Materials Research Proceedings 64 (2026) 872-879 https://doi.org/10.21741/9781644904091-108

Selective Harmonic Elimination in Multilevel Inverters Using Metaheuristic Optimization Algorithms: A MATLAB-Based Simulation Study

Taha Ahmad HUSSEIN[1,a*], Dahaman ISHAK[2,b], Muhammad Najwan HAMIDI[3,c], Jawad Hasan Alkhateeb[2,d]

[1]Northern Technical University, Mosul, Iraq

[2]Prince Mohammed Bin Fahd University Al Khobar 31952, Saudi Arabia

[3]School of Electrical Engineering, Nibong Tebal, 14300 Malaysia

[a]taha.hussein@ntu.edu.iq, [b]dbinishak@pmu.edu.sa, [c]najwan@usm.my, [d]Jalkateeb@pmu.edu.sa

Keywords: SHE, MLI, Metaheuristic Optimization Algorithms, THD

Abstract. Optimizing switching angles in multilevel inverters is explored in this study based on MATLAB simulation. The objective is to achieve selective harmonic elimination (SHE) to eliminate specific low order harmonics while having the fundamental output voltage. The work emphases solution of transcendental equations in SHE for a range of modulation indices from 0 to 1 by employing a group of metaheuristic algorithms including genetic algorithm (GA), gray wolf optimization (GWO), particle swarm optimization (PSO), slim Mould algorithm (SMA), and whale optimization algorithm (WOA). The algorithm performance in terms of the total harmonic distortion (THD) governs the selection of the optimal switching angles for a specific value of the modulation index. The analysis and visualization of algorithm performance are tested within MATLAB environment which offers insights into the effectiveness of biologically inspired optimization techniques for power quality enhancement in multilevel inverter systems.

Introduction

Due to their efficient ability to construct near sinusoidal waveforms with reduced harmonic distortion, Multilevel inverters (MLIs) are employed in applications ranging from medium to high voltage applications [1-3]. Solving non-linear equations association staircase multilevel voltage construction is the key concept that targets specific low order harmonics based on SHE concepts. The complexity increases as the number of inverter levels increases, necessitating the use of advanced optimization techniques [4-9]. One of the developing tools for solving SHE problems emerged from metaheuristic algorithms [10-11]. Brahmbhatt et al. showed the effectiveness of PSO in a five-level cascaded H-bridge topology [12]. Ürgün et al. (2023) evaluated 22 algorithms including GA and GWO for multi-inverter levels, showing that algorithmic performance varies with range of modulation index and inverter topology [13]. Karmakar et al. (2024) emphasized the engagement of PSO and IPSO in achieving low THD in 7- and 15-level inverters, consistent with IEEE 519 standards [14]. Although significant progress has been made, the majority of (SHE) implementations are still restricted to MATLAB simulation, which provides comprehensive capabilities for modeling, optimization, and waveform analysis. Based on earlier algorithmic contributions, this study emphases multiple optimization strategies within a MATLAB-based comparative framework. The objective is to determine the optimal switching angles corresponding to each modulation index and to assess the effectiveness of the algorithms with respect to harmonic elimination and waveform accuracy.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 license. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under license by Materials Research Forum LLC.

Methodology

The MATLAB-based methodology comprises four essential stages; the first is the formation of SHE transcendental equations using Fourier analysis for a 31-level single-phase inverter. Harmonics are selected for cancellation, and constraints are introduced to secure achievable switching angles. In the second stage, Metaheuristic optimization algorithms (PSO, GA, GWO, SMA, WOA) are developed in MATLAB. Each algorithm searches for optimal switching angles across modulation indices ranging from 0.1 to 1. In the third stage comparative selection algorithmic outcomes are evaluated based on total harmonic distortion (THD), harmonic spectrum, and waveform quality. The best-performing angles are selected for each modulation index. In the final stage simulation and visualization MATLAB's signal processing toolbox is used to generate output waveforms and harmonic spectra. Comparative plots and performance metrics highlight the strengths and limitations of each algorithm.

