Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 5, October 2023, pp. 2643~2650
ISSN: 2302-9285, DOI: 10.11591/eei.v12i5.5160

Red deer algorithm-based selective harmonic elimination technique for multilevel inverters

Yasin Bektaş[1], Hulusi Karaca[2], Taha A. Taha[3], Hussein I. Zaynal[4]
[1]Department of Electrical and Energy, Technical Sciences Vocational High School, Aksaray University, Aksaray, Turkey
[2]Department of Electrical and Electronic Engineering, Faculty of Technology, Selçuk University, Konya, Turkey
[3]Department of Electrical Engineering Technology, Northern Technical University, Kirkuk, Iraq
[4]Department of Computer Engineering Technology, Al-Kitab University, Altun Kupri, Iraq

Article Info

Article history:

Received Nov 7, 2022
Revised Dec 16, 2022
Accepted Apr 13, 2023

Keywords:

Cascaded multilevel inverter
Optimization
Red deer algorithm
Selective harmonic elimination
Total harmonic distortion

ABSTRACT

This paper proposed a red deer algorithm (RDA)-based selective harmonic elimination (SHE) method for multilevel inverters (MLIs). To eliminate the desired harmonic orders, the optimum switching angles of the MLI have been calculated using the proposed RDA. The calculated switching angles have been applied to the 3-phase cascaded H-bridged 11-level inverter. In addition, the performance of the proposed RDA method was compared with the results of methods such as the Newton-Raphson (NR) method, LSHADE/EpSin technique (LSHADE), whale optimization algorithm (WOA), and particle swarm optimization (PSO) used for the SHE problem in the literature. The results obtained prove that the proposed RDA optimization solves the SHE problems more effectively than other methods. It has also been observed that RDA produces good solutions in different modulation indexes.

Corresponding Author:

Yasin Bektaş
Department of of Electrical and Energy, Technical Sciences Vocational High School, Aksaray University 68100, Aksaray, Turkey
Email: yasinbektas@aksaray.edu.tr

1. INTRODUCTION

Multilevel inverters (MLIs) are a popular power electronics device used in mid-voltage and high-power applications instead of conventional two-level inverters. Basically, there are three conventional topologies for MLIs these are; cascaded H-bridge MLI (CHB-MLI), capacitor-clamped MLI (CC-MLI), and diode clamped MLI (DC-MLI) [1]–[3]. The robust and modular structure of CHB-MLI made it the most commonly used topology among the existing topologies [4]. Conventional inverters have high efficiency and a high-power ratio. However, the semiconductor switches experience higher stress as the desired power and voltage value are increased. Today, it is not possible to produce semiconductor power switches that can withstand medium voltage levels. Therefore, the use of MLI with lower voltage stress in switches in medium/high voltage applications has become popular [5]–[8].

However, this technology faces a harmonic problem that causes harmful effects on the load. Among harmonics, the most dangerous harmonics for the system are low-order harmonics because these harmonics cause torque fluctuations in electric motors, decrease efficiency, and reduce the lifetime of the system [9]–[12]. The control and modulation methods used by these inverters have become more challenging as MLI topologies have advanced [12]–[14]. An essential issue that needs to be resolved is the existence of low-order dominant harmonics in the cascading output voltage generated by MLI. These harmonics mostly cause malfunction, increased loss, and voltage ripple. These harmonics also have an impact on power quality [15]. Despite the fact that there are other controls and modulation techniques, the selective harmonic elimination (SHE) technique is the primary modulation technique that solves the aforementioned issues.

Hence, the solution to the problem is extremely difficult. Three sorts of techniques can be utilized to address SHE issues; these are numerical techniques, algebraic techniques, and meta-heuristic algorithms. The gradient optimization and Newton-Raphson (NR) [16] methods can be given as examples of numerical methods; however, these iterative methods are mainly sensitive to the initial value and divergence problems are likely to occur, especially as the inverter level increases. If the initial value is not selected properly, the number of iterations may increase greatly or the solution may not be found. Algebraic methods are techniques such as resultant theory and Groebner bases theory for calculating optimized switching angles. These techniques involve the conversion of transcendental equations into the corresponding polynomial equations. These methods do not depend on the initial value but are very complex computationally; therefore, these methods can be applied only to low-level inverters. In meta-heuristic methods, SHE equations are solved using nature-inspired methods such as genetic algorithm (GA) [17] particle swarm optimization (PSO) [17], [18], LSHADE/EpSin technique (LSHADE) [19], whale optimization technique (WOA) [20], [21], and enhanced krill herd (EKH) [22]. There are certain common problems of algorithms such as PSO and GA; these include convergence to local optimum, early convergence, and either only global solution or only local solution.

