarding the modulation-based SHE approach, the following general observation can be made: the utilized optimization method is less effective with the larger divergence in the desired load voltage. The estimated error value is then compared to identify the technique with the lowest error value.

Reducing the THD and THDe values by eliminating the desired harmonics is another SHE objective. Taking into account the two objectives stated, Table I can be interpreted. 5th, 7th, and 11th harmonics are lower for DBO at each modulation index. Thus, the THDe value is calculated in this manner and is expected to be lower when taking into account the optimization fitness function.

At 0.3 modulation index, a 0.42 error value is not effective for PSO. And, the THDe value is determined to be 14.75% even though the amplitude for the 5th harmonic obtained with PSO is more than three times that of the harmonic obtained with DBO. Based on the DBO algorithm, PSO did not work with this value of 13.23 for DBO. In the same way, GA and PSO obtained bigger THD values than DBO.

At 0.6 modulation index, the THDe value is superior for the DBO algorithm. However, THD is obtained as 8.81%. Even though PSO's THD value is somewhat effective, the modulation index error is significantly higher than DBO. On the other hand, GA generates higher values for THD, THDe, and error. GA is unsuccessful. DBO performed better; its error value is nearly zero, and lower THDe is obtained.

Especially, for both 0.3 modulation and 0.6 modulation index, GA is not an effective method to obtain the desired load voltage amplitude. Obtained modulation indexes, 0.29 and 0.35 are higher than DBO and PSO algorithms. For this reason, at suggested modulation indexes, GASHE method is not outstanding.

At 1 modulation index, the THDe value is obtained as 0.06% for the DBO algorithm with a 0.03 % an effective error value. PSO and GA obtain this value as 0.33 and 0.35 respectively. Eliminated harmonics are almost equal to zero and lower than that of PSO and GA. THD is obtained as 6.31%. DBO is still effective in SHE with effective error value and 5th, 7th, and 11th eliminated harmonics. Reducing the THDe value and the cost of the active filter to be used at the output concerns the objective function that is being carried out. Given that the THD values obtained using each of the proposed methods do not fall below 5%, an output filter design will be required to meet the IEEE-519 harmonics standard.

The algorithms' convergence curves for modulation indexes of 0.3, 0.6, and 1.0 can be seen in Fig. 8. The DBO algorithm is the one that finds the solution fastest and with the greatest fitness value.

It is clear from the comparisons that the DBO algorithm outperforms GA and PSO in the SHE method. The key components are obtaining less THDe, decreasing the variation in the required load voltage, and obtaining the harmonic components closer to zero. To reduce THD below 5% under the IEEE-519 harmonic standard, outstanding DBO algorithm is applied to 11-level inverter with the aim of 5th, 7th, 11th, and 13th harmonics. The calculated switching angles are 0.1282, 0.3346, 0.5015, 0.8153, 1.0981 rad. FFT analysis tool interface is given in Fig. 9 and qualities of load voltage can be seen in Table II. 5th, 7th, 11th, and 13th harmonics are calculated as almost equal to zero, same is seen in THDe value, and THD is lower than 5% in accordance with IEEE-519 harmonic standard. By this way, the DBO-based SHE technique obtains quality load voltage without the need of a low-pass filter at the output side of the 3-phase bridgeless multilevel inverter.

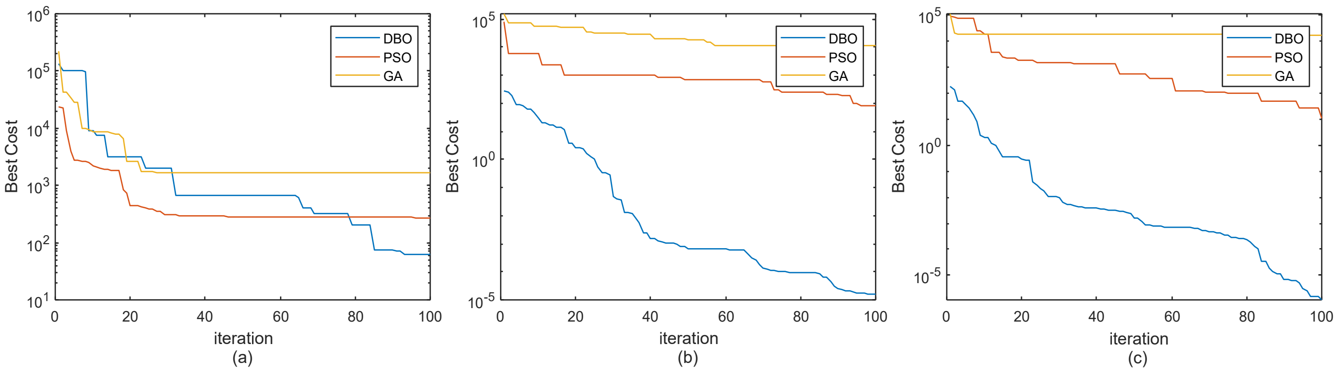


Fig. 8. DBO, PSO, and GA convergence curve a) 0.3 modulation b) 0.6 modulation and c) 1 modulation