Mathematical formulation of SHE problem

The SHE problem is formulated by expressing the output voltage of proposed 31-level single-phase inverter as a Fourier series. The objective is to eliminate selected low-order harmonics (typically the 3rd, 5th, 7th,9th,11th,13th,15th,17th,19th,21st,23rd,25th ,27th, and 29th) while preserving the fundamental component. The Fourier series for the general stair waveform of the inverter output can be written as [15]:

$$v_o(t) = a_0 + \sum_{n=1}^{\infty} a_n cos(nwt) + b_n \sin(nwt) \quad (1)$$

Where: n is the harmonic order, a_0, a_n, $and\ b_n$ are the Fourier coefficients, w is the angular frequency. Due to the quarter symmetry around π/2 of the staircase waveform, a_0, a_n, and the sine terms of even harmonics are canceled. As a result, the equation (1) is reduced to:

$$v_o(t) = \sum_{n=1,3,5,7....}^{29} b_n \sin(nwt) \quad (2)$$

With 31-levels at the output of the single-phase MLI, fourteen harmonics, i.e. 3,5,7,9,11,13,15, 17,19,21,23,25,27and 29 harmonics, can be eliminated or reduced to low values. The optimal fifteen gating angles

($_1$, α_2, α_3, α_4, α_5, α_6, α_7, α_8, α_9, α_{10} , α_{11}, α_{12}, α_{13}, α_{14}, and 15) for the drive switches can be found as follows:

$$b_1 = [\ cos\alpha_1 + cos\alpha_2 + cos\alpha_3 + cos\alpha_4 + cos\alpha_5 + cos\alpha_6 + cos\alpha_7 + cos\alpha_8 + cos\alpha_9 + cos\alpha_{10} + cos\alpha_{11}, cos\alpha_{12} + cos3\alpha_{13} + cos\alpha_{14} + cos\alpha_{15}] = m * V1(rms)$$

where m is the modulation index, and V_1 is the fundamental component

$$b_3 = [\ cos3\alpha_1 + cos3\alpha_2 + cos3\alpha_3 + cos3\alpha_4 + cos3\alpha_5 + cos3\alpha_6 + cos3\alpha_7 + cos3\alpha_8 + cos3\alpha_9 + cos3\alpha_{10} + cos3\alpha_{11}, cos3\alpha_{12} + cos3\alpha_{13} + cos3\alpha_{14} + cos3\alpha_{15}] = 0.$$

$$b_5 = [\ cos5\alpha_1 + cos5\alpha_2 + cos5\alpha_3 + cos5\alpha_4 + cos5\alpha_5 + cos5\alpha_6 + cos5\alpha_7 + cos5\alpha_8 + cos5\alpha_9 + cos5\alpha_{10} + cos5\alpha_{11}, cos5\alpha_{12} + cos5\alpha_{13} + cos5\alpha_{14} + cos5\alpha_{15}] = 0.$$

$$b_{29} = [\ cos29\alpha_1 + cos29\alpha_2 + cos29\alpha_3 + cos29\alpha_4 + cos29\alpha_5 + cos29\alpha_6 + cos29\alpha_7 + cos29\alpha_8 + cos29\alpha_9 + cos29\alpha_{10} + cos29\alpha_{11} + cos29\alpha_{12} + cos29\alpha_{13} + cos29\alpha_{14} + cos29\alpha_{15}] = 0$$

Provided that $0 < \alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5 < \alpha_6 < \alpha_7 < \alpha_8 < \alpha_9 < \alpha_{10} < \alpha_{11} < \alpha_{12} < \alpha_{13} < \alpha_{14} < \alpha_{15} < \pi/2$ (3)

The solution of the trigonometric equations to extract the optimal angles will eliminate the harmonics stipulated in the equations, and thus many harmonics will be eliminated, even if their impact is limited on the efficiency of MLI, for instants 17th , 19th , 23rd , 25th , 27th,and 29th where harmonics position has been in high order and the harmonic content is low.

Materials Research Proceedings 64 (2026) 872-879 https://doi.org/10.21741/9781644904091-108

Optimization algorithm deployment

To solve the SHE equations, multiple metaheuristic algorithms are employed, including (PSO), (GA) , (GWO), (SMA) and (WOA). Each algorithm is executed across a defined range of modulation indices (e.g., 0.1 to 1), generating candidate switching angle sets. The fitness function is designed to minimize total harmonic distortion (THD) while satisfying SHE constraints.

