




OPTIMIZATION-BASED SELECTIVE HARMONIC ELIMINATION FOR AN 11-LEVEL CASCADED H-BRIDGE INVERTER: A COMPARATIVE STUDY

Tabreer T. Al-Shouka ^{1*} , Sarah Amjad Inad ¹ , Mohammed K. Abed ² 

¹Computer and Information Technology College, Anbar University, 31001, Anbar, Iraq

³Electrical Engineering College, Babol Noshirvani University of Technology, 47134, Mazandaran, Iran

* Corresponding author E-mail: mohammed@stu.nit.ac.ir (Mohammed K. Abed)

RESEARCH ARTICLE

ARTICLE INFORMATION

SUBMISSION HISTORY:

Received: 20 May 2026

Revised: 23 June 2026

Accepted: 28 June 2026

Published: 30 June 2026

KEYWORDS:

Multi-level Inverter (MLI);

Selective Harmonic Elimination (SHE);

Genetic Algorithm (GA);

Gravity Search Algorithm (GSA);

Particle Swarm Optimization (PSO)

ABSTRACT

Unlike previous studies, this document proposes an informed baseline solution to SHE. The proposed initialization significantly reduces the search area and the number of iterations needed to converge, while maintaining a high harmonic elimination precision. In this research, a method for multilayer inverters (MLIs) that is based on an initial solution is presented for SHE. The goal is to resolve the SHE issue with high accuracy while simultaneously reducing the number of iterations by a significant amount. The SHE solution is defined as a set of switching angles; the SHE method is implemented to reduce harmonic distortion. To determine the SHE solution, a comparative analysis was conducted on an eleven-level inverter based on the SHE technique, utilizing the Genetic Algorithm, particle swarm optimization algorithm, and gravity search algorithm. MATLAB/SIMULINK simulations with modulation indices of 0.85 were used to solve the multidimensional SHE problem. An inverter with a single-phase Cascade H-bridge (CHB) configuration and 11 levels is used to implement the algorithm.

1. INTRODUCTION

Numerous industrial applications, including driving systems, SVCs, FACTs, and UPSs, employ multi-level inverters [1]. The majority of nations are currently focusing on the growth of renewable energy sources, which has led to the need for advanced, effective energy conversion technologies that enable the integration of renewable energy into modern energy systems [2]. Photovoltaic (PV) technologies appear to be among the most promising, mainly due to their great potential, scalability, and environmental performance [2] [5]. Minimize switching losses, higher productivity, much better power quality, increased inverter reliability because of fault tolerance, increased power range and versatility because of high voltage Proficiency, reduced electromagnetic interference (EMI) [3], improved electromagnetic compatibility (EMC) [4], lower dV/dt , etc. [11]. The most traditional MLI topologies:

1. Neutral-point-clamped (NPC), which self-regulates the DC capacitor voltage with low ripple, since symmetrical and asymmetric loads can be delivered cost-effectively [7] [8].
2. Flying capacitor multi-level inverter (FCMLI) uses floating capacitors to bind semiconductor circuits to a specific level of voltage. Instead of clamps, these capacitors alternately charge and discharge during switching, synthesizing a smooth, stepwise AC waveform from the DC source while reducing harmonic distortion [9].
3. cascaded H-bridge multi-level inverter (CHBMLI) connects several single-phase H-bridge inverters in series. By stacking isolated DC power sources and switching modules, it synthesizes a step-accelerated AC waveform. It offers modularity, requires fewer clamping components than diode-clamped topologies, and reduces overall harmonic distortion (THD) [6] [10].

The three main types of conventional multi-level inverter topologies. Three techniques are employed in selective harmonic elimination: evolutionary algorithms (EAs), algebraic techniques, and numerical techniques [12]. The Newton-Raphson (NR) approach, quadratic programming in sequence, and gradient-based optimization are examples of numerical techniques [13] [14]. Evolutionary optimization algorithms and newly created soft computing are the foundation of the second category [12]. This category is separated into the following categories: genetic algorithm (GA) [15] [17], particle swarm optimization (PSO) [16], gravitational search algorithm (GSA) [18], artificial bee colony (ABC) algorithm [19], cuckoo search algorithm (CSA) [1], etc. [12] [19]. These categories go beyond the limitations associated with increasing the number of inverter levels, which were an issue in the first category, particularly in situations with unequal DC sources.

This article develops a nonlinear mathematical model for energy-efficiency optimization. Various algorithms—including GA, the GSA, and PSO—were employed to solve this nonlinear problem. The corresponding code was developed using MATLAB's optimization tools. Performance metrics—including Total Harmonic Distortion, convergence, and memory requirements—were compared against the obtained results. Furthermore, an eleven-stage simulation validation process was conducted to verify the simulation results.

1.1 Cascaded Multi-Level Inverter

Cascade inverters are the preferred inverter type because they require fewer components and provide identical output signal levels. The 11-level CHB series H-bridge converter consists of five H-bridge cells. Each cell consists of four IGBT semiconductor switches located between two AC terminals. The switches operate in complementary pairs, so the excitation of switches S1 and S2, as well as S3 and S4, is inverse to each other, as displayed in Fig. 1: $S1 = \text{NOT } S2$, $S3 = \text{NOT } S4$. To enhance the degrees of freedom in selecting switching angles and the ability to remove more harmonics from the output voltage, an eleven-level structure was chosen for this study. It is the best option for medium- and high-power applications because the output waveform approaches a perfect sine wave as the number of voltage levels climbs and the THD falls. The switching circuit used in this study is designed to prevent DC-link short circuits. In this structure, each converter cell can generate three output voltage levels: (+Vdc), (-Vdc), and zero voltage.