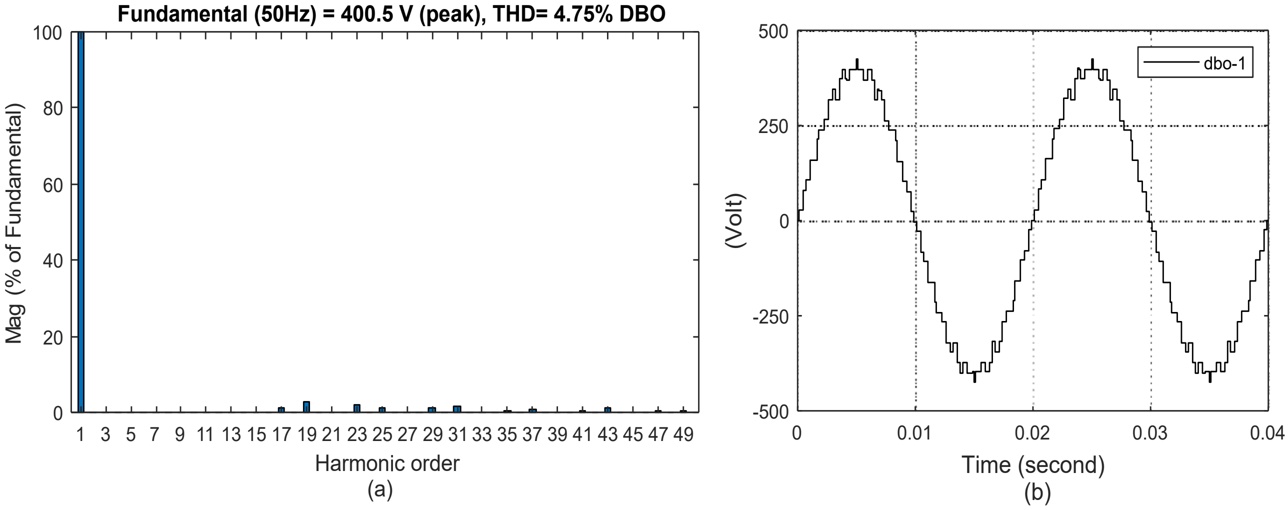


Fig. 9. DBOSHE for 11-level inverter at 1 modulation a) FFT analysis and b) Load voltage

TABLE I. 9-LEVEL LOAD VOLTAGE ANALYSIS FOR EACH ALGORITHM

Algorithm	Load voltage (Yn)					Harmonic details %				
	Modulation	V_{ref}	V_1	Error %		THD	THD_e	5th	7th	11th
DBO	0.3	120	119.8	0.17		16.75	13.23	0.58	8.02	10.51
	0.6	240	240.3	-0.13		8.81	0.05	0.02	0.03	0.01
	1	400	399.9	0.03		6.31	0.06	0.03	0.01	0.02
	0.3	120	120.5	-0.42		18.09	14,75	1.78	8.57	11.88
PSO	0.6	240	239.4	0.25		8.25	3.11	2.54	1.79	0.09
	1	400	398.7	0.33		6.02	0.31	0.13	0.23	0.16
	0.3	120	124.2	-3.5		18.64	14.84	13.63	3.83	4.42
GA	0.6	240	239.3	0.29		8.89	0.07	0.06	0.02	0.01
	1	400	398.6	0.35		6.23	0.06	0.04	0.03	0.01

TABLE II. 11-LEVEL LOAD VOLTAGE ANALYSIS FOR DBO ALGORITHM

Load voltage (Yn)					Harmonic details %					
Modulation	V_{ref}	V_1	Error %		THD	THD_e	5th	7th	11th	13th
1	400	400.5	-0.13		4.75	0.06	0.03	0.02	0.03	0.01

V. CONCLUSION

This study introduces and evaluates three distinct techniques for enhancing the performance of three-phase bridgeless multilevel inverters (MLIs): DBO-based Selective Harmonic Elimination (DBOSHE), PSO-based SHE (PSOSHE), and GA-based SHE (GASHE). Operating with each phase voltage level set at 100 V, the output demonstrates a 9-level stepped waveform for phase voltage and a 15-level waveform structure for line voltage, reflecting phase differences. The proposed bridgeless MLI configuration offers notable advantages, such as cost-effective hardware deployment and elimination of the need for an H-bridge inverter.

In contrast to traditional methods requiring a time-consuming calculation or limited options for the solution, DBO opens new avenues for a more ingenious and adjustable approach fit for the switching angles determination. Besides that, the DBOSHE tech for the 9-level inverter scheme has been found to give the most impact. It provides a perfect elimination of odd harmonics and THDe as the harmonics are significantly close to zero and hence it highly reduce Total Harmonic Distortion minus fundamental (THDe).

During the experiment, the DBOSHE algorithm which targets the 5th, 7th, and 11th harmonics is extended to an 11-level inverter so as to remove also the 13th harmonic. The findings of the study show the capability of the DBO algorithm to meet the required IEEE-519 standard constant and at the same time decrease the THDe and completely nullify the odd harmonics.

- Incorporate Limitations Discussion: Describe the main pitfalls and difficulties related to the proposed techniques, such as computational complexity and scalability problems, in order to make your review complete and give more information about the practical implementation issues.
- Include Comparative Analysis: Describe the respective performance metrics and computation efficiency for each method to allow the better understanding of their particular strengths and drawbacks, which, in turn, helps readers in choosing appropriate approaches for various applications.
- Highlight Practical Implications: Explain the consequences of bringing the technology developed to industrial or commercial settings and talk about the

problems that may arise with living costs, the system reliability and the ease of implementation.

- Outline Future Research Directions: Discover the areas of research which collaborate in the exploration of the topic and result in generating new knowledge and improvements in the technology of power electronics and harmonics mitigation.

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