Results and discussion

For each modulation index, the switching angle set yields the lowest THD, and best waveform quality is selected from among the algorithmic outputs. This comparative selection ensures that only the most effective solution regardless of algorithm origin is used as shown for the optimum THD dotted curve in Fig. 1. The optimized angles in relation to modulation index for PSO, GA, GWO, SMA, and WOA are shown in figures (2a, b, c, d and e) respectively. These figures contain multiple curves, each representing a different alpha parameter (α_1 *to* α_{15}). The selected angle sets are stored in lookup tables indexed by modulation level. For instance, modulation index m= 0.75 is selected, and the optimal angles were extracted from the optimum THD curve as follows:

$\alpha_1 = 2.5°$, $\alpha_2 = 6°$, $\alpha_3 = 9.5°$, $\alpha_4 = 15.1°$, $\alpha_5 = 19.2°$, $\alpha_6 = 24°$, $\alpha_7 = 28.2°$, $\alpha_8 = 33.1°$, $\alpha_9 = 39.2°$, $\alpha_{10} = 44.1°$, $\alpha_{11} = 51.2°$, $\alpha_{12} = 60.2°$, $\alpha_{13} = 67.5°$,

$\alpha_{14} = 79.1°$, *and* $\alpha_{15} = 88°$

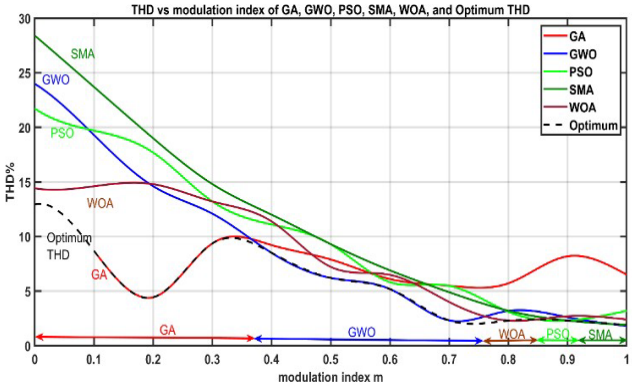


Fig. 1 Optimum THD curve selection

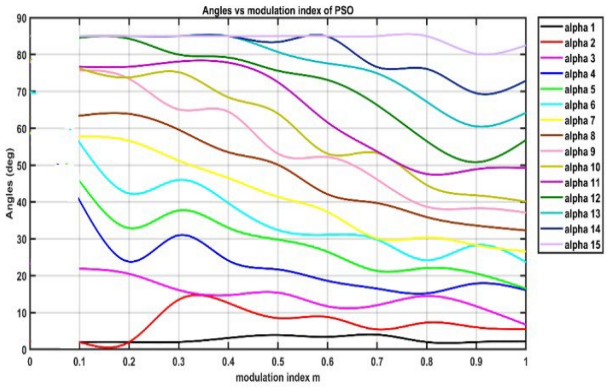


Fig. 2a Angles in relation to (m) for PSO

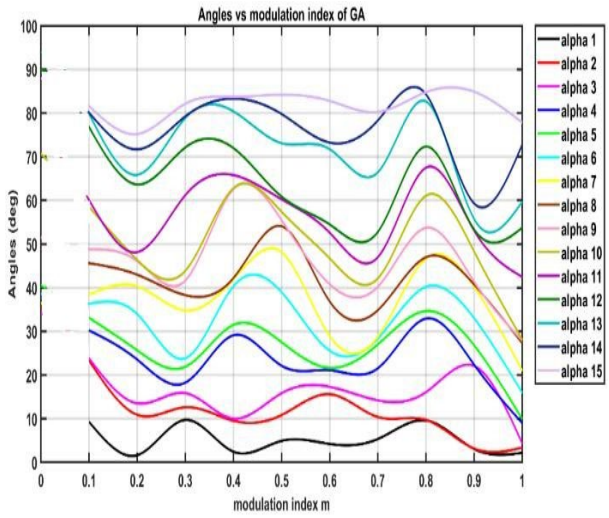


Fig. 2b Angles in relation to (m) for GA

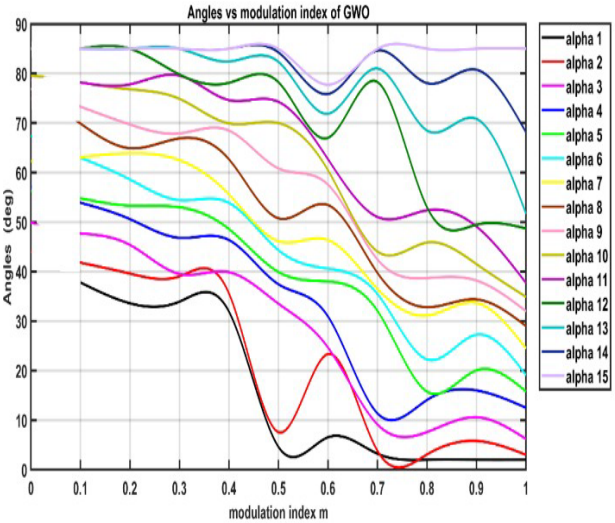


Fig. 2c Angles in relation to (m) for GWO