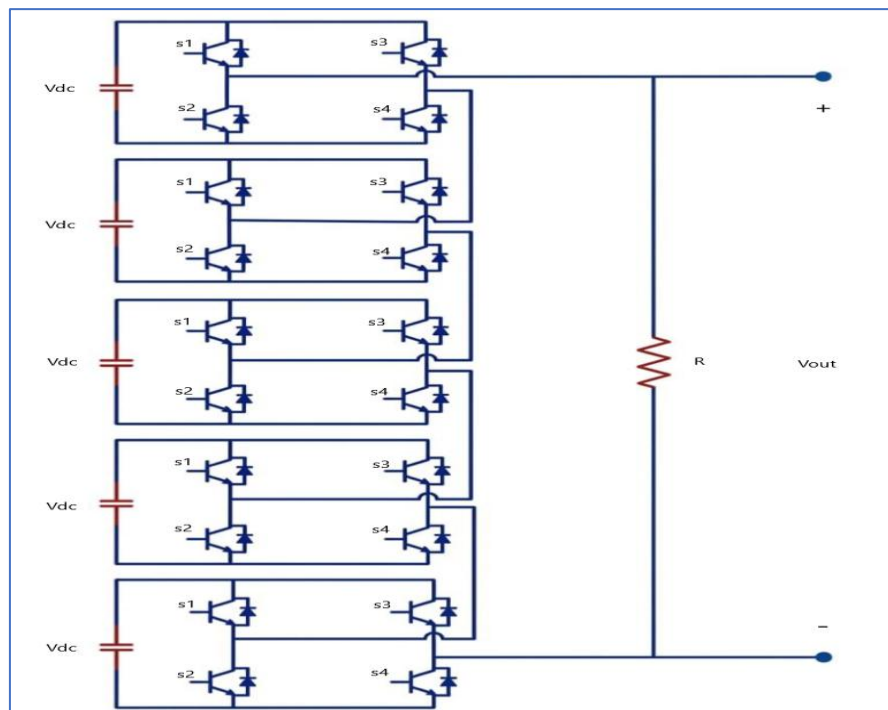


Figure 1. Structure of the 11-level CHB with a single-phase leg.

Accordingly, as shown in Fig. 2, the five switching angles ($\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$) are used for the 11-level CHB inverter. Selecting this number of angles, in addition to suppressing low-order harmonics, reduces the THD.

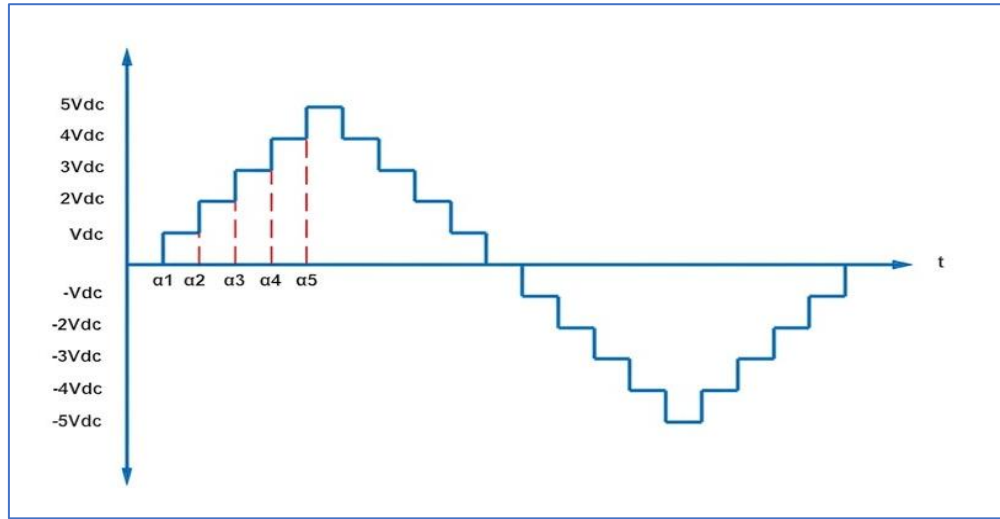


Figure 2. Output voltage waveform of a 11-level inverter.

2. BACKGROUND

2.1 Formulation of The SHE Problem

The SHE approach may model all output-phase voltage harmonics using the Fourier analysis function. As a result, the 11-level CHB inverter's output phase voltage waveform's Fourier series expansion, as shown in Fig. 1, is represented by formula (1) [20]. To improve the quality of the output voltage and to meet harmonics standards in the wider frequency range, the harmonic constraint has been extended to all significant odd harmonics up to the 49th order. This allows optimization algorithms to suppress a broader range of low- and medium-order harmonics, thereby increasing inverter efficiency (4).

$$V(t) = \frac{4Vdc}{n\pi} \sum_{n=1,5,7\dots}^{49} \cos(n\alpha i) \sin(\omega t) \quad \dots (1)$$