This study proposes a novel red deer algorithm (RDA)-based optimization approach to the SHE problem that can overcome the above problems. The proposed RDA optimization has been applied for the first time for the SHE problem [23], [24]. According to the optimization methods used for the SHE problem in the literature, the most obvious superiority of RDA optimization is that it can adjust the diversification and intensification phases. Owing to this feature, RDA can trade off between the optimal minimization total harmonic distortion (OMTHD) and SHE (it can use the local and global search together). To validate the concept, switching angles for OMTHD and SHE-pulsewidth modulation (SHE-PWM) using RDA are found and applied to a 3-phase 11-level CHB-MLI. In addition, the harmonic results of the RDA-based SHE technique have been compared with the results of other techniques in the literature.

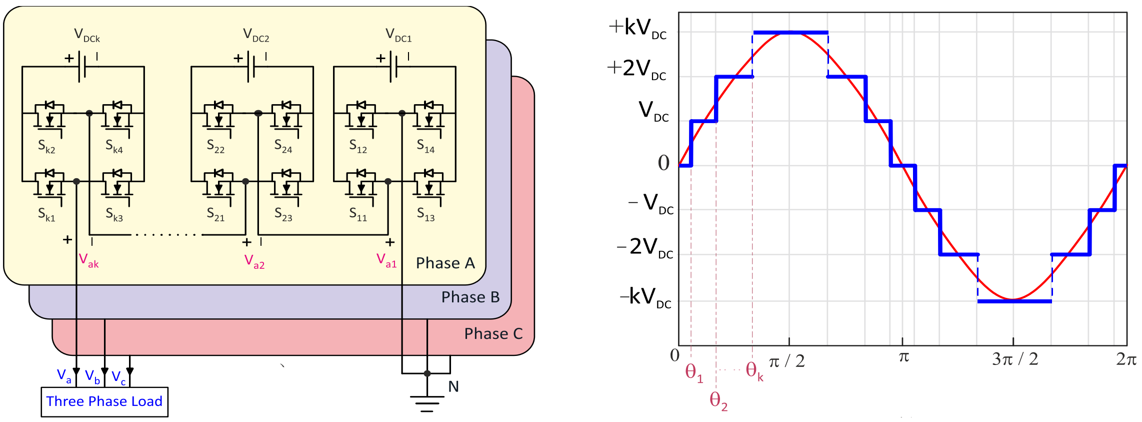
2. CASCADED H-BRIDGE MULTILEVEL INVERTER

Figure 1(a) displays the circuit diagram for the N-level three-phase CHB-MLI. Each phase is made up of a single-phase H-bridge inverter that is connected in series and is powered by a separate, discrete DC source. If the voltage value of DC sources is equal, it is called a symmetrical MLI, otherwise, it is called an asymmetric MLI. The proposed algorithm in this study is applied to the symmetrical structure. Figure 1(b) depicts the AC output voltage waveform (V_0) for an N-level MLI supplied by a symmetrical source. The output voltage for each phase can be expressed as (1):

$$V = \pm V_{DC} \quad (1)$$

Where k is the number of discrete DC sources. Also, k represents the number of H-bridge modules. The relationship between the number of DC sources (k) and the voltage level N can be given as (2):

$$N = 2k + 1 \quad (2)$$



(a) (b)

Figure 1. Three-phase N-level CHB-MLI (a) circuit diagram and (b) output voltage waveform for single phase

3. SELECTIVE HARMONIC ELIMINATION PROBLEM IN MULTILEVEL INVERTERS

Low-order harmonics are eliminated by the SHE-PWM switching method via the creation of switching angles at the fundamental frequency. The number of discrete DC sources in this approach equals the number of switching angles (k). Switching each module just once will eliminate k-1 maximum number of harmonics from the output voltage of the inverter. The output voltage can be fourier expanded to reflect the required nonlinear harmonic equations to attain the optimal switching angles. The expression of the output voltage that contains all the harmonic components is given as (3) [5], [6]:

$$V_0(\omega t) = \sum_{(\text{ockl } n=1,3,\ldots}^{\infty} \frac{4kV_{DC}}{\pi n}[\cos(n\theta_1) + \cos(n\theta_2) + \cdots + \cos(n\theta_k)]\sin(\omega t) \tag{3}$$

For the output voltage, the harmonic components are mostly composed of the fundamental frequency and its multiple. The symmetrical output voltage represented in Figure 1(b) ensures the non-availability of even harmonic components. The output voltage consists of only odd harmonic components as expressed in (3), where ω=2πf and f is the fundamental frequency. The expression of the fundamental harmonic component (V_1) of the output voltage is given thus:

$$V_1(\omega t) = \frac{4kV_{DC}}{\pi}[\cos(\theta_1) + \cos(\theta_2) + \cdots + \cos(\theta_k)]\sin(\omega t) \tag{4}$$