Materials Research Proceedings 64 (2026) 872-879 https://doi.org/10.21741/9781644904091-108

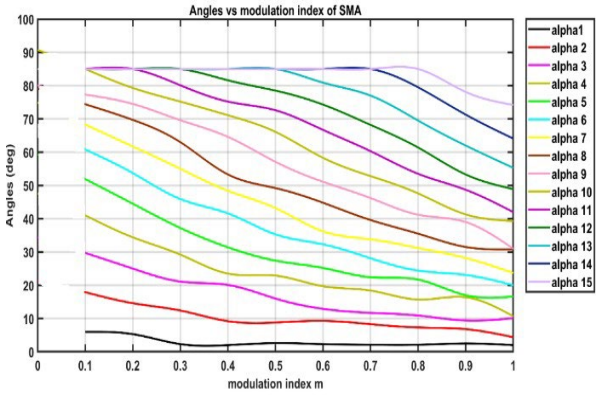


Fig. 2d Angles in relation to (m) for SMA

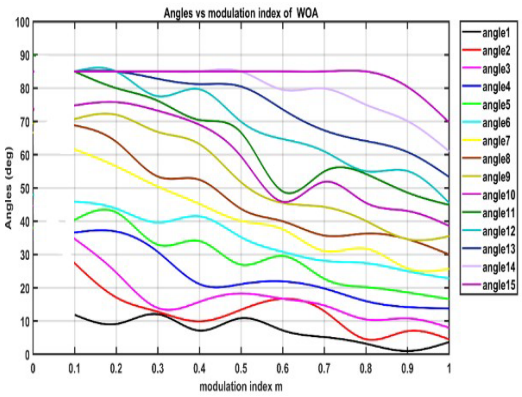


Fig. 2e Angles in relation to (m) for WOA

Fig. 3 demonstrates the step-by-step voltage level, showing the waveform progression from 0 to 15 positive levels. Same procedure is followed by 15 negative levels forming a symmetric multilevel output. The number of levels obtained in the inverter depends on the number of basic units. Each basic unit uses two DC sources, and therefore the total number of levels is

$$number\ of\ leveles = 2^n - 1 \tag{4}$$

where n is number of DC sources. For instance, A single unit in Fig. 4 have two DC sources, namely V_1= VDC and V_2= $2V_{DC}$ with power switches (S1, S2, S5, S6, S9 and S10) produces 3 levels at the positive cycle and 3 levels at the negative cycle with a total of 7 levels when the zero level is added. Fig. 4 displays the circuit topology used to achieve 31 voltage levels includes power switches (S1, S2, S3, S4, S5, S6, S7, S8, S9 and S10), DC sources (V_1=Vdc, V_2=2Vdc, V_5=5Vdc, and V_{10} =10Vdc). As the number of levels in a multilevel inverter increase, THD decreases. This is because more voltage steps allow the output waveform to approximate a pure sine wave more closely, reducing harmonic content and improving power quality.