Where $V(t)$ is the source voltage, Vdc : Voltage of voltage sources for each cell, n : Harmonic order, α : Angle, and i : Angle number. The number of switching angles required for a multi-mode H -bridge inverter shall be determined by the number of voltage levels of the output, depending on formula (2), where $N(\alpha)$: Number of angles, L : number of levels.

$$N(\alpha) = \frac{L-1}{2} \quad \dots (2)$$

Switching the angles $\alpha 1$ to $\alpha 5$ satisfies the following condition given by formula (3). The output voltage waveform of the 11-level CHB converter can be written as a Fourier series as follows (4). The mains voltage ($V1$) is achieved when all switching angles are as in formula (5).

$$0 < \alpha 1 < \alpha 2 < \alpha 3 < \alpha 4 < \alpha 5 < \frac{\pi}{2} \quad \dots (3)$$

$$V_o(\omega t) = \sum_{n=1,3,\dots}^{49} \frac{4Vdc}{n\pi} (\cos(n\alpha 1) + \cos(n\alpha 2) + \cos(n\alpha 3) + \cos(n\alpha 4) + \cos(n\alpha 5)) \sin(\omega t) \quad \dots (4)$$

$$V1 = \frac{4Vdc}{\pi} \quad \dots (5)$$

Where $V1$: Fundamental voltage. Therefore, the expression for M in (6) is the modulation index, where $0 < M < 1$.

$$M = \frac{\pi V1}{4Vdc} \quad \dots (6)$$

The goal here is to minimize THD and eliminate lower harmonics. The remaining harmonics must be filtered using filter circuits. The dominant harmonics are the 5th and 7th for 11-levels, which must be eliminated in this work. The nonlinear problem is posed using equations (7-11) for

11 levels, which must be solved [3] [21].

$$\frac{4V_{dc}}{\pi} (\cos\alpha_1 + \cos\alpha_2 + \cos\alpha_3 + \cos\alpha_4 + \cos\alpha_5) = \frac{4V_1}{\pi} \quad \dots (7)$$

$$(\cos 3\alpha_1 + \cos 3\alpha_2 + \cos 3\alpha_3 + \cos 3\alpha_4 + \cos 3\alpha_5) = 0 \quad \dots (8)$$

$$(\cos 5\alpha_1 + \cos 5\alpha_2 + \cos 5\alpha_3 + \cos 5\alpha_4 + \cos 5\alpha_5) = 0 \quad \dots (9)$$

$$(\cos 7\alpha_1 + \cos 7\alpha_2 + \cos 7\alpha_3 + \cos 7\alpha_4 + \cos 7\alpha_5) = 0 \quad \dots (10)$$

$$(\cos 9\alpha_1 + \cos 9\alpha_2 + \cos 9\alpha_3 + \cos 9\alpha_4 + \cos 9\alpha_5) = 0 \quad \dots (11)$$

The total harmonic distortion (THD) for a stepped waveform is expressed by equation (12) [3]. Where V_n represents the amplitude of the n -th harmonic (from 3 to 49), which is expressed by equations (8) to (11); the fundamental value V_1 is the fundamental value in equation (7).

$$THD = \sqrt{\sum_{n=2}^{49} V_n^2 / V_1^2} \quad \dots (12)$$

Finding five switching angles that simultaneously satisfy these equations over the modulation index range is now our objective.

2.2 Comparison of Algorithms

To find the optimal switching angles for the 11-level CHB converter, the optimization algorithms solve the system of equations (7-11). In this objective problem, each candidate solution is treated as an individual solution consisting of five switching angles $[\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5]$. The constraints on the switching angles are given by equation (3) [22]. The fitness function, or cost function, is formed by combining the main objective function and a penalty term, as shown in equation (13). The fitness value is considered a criterion for evaluating the quality of each solution with respect to the main objective. Finding a range of switching angles where the out/put voltage's fundamental component's amplitude achieves the target value is the primary objective. Therefore, for each candidate solution, the fitness value is calculated based on its closeness to the ideal conditions and compliance with the harmonic constraints [23].

$$\min f(\alpha) = K_1 \cdot (V_1 - V_{target})^2 + K_2 \cdot \sum_{h \in H} (V_h(\alpha))^2 + THD \quad \dots (13)$$

Where $f(\alpha)$: Objective function, K_1, K_2 : Weighting coefficients, V_1 : fundamental voltage component, V_{target} : desired fundamental voltage, $V_h(\alpha)$: Harmonic amplitudes for orders. H : Harmonic orders, THD : Total Harmonic Distortion. Where M : Modulation index, V_{dc} : Voltage of voltage sources for each cell, i : Angle number.

$$V_{target} = M * V_{dc} * i \quad \dots (14)$$

The objective function is designed to meet the basic voltage requirements while improving the harmonic output voltage performance. The first term minimizes the error between the generated baseline voltage and the required reference voltage, ensuring that the desired modulation index is achieved. The second term minimizes the selected harmonic components included in the harmonic series (H). In contrast, the third term assesses the total harmonic distortion of the output voltage using the THD index. The optimization process therefore determines the optimal switching angles that meet the SHE limitations while improving the harmonic quality of the output voltage. The weighting coefficients (K_1, K_2) have been selected empirically and assigned equal values to ensure that both the fundamental error in the voltage and the minimization of harmonics are balanced. This equal weighting provides efficient optimization while maintaining the required basic voltage and achieving a low harmonic distortion.