Where θ_1, θ_2,…, θ_k are switching angles and must meet the following condition:

$$0 \leq \theta_1 < \theta_2 < \cdots < \theta_k \leq \pi/2 \tag{5}$$

In the SHE technique, the control of the fundamental voltage is carried out with the modulation index (M) which is the ratio of the peak value of the desired basic voltage (V_{1p}) to the total DC input voltage given in (6):

$$M = \frac{V_{1p}}{k \cdot V_{dc}} \tag{6}$$

The 3rd harmonic components and multiples of 3rd harmonics at phase-to-phase voltages can be disregarded in a balanced 3-phase system. As a result, the line voltage waveform's 5th, 7th, and 11th … harmonic orders can be removed at the low switching frequency. In a 3-phase 11-level MLI, the following equations must be solved to eliminate undesired harmonics and generate fundamental harmonics of specified amplitude:

$$\begin{aligned}
V_1 &= \cos(\theta_1) + \cos(\theta_2) + \cdots + \cos(\theta_5) = Mk\pi/4 \\
V_5 &= \cos(5\theta_1) + \cos(5\theta_2) + \cdots + \cos(5\theta_5) = 0 \\
V_7 &= \cos(7\theta_1) + \cos(7\theta_2) + \cdots + \cos(7\theta_5) = 0 \\
V_{11} &= \cos(11\theta_1) + \cos(11\theta_2) + \cdots + \cos(11\theta_5) = 0 \\
V_{13} &= \cos(13\theta_1) + \cos(13\theta_2) + \cdots + \cos(13\theta_5) = 0
\end{aligned} \tag{7}$$

The fundamental waveform's amplitude is managed by the first SHE equation, as shown in (7). To remove the selected harmonics, other equations are set to zero. After that, these equations are correctly solved. The goal is to remove or significantly reduce the low-order harmonics (V5, V7, V11, and V13) while ensuring the fundamental frequency maintains a steady voltage value at the desired value. To find the optimal SHE equation solutions, an RDA optimization strategy is suggested in this study.

4. IMPLEMENTATION OF RDA OPTIMIZATION TO SHE TECHNIQUE

The RDA [25] was first reported; this was followed by the introduction of a new RDA optimization strategy [26]. The main source of inspiration for this meta-heuristic was the unusual mating pattern of Scottish red deers (RDs) during the breeding season. Like other meta-intuitive methods, RDA is initiated with a set of randomly selected RDs, where the best RDs in the population are considered the "male RDs," while the others are called "hinds." The male RD should roar first; they are split into two categories-single male deer (stags) and commanders based on the strength of the roar phase. The commanders engage the stags in a battle to claim their harems. Here, only the commanders can create the harems. The number of hinds in the harems of the leaders is directly related to their roar and their prowess in the battle phase. The commanders consequently mate a number of hinds in their harems but each commander is allowed a limited number of mating with hinds from various harems. The other male deers (stags) can also mate with the closest hinds irrespective of the size of the harem. Both exploration and concentration phases are also focused on in this step. The mating procedure by which RDs offspring are created is a significant stage in RDA optimization. This stage also offers new solutions to the optimization problem. The next algorithmic stage is finally created by considering the solutions that are evolutionarily weak [26]. The following steps are performed to solve the SHE problem with RDA:

a. Determination of the fitness function: the cost function for the SHE problem is defined as (8):

$$f = \min_{\theta i}\left\{\left|V_{1p} - \left(\frac{4V_{DC}}{\pi}\right)\cdot\left(\sum_{i=1}^{k}\cos\left(\theta_i\right)\right)\right| + \left(\frac{4V_{DC}}{n\pi}\cdot\left(\sum_{i=1}^{k}\cos\left(n\theta_i\right)\right)\right)^2\right\} = 0 \quad (8)$$

Where V_{1p} (H_1) is the desired fundamental harmonic, h_n; are the harmonics that need to be eliminated. The first term controls the fundamental voltage and the second term represents low-order harmonics in the cost function.

b. Creation of the initial population: create the initial population according to (9):

$$\text{Value} = f(\text{Red Deer}) = f\left(X1, X2, X3, \dots, X_{N_{var}}\right) \quad (9)$$

Where X_{Nvar} specifies the size of the array, while the values X1, X2, and X3. are the array's components. Five variables are defined (θ_1, θ_2, θ_3, θ_4, and θ_5) since only one switching is made for each bridge in the eleven-level CHB-MLI. The number of variables will be the number of positions assigned to each deer. To start the algorithm, a random initial population of Npop size is created, taking into account the fitness function.

c. Choosing the best solutions: randomly generated switching angles are evaluated according to the fitness function. Some of the best solutions (depending on the value selected in Table 1) are identified and stored as male RD.