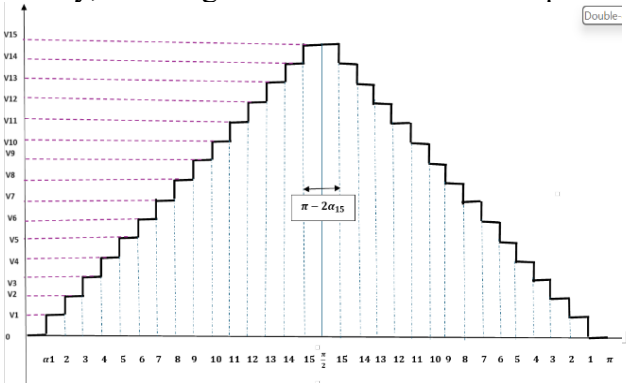


Fig. 3 synthesis of 31-levels

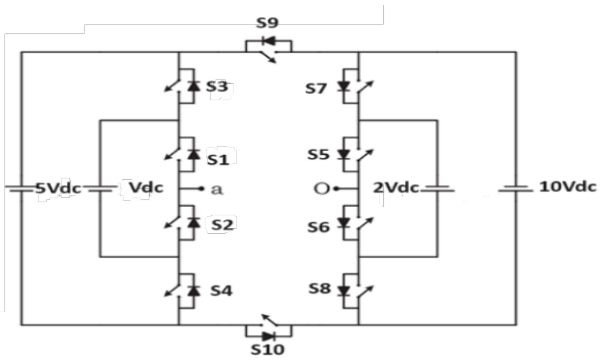


Fig. 4 31-level inverter topology

Table 1 defines how combinations of ten switches (S1 to S10) are activated to generate each of the 16 positive voltage levels (from level 0 to level 15). Each row corresponds to a specific level and includes switching configuration: Binary states (1 = ON, 0 = OFF) for switches S1 through S10, level index indicates which output voltage level is being synthesized, duration calculates time interval associated with that level and DC sources involved which specifies which voltage sources contribute to the output at that level.

Materials Research Proceedings 64 (2026) 872-879 https://doi.org/10.21741/9781644904091-108

Table 1 Switches statues for construction of 31-levels

S1 S2 *	S3 S4 *	S5 S6 *	S7 S8 *	S9 S10 *	Level	Duration	DC sources
1	1	1	1	1	0	Φ_1	No DC source
0	1	1	1	1	1	$\Phi_2 - \Phi_1$	V_1
1	1	0	1	1	2	$\Phi_3 - \Phi_2$	V_2
0	1	0	1	1	3	$\Phi_4 - \Phi_3$	V_1+V_2
1	0	1	1	1	4	$\Phi_5 - \Phi_4$	$V_5 - V_1$
0	0	1	1	1	5	$\Phi_6 - \Phi_5$	V_5
1	0	0	1	1	6	$\Phi_7 - \Phi_6$	$V_5 + V_2 - V_1$
0	0	0	1	1	7	$\Phi_8 - \Phi_7$	$V_5 + V_2$
1	1	1	0	1	8	$\Phi_9 - \Phi_8$	$V10 - V2$
0	1	1	0	1	9	$\Phi10 - \Phi9$	$V10 - V2 + V1$
1	1	0	0	1	10	$\Phi11 - \Phi10$	V_{10}
0	1	0	0	1	11	$\Phi12 - \Phi11$	$V10 + V1$
1	0	1	0	1	12	$\Phi13 - \Phi12$	$V10 - V2 - V1 + V5$
0	0	1	0	1	13	$\Phi14 - \Phi13$	$V10 - V2 + V5$
1	0	0	0	1	14	$\Phi15 - \Phi14$	$V10 - V1 + V5$
0	0	0	0	1	15	$\pi - 2\Phi_{15}$	$V10 + V5$

Currents path shown in Fig. 5 Illustrates how current flows through switches and sources for the first three voltage levels. Remaining levels can be drawn according to table 1.