2.2.1 Genetic Algorithm (GA)

The GA method is frequently employed in the literature across many domains. The most significant aspect of GA is its foundation in natural selection and genetic research. Because it can handle complex problems with ease across several domains, particularly in computer science, this biologically inspired approach has played a significant role in the development of promising and successful applications. [15, 17].

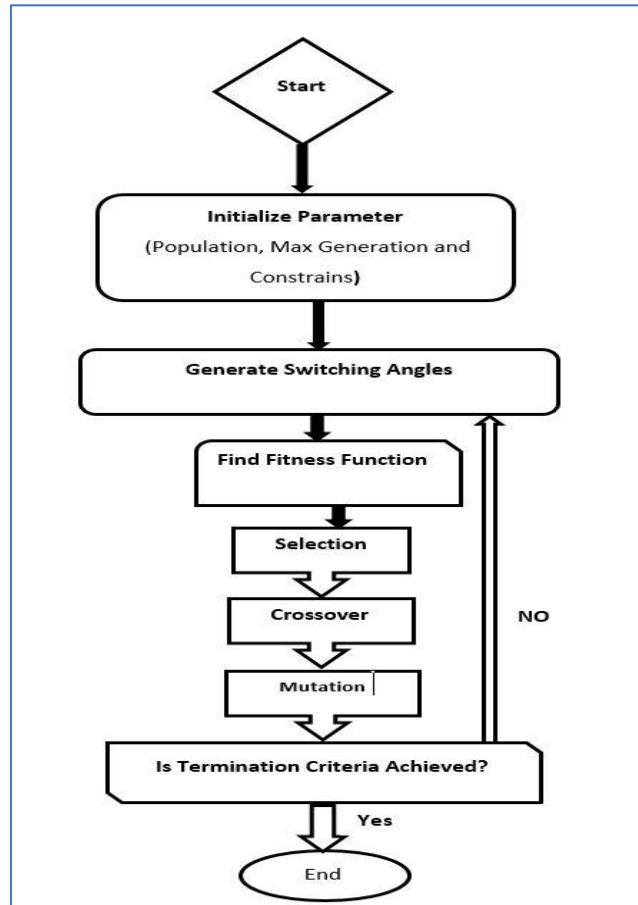


Figure 3. Flowchart of GA.

Fig. 3 shows that the genetic algorithm (GA) begins by generating random switching angles as an initial population. Each solution is evaluated using a fitness function that eliminates selected harmonics while maintaining the intended fundamental voltage. The best solutions are selected and combined using crossover to produce new offspring, while mutation randomly changes some switching angles to increase diversity and avoid local minima. The population is updated iteratively over several generations until a stopping condition is reached. Finally, optimal switching angles with minimal harmonic distortion are obtained for the SHEPWM inverter.

2.2.2 Gravitational Search Algorithm (GSA)

The Gravitational Search (GSA) algorithm is a unique performance optimization methodology based on mass interactions and the law of gravity. In 2009, E. Rashdi et al. presented the initial proposal for this algorithm. The elements in this system are considered as objects, and their masses are used to evaluate their performance [24]. In Fig. 4, GSA begins by generating random agents representing switching angles for a SHEPWM inverter. Each agent is evaluated using a fitness function that accounts for THD reduction, harmonic elimination, and fundamental voltage control. Agents with the best fitness are assigned larger masses and attract weaker agents using gravitational forces [18]. The agent positions and velocities are then iteratively updated to find the best solutions. Until the maximum number of iterations is reached, this optimization process continues. Finally, the best agent provides optimal switching angles that minimize harmonics and distortion, thereby improving inverter performance.

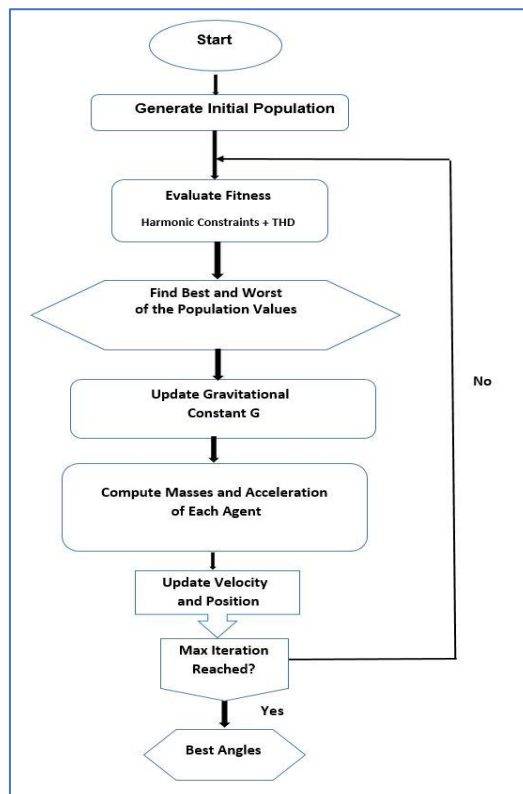


Figure 4. Flowchart of GSA.

2.2.3 Particle Swarm Optimization (PSO)

Inspired by the bird flock idea, the particle swarm search algorithm is a straightforward, reliable random search method. Numerous optimization issues have been successfully solved using this approach. The motion of the particle dictates the velocity of the particle in the search space. As illustrated in Fig. 5 [25], the global minimum is updated with "gbest" (the global minimum) in relation to velocity at each iteration, and Local minima are indicated by "pbest" values that are updated for each particle.