Table 1. RDA optimization parameters

Parameters	Value	Parameters	Value
Number of variables	5	Alfa (α)	1.0
Iteration number	100	Beta (β)	0.6
Number of the population	20	Gamma (γ)	0.5
Number of male RD	5	Roar	0.2
Number of hinds	15	Fight	0.5
		Mating	0.8

d. Selection of commanders and stags: select the commander and stags according to (10):

$$N_{\text{Com}} = \text{round}\,\{\gamma \cdot N_{\text{male}}\} \quad (10)$$

$$N_{\text{stag}} = N_{\text{male}} - N_{\text{Com}} \quad (11)$$

Where N_{male} is the number of all male deers, N_{com} represents the number of commanders, and finally, N_{stag} is the number of stags (single male deers).

e. Fight: each commander randomly fights the stags. The fighting process is performed using (12):

$$\begin{aligned} \text{New}_1 &= \frac{(\text{Com+Stag})}{2} + b_1 \times \left(\left((\text{UB} - \text{LB})^* \, \text{b}_2\right) + \text{LB}\right) \\ \text{New}_2 &= \frac{(\text{Com+Stag})}{2} - \text{b}_1 \times \left(\left((\text{UB} - \text{LB})^* \, \text{b}_2\right) + \text{LB}\right) \end{aligned} \quad (12)$$

Where UB is the upper bound of the search space while LB is the lower bound. The fighting step is a random process and as such, the selection of b_1 and b_2 is done randomly between 0 and 1 in a uniformly distributed manner. A commander can approach a stag or vice versa in the resolution area. Any of the four solutions [single male RD (Stag), commander (Com), New1 (new status1), and New2 (new status2)] with better FF becomes the new commander.

f. Create harems: a harem is made up of a male commander and a group of captured female deer (hinds). The fighting capability of the commander determines the number of female deer in the harems.

g. Mating: mating can be done in three ways: i) mating each commander with females from his harem; ii) mating any commander with hinds from another harem; and iii) mating the stag with the nearest hind, irrespective of the harem restrictions.

h. Creation of offspring: during the mating phase, offspring are produced in all three cases according to (13). The Stag replaces Com during the third case in the mating phase:

$$\text{ofss} = \frac{(\text{Com+Hind})}{2} + (\text{UB} - \text{LB}) \times c \quad (13)$$

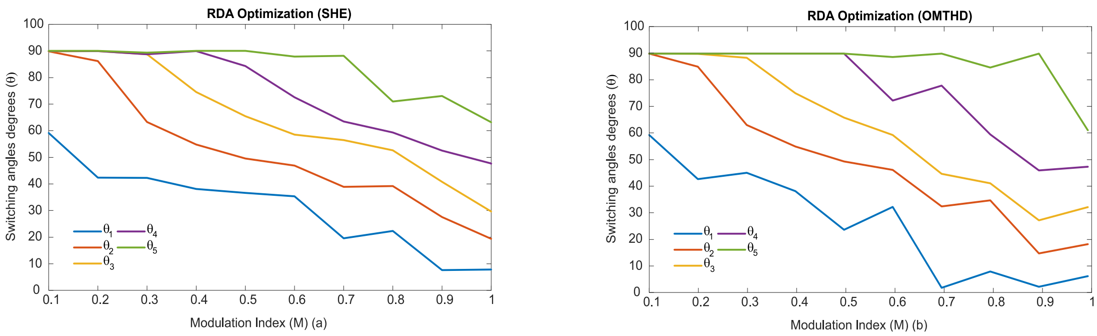
Where c is randomly generated in a uniformly distributed manner between 0 and 1.

i. Selection of the new generation: the next generation is chosen using two alternative methods. The first method involves keeping the best male RDs (Stag and Com) (a given proportion of the optimal solutions).

The second technique requires the selection of the hinds for the next generation utilizing a fitness competition or roulette wheel mechanism; the selection is done from among all the hinds and produced offspring during the mating stage. The selected male and female RDs produce the next generation.