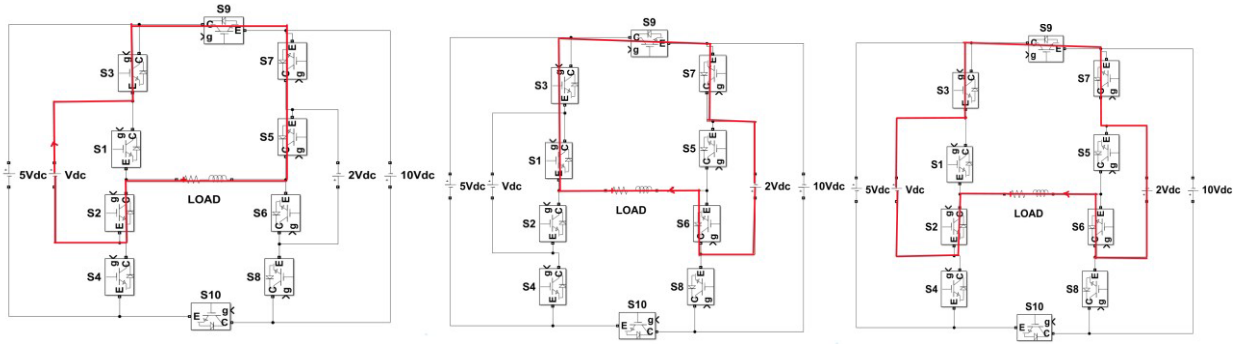
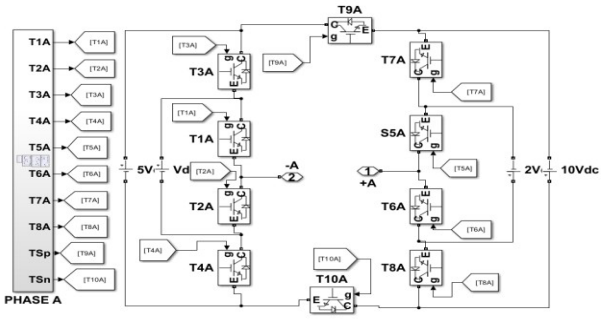


Fig. 5 current path for first level second level and 3rd levels

The Simulink blocks for the 31-level inverter shown in Fig. 6 show the MATLAB/Simulink model structure and include blocks for switches, control logic, sources, and load (MATLAB R2024a , toolbox Powertrain Block set). Fig. 7 illustrates the details of the logic used to generate gate signals for switches S1–S10.

Materials Research Proceedings 64 (2026) 872-879 https://doi.org/10.21741/9781644904091-108



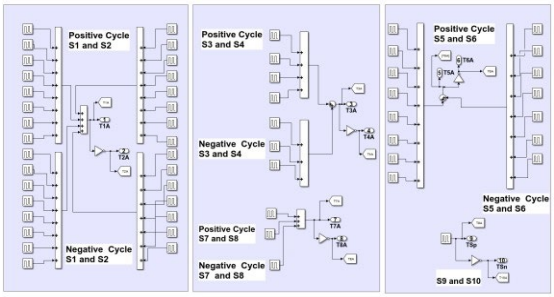


Fig. 6 Simulink blocks for the inverter *Fig. 7 Gating synthesis for the ten switches*

Timing diagrams of gate signals is shown in Fig. 8 which verify synchronization and switching sequence.

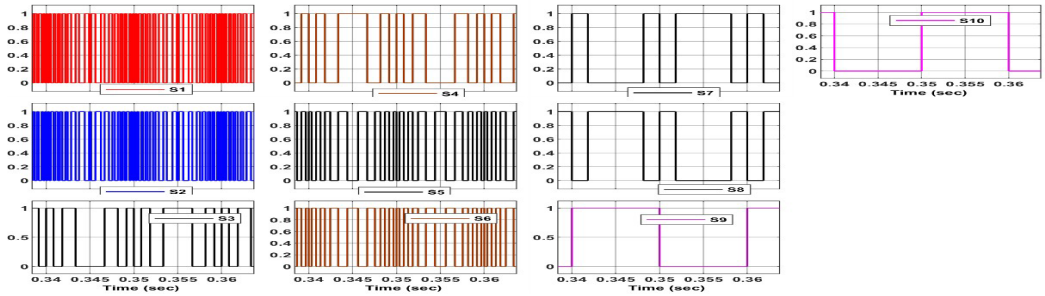
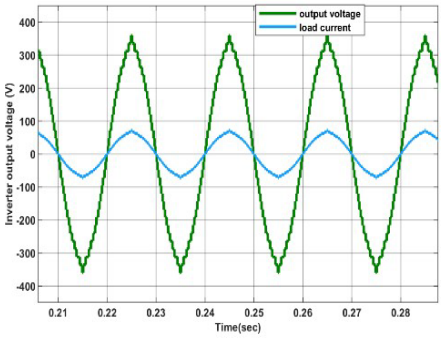
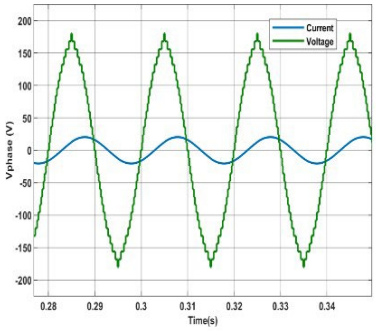