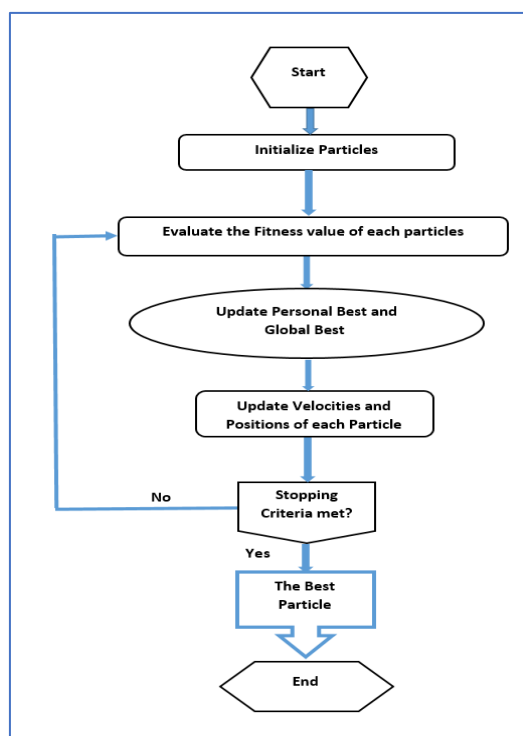
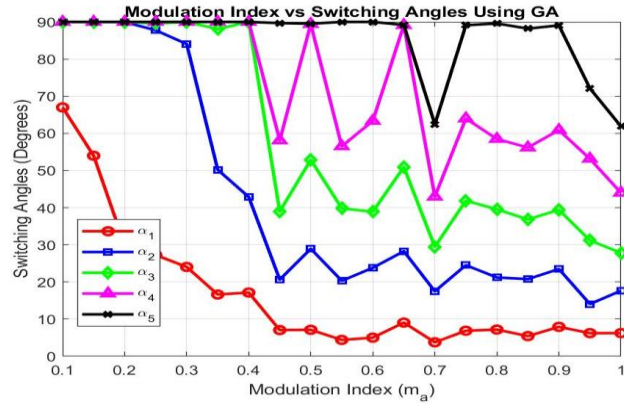


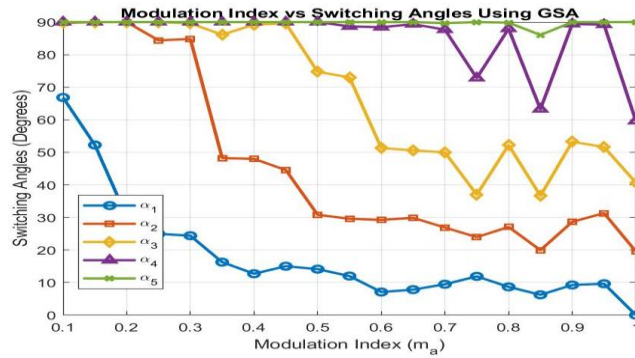
Figure 5. Flowchart of PSO.

3. SIMULATION RESULTS

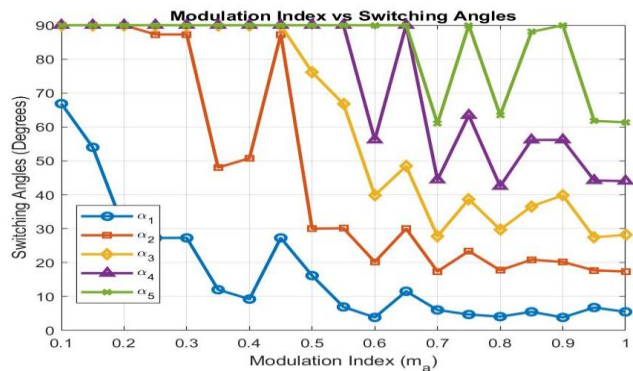
The development and execution of the proposed algorithms have been performed using an optimization toolkit and MATLAB and Simulink. The resulting switching angles were used to validate the proposed SHE approach by simulation. Fig. 6 shows the relationship between modulation index and switching angles of the different optimization algorithms. In all cases, the conversion angles satisfy the constraint $\alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5 < \pi/2$.



(a)



(b)



(c)

Figure 6. Switching angles VS modulation index of (a).GA (b). GSA (c). PSO.

The parameters related to the inverter and load characteristics used in the simulation are shown in Table 1.

Table 1. Selected Switching Angles for Testing the 11-level Inverter for M=0.85.

Optimization	α_1 In/degree	α_2 In/degree	α_3 In/degree	α_4 in/degree	α_5 In/degree
GA	5.4189	20.768	36.835	56.181	88.194
GSA	6.236	19.946	36.639	63.25	86.036
PSO	5.6516	20.9522	36.1307	56.0385	87.7283

The modulation index was set at ($M = 0.85$) throughout the study to ensure a consistent operational state for a fair comparison between the algorithms GA, PSO, and GSA. Using the same modulation index ensures that any difference in the switching angles obtained and in the THD is attributed solely to optimization algorithms, not to operating-point variations, Table 2. Matlab _ Simulink was used to confirm the proposed algorithm's outcomes. A symmetrical topology was considered, using an 11-level CHB inverter. Each module is composed of four power switches and a DC supply. To make the switching angle more efficient. An FFT analysis was performed on the line-voltage waveform for the RL load. The results are displayed in Fig. 7 for each algorithm, respectively.