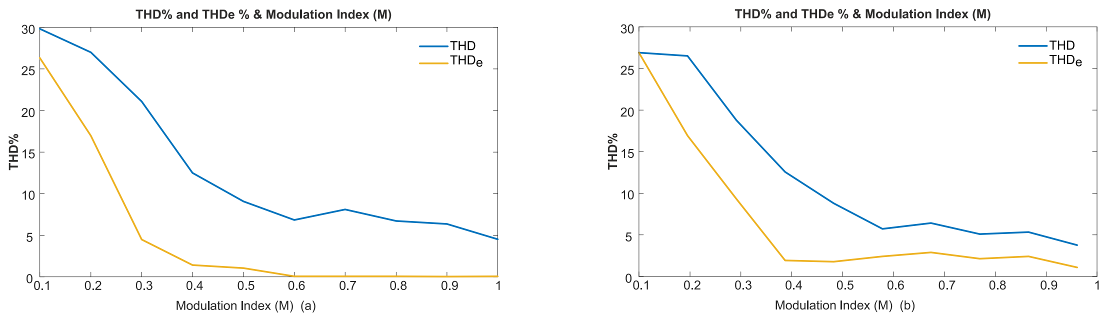
j. Stop criterion: the number of iterations, the best-found solution, or a given time interval can all be considered as the stopping condition. The number of iterations is used as the stopping condition for RDA-based SHE-PWM. Repeat steps c through j until the stopping condition is satisfied.

Details of how RDA optimization can be used with SHE equations have been provided by [23], [24]; readers are referred to the relevant articles for more explicit information. RDA optimization parameters are adjusted to solve SHE equations in 11-level three-phase CHB-MLI. Figure 2(a) shows the optimum switching angles that the RDA optimization found in the range of modulation index of 0.1 to 1.0 to solve the SHE equation. Figure 2(b) shows the optimum switching angles that the proposed method finds to provide the OMTHD value. Figures 3(a) and (b) show total harmonic distortion (THD) and THD_e values within the modulation index range of 0.1 to 1.0 for SHE and OMTHD, respectively. Evidently, the proposed RDA-based method finds suitable solutions for SHE and OMTHD in the modulation index range of 0.4 to 1.0.



(a) (b)

Figure 2. Switching angles according to modulation index (a) for SHE and (b) for OMTHD



(a) (b)

Figure 3. THD% and THD_e% according to modulation index (a) for SHE and (b) for OMTHD

Two types of THD are computed in this work; the first is the overall THD; the second is the THD_e value that stands for the total of harmonics until the eliminated maximum harmonic orders. In the 11-level three-phase CHB-MLI, THD, and THD_e can be calculated as given in (14) and (15), respectively. The upper limit for THD is infinite, but THD_e is calculated up to the minimized harmonic orders.

$$THD = \frac{\sqrt{V_5^2+V_7^2+V_{11}^2+\cdots}}{|V_1|} \tag{14}$$

$$THD_e = \frac{\sqrt{V_5^2+V_7^2+V_{11}^2+\cdots+V_{3k-2}^2}}{|V_1|}, \text{(for odd k.)} \tag{15}$$

5. RESULT

To prove the effectiveness of the proposed algorithm, the calculated switching angles were applied to the three-phase 11-level CHB-MLI. Each H-bridge module input voltage is selected as 50 V (V_{dc}=50 V).

These results show that the selected harmonics are minimized almost to zero and the fundamental harmonic is kept very close to the desired value. The switching angles in the unit modulation index to be minimized of selected harmonics are estimated as θ_1=6.75°, θ_2=18.98°, θ_3=27.53°, θ_4=45.49°, and θ_5=62.40°. The switching angles in the unit modulation index for the best OMTHD value are obtained as θ_1=8.02°, θ_2=19.2°, θ_3=27.82°, θ_4=46.45°, and θ_5=61.16°. For the best SHE solution, the inverter output phase voltage waveform is given in Figure 4(a). The frequency spectra of line voltage for THD and THD_e are depicted in Figures 4(b) and 4(c), respectively. Similarly, the output phase voltage and the frequency spectra of line voltage for THD and THD_e are given in Figures 5(a)-(c), respectively.

For SHE and OMTHD, the fundamental phase voltage is normally V_1=250 V for M=1.0 from (6). The switching angles, THD, and THD_e values calculated for the NR, LSHADE, WOA, PSO, and the proposed RDA-based technique are given in Table 2. As can be seen, the proposed RDA-based SHE-PWM technique (RDA-SHE) eliminates selected harmonics better than another optimization techniques. The smallest THD_e value proves that the selected harmonics are efficiently minimized.

The table suggests that when the calculated switching angles for the RDA-SHE are applied, the THD_e% value is obtained as 0.04% and the THD% value as 4.50%. By using the suggested RDA method, the amount of intensification can be adjusted between the harmonics desired to be eliminated and the THD value. If prompted to obtain the best THD value, the intensification of the THD can be increased in the fitness function. In this case, the THD_e% and THD% values are obtained as 1.29 % and 3.96 %, respectively. From the perspective of minimum THD, the proposed RDA has given the best performance, but the harmonic value is higher than the calculated value for the SHE because optimization (RDA-OMTHD) is intensified to find a solution for the minimum THD value.