Fig. 8 Gating pulses for the inverter switches

Voltage and current waveforms for resistive (R=5Ω) and inductive loads (R=5Ω, L=20mH) are shown in Fig. 9 and 10 respectively. Fig. 11 simulates motor performance for two external torques at simulations times=0.4sec and 0.6 sec respectively and is useful for dynamic response and control validation.





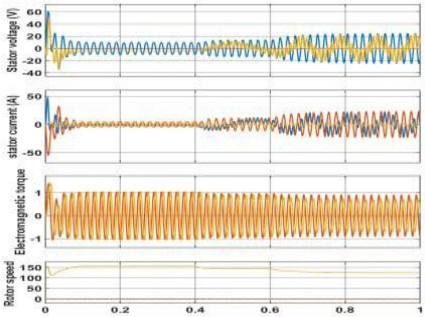


Fig. 9 Output for resistive load *Fig. 10 Output for inductive load* *Fig. 11 Motor parameters*

Total harmonic distortion THD% =4% for 31-level inverter output voltage waveform is illustrated in Fig. 12 which is below the standard 5% stated at IEEE 519 standards and indicates quality of synthesized waveform while Fig. 13 shows THD%=0.62% for current under inductive load conditions.

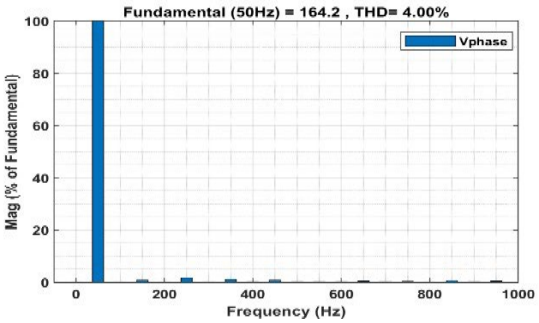


Fig. 12 THD for the output voltage

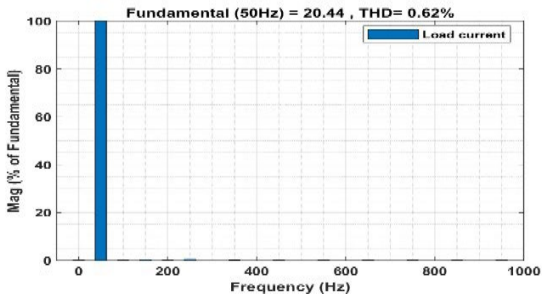


Fig. 13 THD for the inductive load current

Simulation results demonstrate that biologically inspired algorithms offer diverse performance profiles depending on the modulation index and harmonic targets. PSO and GA consistently yield low THD values in mid-range modulation indices, while GWO and SMA show superior convergence behavior in higher-level configurations. WOA ensures waveform symmetry and minimizes the distribution of switching angles. Optimized angles prove effective in harmonic suppression, as verified by visual inspection of output waveforms. Comparative THD results show that each algorithm has strengths and weaknesses depending on the test case, requiring application-based selection. It is suggested to extend the MATLAB-based 31-level inverter design to FPGA implementation for experimental validation. This will confirm simulation results and enable optimization of control strategies for real-time applications.

Conclusion

Switching angle optimization in multilevel inverters is achieved through a MATLAB-based selective harmonic elimination environment. Multiple metaheuristic algorithms are integrated and tested across modulation indices, exposing their respective strengths and optimization constraints. The study confirms MATLAB works well for algorithm development, comparative analysis, and waveform visualization in SHE. Table 2 illustrates the performance of each algorithm across modulation indices.