Table 2: Performance Comparison of the Effectiveness of ML Algorithms

Parameter	Value
Fundamental frequency	50 Hz
DC link voltage	100 V
Load resistance (R)	10 Ohm
Modulation index	0.85
Fundamental voltage (target)	425 v

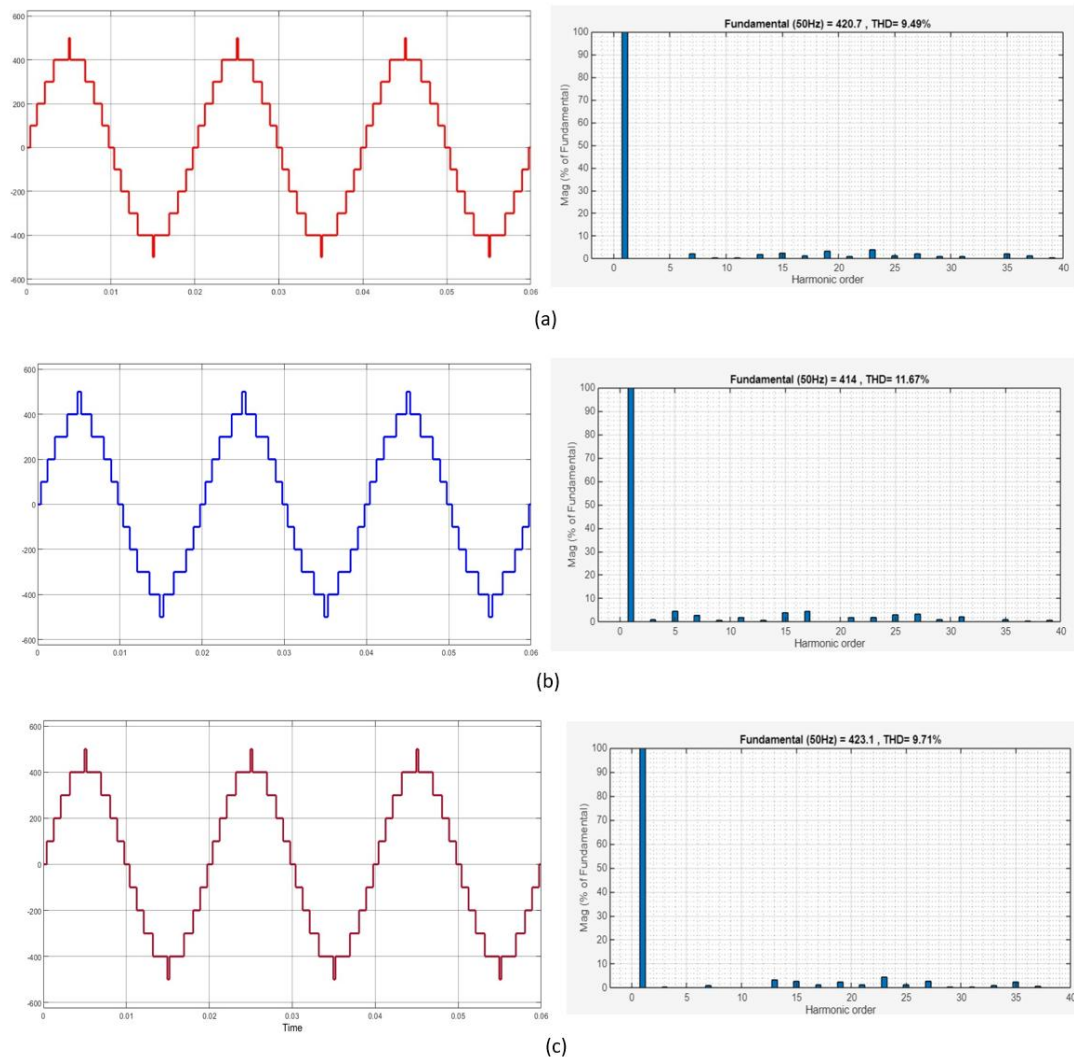


Figure 7. A 11-level cascaded H-Bridge inverter output voltage wave and harmonic spectrum at modulation index = 0.85 of (a).GA (b). GSA (c). PSO.

Table 3 compares the THD values obtained in this work with those reported in recent SHE optimization studies for various multiple-inverter systems. The comparison evaluates the harmonic reduction performance of the optimization algorithms investigated and places the proposed

approach in relation to the existing literature. The results show that the proposed method achieves competitive harmonic performance under the specified operating conditions.

Table 3. Comparison of harmonic elimination performance and THD values with recent optimization-based SHE studies.

Scheme	Level	Algorithm	Harmonics _{3,5,7}	THD%	Ref
CHB	7	GA	Low	8.66	[26]
	7	GSA	High	17.07	[27]
	7	PSO	Low	10.87	[25]
	11	GA	Low	9.49	This work
	11	GSA	Low	11.67	This work
	11	PSO	Near zero	9.71	This work

Differences in the results obtained may be attributed to the optimization algorithms' search strategies. PSO converged to a viable solution with fewer iterations due to its efficient particle update mechanism. At the same time, GA achieved the lowest THD by more effectively exploring the space through its mutation and crossover operators. On the other hand, GSA showed a relatively lower harmonic performance for the given SHE optimization problem, which can be attributed to its gravity search mechanism. These observations show that the choice of optimization algorithm affects both the convergence properties and the harmonic performance of the solution of the SHE.