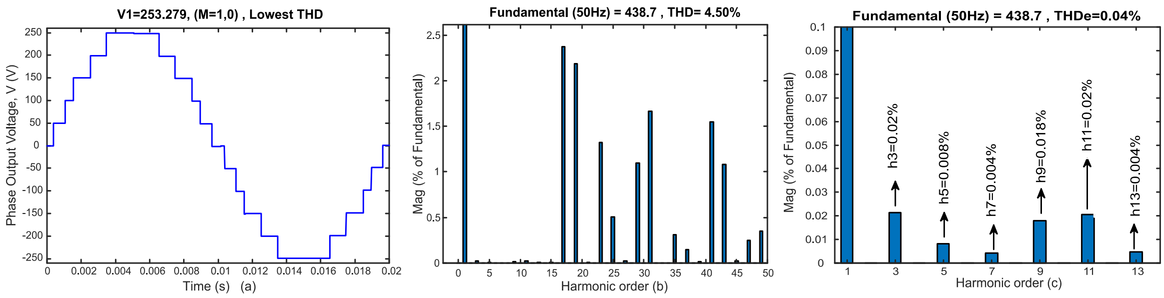


Figure 4. For SHE solution (a) phase voltage waveform, (b) THD value of line voltage, and (c) THD_e value of line voltage

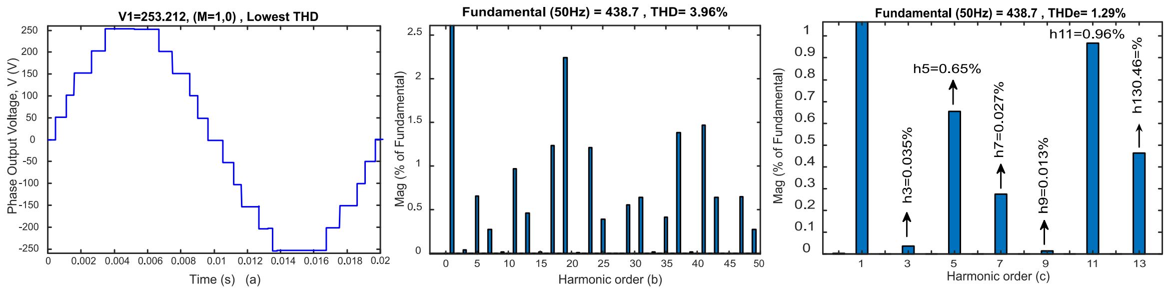


Figure 5. For OMTHD solution (a) phase voltage waveform, (b) THD value of line voltage, and (c) THD_e value of line voltage

Table 2. Comparison of THD% and THD_e% values of different algorithms

Optimization techniques	Modulation index (M)	Switching angles (degree)					THD%	THD_e%
		Θ1	Θ2	Θ3	Θ4	Θ5		
NR method [16]	1.00	6.56	18.93	27.17	45.12	61.87	4.35	0.26
PSO [18]	1.00	6.72	19.00	27.39	45.10	62.16	4.45	0.17
LSHADE [19]	1.00	5.49	16.68	28.58	42.06	59.46	4.67	1.83
WOA [20]	1.00	6.60	18.80	27.30	45.10	62.20	4.53	0.09
Proposed RDA-SHE	1.00	6.75	18.98	27.53	45.49	62.40	4.50	0.04
Proposed RDA-OMTHD	1.00	8.02	19.28	27.82	46.45	61.16	3.96	1.29

6. CONCLUSION

In this paper, an RDA optimization is proposed for the elimination of selected harmonic orders in three-phase 11-level CHB-MLI fed by symmetric sources. Suitable switching angles for the modulation index values between 0.1 and 1 for the suggested RDA optimization were quickly calculated. The results show that the RDA method can successfully attenuate low-order harmonics while maintaining the fundamental output voltage. Furthermore, the proposed method can be used effectively to achieve the optimal THD value. Consequently, the proposed optimization method produces better solutions within the specified modulation index range compared to other existing optimization methods.

REFERENCES

[1] M. Malinowski, K. Gopakumar, J. Rodriguez and M. A. Pérez, "A Survey on Cascaded Multilevel Inverters," *in IEEE Transactions on Industrial Electronics*, vol. 57, no. 7, pp. 2197-2206, July 2010, doi: 10.1109/TIE.2009.2030767.

[2] M. V. Rajkumar, and P. S. Manoharan. "Modeling and Simulation of Three-phase DCMLI using SVPWM for Photovoltaic System." *Power Electronics and Renewable Energy Systems: Proceedings of ICPERES 2014*. Springer India, 2014, doi: https://doi.org/10.1007/978-81-322-2119-7_5.

[3] R. A Rana, S. A. Patel, A. Muthusamy, C. W. Lee and H. J. Kim "Review of multilevel voltage source inverter topologies and analysis of harmonics distortions in FC-MLI." *Electronics,* Vol. 8, No. 11, p. 1329, 2019, doi: https://doi.org/10.3390/electronics8111329.