Table 2 Performance of each algorithm vs modulation indices

Modulation index range	Algorithm used
0-0.38	GA
0.39-0.75	GWO
0.76-0.85	WOA
0.86-0.92	PSO
0.93 -1	SMA

Further development may involve embedded real-time validation, adaptive algorithm choice, and integration with grid systems. This work advances inverter control methods and supports the development of efficient power conversion systems.

References

[1] Xie, J. Application of optimized photovoltaic grid-connected control system based on modular multilevel converters. Energy Inform 7, 24 (2024). https://doi.org/10.1186/s42162-024-00317-3

[2] Vaidya, S.; Prasad, K.; Kilby, J. The Role of Multilevel Inverters in Mitigating Harmonics and Improving Power Quality in Renewable-Powered Smart Grids: A Comprehensive Review. Energies 2025, 18, 2065. https://doi.org/10.3390/en18082065

[3] V. V. A. B, K. Srinivas, J. V. Kumar and D. B. Apoor, "Comprehensive Analysis of Integrated Renewable Energy Resources Based Multi-Level Inverter Fed Various Motors Drives," 2025 6th International Conference for Emerging Technology (INCET), BELGAUM, India, 2025, pp. 1-6, doi: 10.1109/INCET64471.2025.11140879

[4] Hussein, T.A.; Ishak, D.; Tarnini, M. A Three-Phase Multilevel Inverter Synthesized with 31 Levels and Optimal Gating Angles Based on the GA and GWO to Supply a Three-Phase Induction Motor. Energies 2024, 17, 1267. https://doi.org/10.3390/en17051267.

[5] Sharma, B., Manna, S., Saxena, V. et al. A comprehensive review of multi-level inverters, modulation, and control for grid-interfaced solar PV systems. Sci Rep 15, 661 (2025). https://doi.org/10.1038/s41598-024-84296-1.

[6] Bughneda, A.; Salem, M.; Richelli, A.; Ishak, D.; Alatai, S. Review of Multilevel Inverters for PV Energy System Applications. Energies 2021, 14, 1585. https://doi.org/10.3390/en14061585.

[7] Jarjes, Muhammmed. (2023). "Comparative study of SPWM and SVPWM techniques for the control of threephase grid connected inverter" . PRZEGLĄD ELEKTROTECHNICZNY. 1. 116-121. 10.15199/48.2023.05.21.

[8] Xin-She Yang “Benchmarks and hybrid algorithms in optimization and applications”, SPRINGER , https://doi.org/10.1007/978-981-99-3970-1

[9] T. A. Hussein, "Voltage Spikes and Harmonics Reduction for Inductive Load Single Phase Matrix Converter Using MATLAB," 2009 Second International Conference on Computer and Electrical Engineering, Dubai, United Arab Emirates, 2009, pp. 219-223, doi: 10.1109/ICCEE.2009.8.

[10] Sharma, P. V. V. R., & K, N. (2024). A review on intelligence algorithms for THD minimization in multi-level inverter. International Journal of Modelling and Simulation, 45(5), 1671–1687. https://doi.org/10.1080/02286203.2023.2298174.

[11] T. A. Hussein and D. Ishak, "Three-phase MLI with Reduced Number of Switches and Hybrid Optimized Switching," 2023 International Conference on Energy, Power, Environment, Control, and Computing (ICEPECC), Gujrat, Pakistan, 2023, pp. 1-6, doi: 10.1109/ICEPECC57281.2023.10209481.

[12] Bhavik Brahmbhatt. (2024). Selective Harmonics Elimination Technique using Particle Swarm Optimization algorithms in Multilevel H_5 Inverter Topology. International Journal of Intelligent Systems and Applications in Engineering, 12(21s), 4542.

[13] Yiğit, H., Ürgün, S. & Mirjalili, S. Comparison of recent metaheuristic optimization algorithms to solve the SHE optimization problem in MLI. Neural Comput & Applic 35, 7369–7388 (2023). https://doi.org/10.1007/s00521-02207980-1.

[14] Karmakar, S., Singh, B. Selective Harmonic Elimination Modulated Multipulse Voltage Source Converter for Grid Tied Solar Photovoltaic with Battery Energy Storage. Trans Indian Natl. Acad. Eng. 10, 609–619 (2025). https://doi.org/10.1007/s41403-025-00541-7.

[15] M.H.Rashid, Power electronics circuits, devices and applications, 3rd edition 2004, pearson prentice hall