5. CONCLUSION

This study compares optimization-based methods for determining switching angles using the Selective Harmonic Elimination (SHE) approach to reduce Total Harmonic Distortion (THD) in the output voltage of a multi-level inverter. Suppressing low-order harmonics while maintaining the intended essential output voltage is the goal of the optimization procedure. The performance of three popular optimization algorithms—the Genetic Algorithm (GA), Gravity Search Algorithm (GSA), and Particle Swarm Optimization (PSO)—in solving the nonlinear SHE equations was assessed under identical operating conditions. The results obtained showed that all the algorithms tested were able to find viable solutions and improve harmonic performance. Among the methods assessed, PSO showed competitive performance in optimization, while GA had the lowest THD (9.49), and PSO was close behind (9.71). The GSA algorithm yielded the highest THD (11.67) under the same operating conditions. These results show that both GA and PSO provide effective solutions to the SHE problem, with GA offering a slight advantage in reducing THD.

In addition, PSO has demonstrated faster convergence, achieving a feasible optimal solution in fewer iterations than GA, while maintaining a competitive level of harmony. GA, on the other hand, achieved the lowest THD among the algorithms tested, indicating its efficiency in harmonic reduction. Overall, the comparative analysis confirms that both PSO and GA provide reliable and effective solutions for optimizing SHE in multi-level inverters. In addition, the proposed approach may be extended to other nonlinear optimization problems in electrical engineering and power electronics.

Future work will focus on extending the assessment of the proposed method to a broader range of modulation indices and, further, on investigating its robustness and efficiency under different operational conditions.

CONFLICT OF INTEREST

The authors affirm that they have *no conflicts* of interest with relation to this paper's publication.

REFERENCES

- [1] V. Kaviya and V. Kirubakaran, "A review of inverter designs for solar PV systems and their performance enhancement via intelligent FACTS-based grid support," *Discover Applied Sciences* 2026, Jun. 2026, doi: 10.1007/S42452-026-08955-W.
- [2] S. M. Baraa, H. Desa, K. S. Mohammed, and T. A. Al-malaisi, "Selective Harmonic Elimination in Reduced-Switch Multi-level Inverters for PV Systems Using the Sparrow Search Algorithm," vol. 6, no. 1, 2025, doi: 10.18196/jrc.v6i1.25108.
- [3] M. Salem, A. Richelli, K. Yahya, M. N. Hamidi, T. Z. Ang, and I. Alhamrouni, "A Comprehensive Review on Multi-level Inverters for Grid-Tied System Applications," *Energies* 2022, Vol. 15, Page 6315, vol. 15, no. 17, p. 6315, Aug. 2022, doi: 10.3390/EN15176315
- [4] M. Wu et al., "A Generalized Selective Harmonic Elimination PWM Formulation With Common-Mode Voltage Reduction Ability for Multi-level Converters," *ITPE*, vol. 36, no. 9, pp. 10753–10765, Sep. 2021, doi: 10.1109/TPEL.2021.3063299.
- [5] M. Jahnes and M. Preindl, "Controllability Techniques for the Multi-level Power Converter Manhattan Topology," 2023 IEEE Transportation Electrification Conference & Expo (ITEC), Detroit, MI, USA, 2023, pp. 1-5, doi: 10.1109/ITEC55900.2023.10186913.
- [6] M. Sharifzadeh, G. Chouinard, and K. Al-haddad, "Compatible Selective Harmonic Elimination for Three-Phase Four-Wire NPC Inverter with DC-Link Capacitor Voltage Balancing," vol. 3203, no. c, 2019, doi: 10.1109/TII.2019.2934467.
- [7] I. Khoukha, C. Hachemi and B. El Madjid, "Multi-level selective harmonic elimination PWM technique in the nine level voltage inverter," 2007 International Conference on Computer Engineering & Systems, Cairo, Egypt, 2007, pp. 387-392, doi: 10.1109/ICCES.2007.4447075.
- [8] K. A. Mahafzah, R. M. Negry, M. A. Obeidat, and H. Alsalem, "An improved modulation technique suitable for a three level flying capacitor multi-level inverter," vol. 14, no. 3, pp. 2522–2532, 2024, doi: 10.11591/ijece.v14i3.pp2522-2532.
- [9] S. A and H. R. Ramesh, "Chao Orangutan Optimized Cascaded Controller for 5-Level Asymmetrical Multi-Level Inverter to Improve Stability in Islanded Microgrid," 2025 3rd International Conference on Self Sustainable Artificial Intelligence Systems (ICSSAS), Erode, India, 2025, pp. 239-245, doi: 10.1109/ICSSAS66150.2025.11080836.
- [10] A. B. Barnawi, A. R. A. Alfifi, Z. M. S. Elbarbary, S. F. Alqahtani, and I. M. Shaik, "Review of multi-level inverter for high-power applications," *Frontiers in Engineering and Built Environment*, vol. 4, no. 2, pp. 77–89, May 2024, doi: 10.1108/FEBE-05-2023-0020.
- [11] N. I. Siddiqui et al., "Artificial Jellyfish Search Algorithm-Based Selective Harmonic Elimination in a Cascaded H-Bridge Multi-level Inverter," *Electronics* 2021, Vol. 10, Page 2402, vol. 10, no. 19, p. 2402, Oct. 2021, doi: 10.3390/ELECTRONICS10192402.
- [12] O. A. Y. Amran, N. A. Windarko, I. Syarif, and T. B. J. Gemilang, "Application of the Newton–Raphson algorithm for enhanced harmonic reduction in seven-level packed U-cell multi-level inverters," *Electrical Engineering & Electromechanics*, vol. 2026, no. 3, pp. 79–84, May 2026, doi: 10.20998/2074-272X.2026.3.12.
- [13] Y. Yu, J. Wang, F. Meng, and D. Cao, "Intelligent Solution for Switching Angles in Multi-Level SHEPWM: An Application of an Enhanced BKA Algorithm," *Electronics* 2026, Vol. 15, Page 1350, vol. 15, no. 7, p. 1350, Mar. 2026, doi: 10.3390/ELECTRONICS15071350.
- [14] H. Iqbal and A. Sarwat, "Improved Genetic Algorithm-Based Harmonic Mitigation Control of an Asymmetrical Dual-Source 13-Level Switched-Capacitor Multi-level