[4] K. Corzine and Y. Familiant, "A new cascaded multilevel H-bridge drive," *IEEE Transactions on Power Electronics*, vol. 17, no. 1, pp. 125–131, Jan. 2002, doi: 10.1109/63.988678.

[5] H. Karaca and E. Bekta, "GA based selective harmonic elimination for multilevel inverter with reduced number of switches," in *Proceedings of the World Congress on Engineering and Computer Science 2015*, 2015, pp. 204–209.

[6] H. Karaca and E. Bektas, "Selective harmonic elimination using genetic algorithm for multilevel inverter with reduced number of power switches," *Engineering Letters*, vol. 24, no. 2, pp. 138–143, 2016.

[7] P. T. Giang, V. T. Ha, and V. H. Phuong, "Drive control of a permanent magnet synchronous motor fed by a multi-level inverter for electric vehicle application," *Engineering, Technology & Applied Science Research*, vol. 12, no. 3, pp. 8658–8666, Jun. 2022, doi: 10.48084/etasr.4935.

[8] M. S. Choudhary *et al.*, "Solar powered space vector pulse width modulation based induction motor drive for industry applications," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 4, pp. 1828–1836, Aug. 2022, doi: 10.11591/eei.v11i4.3023.

[9] Ö. A. Karaman, F. Erken, and M. Cebeci, "Decreasing harmonics via three phase parallel active power filter using online adaptive harmonic injection algorithm," *Tehnicki vjesnik - Technical Gazette*, vol. 25, no. 1, pp. 157–164, May 2018, doi: 10.17559/TV-20180111132233.

[10] N. F. O. Serteller, Y. Bektas, S. Nogay, and T. C. Akinci, "Speed estimation of brushless direct current (BLDC) motor with multilayer perceptron," *Przeglad Elektrotechniczny*, vol. 88, no. 9, pp. 255–260, 2012.

[11] W. U. K. Tareen and S. Mekhielf, "Three-phase transformerless shunt active power filter with reduced switch count for harmonic compensation in grid-connected applications," *IEEE Transactions on Power Electronics*, vol. 33, no. 6, pp. 4868–4881, Jun. 2018, doi: 10.1109/TPEL.2017.2728602.

[12] V. T. Ha, P. T. Giang, and P. Vu, "Multilevel inverter application for railway traction motor control," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 4, pp. 1855–1866, Aug. 2022, doi: 10.11591/eei.v11i4.3964.

[13] V. A. Kumar and A. Mouttou, "Improved performance with fractional order control for asymmetrical cascaded H-bridge multilevel inverter," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 4, pp. 1335–1344, Aug. 2020, doi: 10.11591/eei.v9i4.1885.

[14] M. P. Thakre, J. A. Gangurde, R. Shriwastava, D. P. Kadam, S. S. Kadlag, and H. S. Sonawane, "Investigative uses of overmodulation techniques in modular multilevel cascaded converter," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 6, pp. 3147–3156, Dec. 2022, doi: 10.11591/eei.v11i6.3958.

[15] M. A. Hutabarat, S. Hasan, A. H. Rambe, and S. Suherman, "Design and simulation hybrid filter for 17 level multilevel inverter," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 3, pp. 886–897, Jun. 2020, doi: 10.11591/eei.v9i3.890.

[16] S. S. Letha, T. Thakur, and J. Kumar, "Harmonic elimination of a photo-voltaic based cascaded H-bridge multilevel inverter using PSO (particle swarm optimization) for induction motor drive," *Energy*, vol. 107, pp. 335–346, Jul. 2016, doi: 10.1016/j.energy.2016.04.033.

[17] A. Parkash, S. L. Shimi, and S. Chatterji, "Harmonics reduction in Cascade H-bridge multilevel inverters using GA and PSO," *International Journal of Engineering Trends and Technology*, vol. 12, no. 9, pp. 453–465, Jun. 2014, doi: 10.14445/22315381/IJETT-V12P287.

[18] E. S. Durak, H. I. Okumus, M. A. Usta, and H. Kahveci, "Selective harmonic elimination with particle swarm optimization in multilevel inverters," in *2018 IEEE 18th International Power Electronics and Motion Control Conference (PEMC)*, Aug. 2018, pp. 1019–1024, doi: 10.1109/EPEPEMC.2018.8521959.

[19] P. P. Biswas, N. H. Awad, P. N. Suganthan, M. Z. Ali, and G. A. J. Amaratunga, "Minimizing THD of multilevel inverters with optimal values of DC voltages and switching angles using LSHADE-EpSin algorithm," in *2017 IEEE Congress on Evolutionary Computation (CEC)*, Jun. 2017, pp. 77–82, doi: 10.1109/CEC.2017.7969298.

[20] S. K. Dash, B. Nayak, and J. B. Sahu, "Selective harmonic elimination of an eleven level inverter using whale optimization technique," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 9, no. 4, pp. 1944–1951, Dec. 2018, doi: 10.11591/ijpeds.v9.i4.pp1944-1951.

[21] A. K. V. K. Reddy and K. V. L. Narayana, "Optimal total harmonic distortion minimization in multilevel inverter using improved whale optimization algorithm," *International Journal of Emerging Electric Power Systems*, vol. 21, no. 3, pp. 1–25, Aug. 2020, doi: 10.1515/ijeeps-2020-0008.

[22] V. K. R. A. Kalananda and V. L. N. Komanapalli, "Enhanced krill herd optimization algorithm: total harmonic distortion minimization," in *Advances in Automation, Signal Processing, Instrumentation, and Control: Select Proceedings of i-CASIC 2020*, 2021, pp. 2421–2429, doi: 10.1007/978-981-15-8221-9_226.

[23] Y. Bektaş and H. Karaca, "Red deer algorithm based selective harmonic elimination for renewable energy application with unequal DC sources," *Energy Reports*, vol. 8, pp. 588–596, Nov. 2022, doi: 10.1016/j.egyr.2022.05.209.

[24] Y. Bektas and H. Karaca, “Red deer algorithm based harmonic mitigation for asymmetric cascaded multilevel inverters,” in *2022 57th International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST)*, Jun. 2022, pp. 1–4, doi: 10.1109/ICEST55168.2022.9828611.
[25] A. M. F. Fard, M. Hajiaghaei-Keshteli, and R. Tavakkoli-Moghaddam, “Red deer algorithm (RDA); a new optimization algorithm inspired by red deers’ mating,” in *12Th International Conference on Industrial Engineering*, 2016, pp. 1–10.
[26] A. M. Fathollahi-Fard, M. Hajiaghaei-Keshteli, and R. Tavakkoli-Moghaddam, “Red deer algorithm (RDA): a new nature-inspired meta-heuristic,” *Soft Computing*, vol. 24, no. 19, pp. 14637–14665, Oct. 2020, doi: 10.1007/s00500-020-04812-z.

BIOGRAPHIES OF AUTHORS

Yasin Bektaş born in Sivas, Turkey, in 1982. He received a B.S. degree in Electrical Education from Marmara University, Istanbul, Turkey, in 2008, an M.S. degree in Electrical Education from Marmara University, Istanbul, Turkey, in 2011. His MSc thesis about analysis, development, and computer-based study of Brushless Direct Current (BLDC) motor and its driver circuit training set. He received a B.S. degree in Electrical and Electronics Engineering from Selçuk University, Konya, Turkey, in 2015. He is a Ph.D. student at Selçuk University, Department of Electrical and Electronics, at the thesis stage. He is currently as lecturer at the Department Electrical and Energy of Aksaray University Technical Sciences Vocational High School. His current research interests include power systems, renewable energy, and multi-level inverters. He can be contacted at email: yasinbektas@aksaray.edu.tr.

Hulusi Karaca born in Yozgat, Turkey, in 1979. He received the B.S., M.S. and Ph.D. degrees in Electrical and Electronics Engineering from Selçuk University, Konya, Turkey, in 2001, 2004 and 2010, respectively. He is currently an Associate Professor with the Department of Electrical-Electronics Engineering, Selçuk University, Konya. His research interests include matrix converters, electrical machines and drives and power electronics, multilevel inverters, grid synchronization and phase lock loop methods. He can be contacted at email: hkaraca@selcuk.edu.tr.

Taha A. Taha he received the mixed-mode master’s degree M.Sc., in Electrical Power Engineering from the University Malaysia Perlis (2019) (Malaysia). He received the Bachelor’s degree, from University Malaysia Perlis (UniMAP), school of Electrical system (2017). He received the diploma in lT Skills–University of Cambridge, UK (2012). He can be contacted at email: t360pi@gmail.com.

Dr. Hussein I. Zaynal academic achievement Ph.D Electrical Engineering – Power Electronics, date of first appointment: 15/3/1983 in the college of Engineering salahaddin University in Erbil, retirement date 1/7/2017, duration of University Service 35 years, bachelor’s degree in Electrical Engineering 1976 Mosul University, Master degree in Electrical Engineering 1979 Mosul University, Ph.D power Electronics 2001 Mosul University, assistant professor from 16/12/2007, supervised ten master and doctoral students, fifteen research papers in magazines and conference inside and outside the country including IEEE journals. He can be contacted at email: drhussain.i.zainal@gmail.com.