- Inverter," *Energies* 2025, Vol. 18, Page 35, vol. 18, no. 1, p. 35, Dec. 2024, doi: 10.3390/EN18010035.
- [15] M. Tabrez, P. K. Sadhu, A. Iqbal, M. A. Husain, F. I. Bakhsh, and S. P. Singh, "Equivalent circuit modelling of a three-phase to seven-phase transformer using PSO and GA," *Journal of Intelligent and Fuzzy Systems*, vol. 42, no. 2, pp. 689–698, 2022, doi: 10.3233/JIFS-189741.
- [16] A. Singh, A. Kumari, A. R. Singh, A. Kumar, and P. Kumar, "A Reduced Switch Single-Source Multi-level Inverter with GA-Based Selective Harmonic Elimination," vol. 55, no. 1, pp. 157–174, 2026, doi: 10.2478/pead-2026-0010.
- [17] V. Singh, S. Gupta, and S. Pattnaik, "Modified GSA for minimisation of THD of voltage source multi-level inverter," *International Journal of Power Electronics*, vol. 12, no. 2, pp. 191–212, 2020, doi: 10.1504/IJPELEC.2020.108841.
- [18] M. S. A. Dahidah, G. Konstantinou, and V. G. Agelidis, "A Review of Multi-level Selective Harmonic Elimination PWM: Formulations, Solving Algorithms, Implementation and Applications," *IEEE Transactions on Power Electronics*, vol. 30, no. 8, pp. 4091–4106, 2015, doi: 10.1109/TPEL.2014.2355226.
- [19] G. K. Devineni and A. Ganesh, "Problem Formulations, Solving Strategies, Implementation Methods & Applications of Selective Harmonic Elimination for Multi-level Converters", doi: 10.18280/jesa.530620.
- [20] M. Ali, M. Tariq, R. K. Chakraborty, M. J. Ryan, B. Alamri and M. A. Bou-Rabee, "11-Level Operation With Voltage-Balance Control of WE-Type Inverter Using Conventional and DE-SHE Techniques," in *IEEE Access*, vol. 9, pp. 64317–64330, 2021, doi: 10.1109/ACCESS.2021.3072905.
- [21] N. El Houda Gabour, F. Habbi, M. Bounekhla and E. G. Boudissa, "Enhanced Harmonic Elimination Using Genetic Algorithm Optimization in Multi-level Inverters," 2021 18th International Multi-Conference on Systems, Signals & Devices (SSD), Monastir, Tunisia, 2021, pp. 323–329, doi: 10.1109/SSD52085.2021.9429364.
- [22] P. L. Kamani, R. K. Patel, M. K. Kathiria, D. P. Majithiya, and J. H. Brahmkhatri, "Implementing selective harmonic elimination in multi-level inverters with optimal dc source," *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 8, p. 100622, Jun. 2024, doi: 10.1016/J.PRIME.2024.100622.
- [23] A. S. Pabbewar and M. Kowsalya, "Three Level Neutral Point Clamped Inverter Using Space Vector Modulation with Proportional Resonant Controller," *Energy Procedia*, vol. 103, pp. 286–291, Dec. 2016, doi: 10.1016/J.EGYPRO.2016.11.287.
- [24] O. Sánchez Vargas, L. G. Vela Valdés, M. Borunda, R. E. Lozoya-Ponce, J. Aguayo Alquicira, and S. E. De León Aldaco, "ANFIS-PSO-Based Optimization for THD Reduction in Cascaded Multi-level Inverter UPS Systems," *Electronics* 2024, Vol. 13, Page 4456, vol. 13, no. 22, p. 4456, Nov. 2024, doi: 10.3390/ELECTRONICS13224456.
- [25] 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.
- [26] V. Singh, S. Pattnaik, and S. Gupta, "Application of Curve Fitting Techniques Using Soft Computing Techniques (GA, GSA, POS AND NR) in Multi-level Inverters for Harmonic Minimization," *Journal of Engineering Science and Technology*, vol. 12, no. 12, pp. 3358–3375, 2017.