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Application of the Newton–Raphson algorithm for enhanced harmonic reduction in seven-level packed U-cell multilevel inverters

Introduction. *Recently, multilevel inverters (MLIs) have been widely investigated for industrial and renewable energy systems as they are valuable in applications where they can produce clean, high-fidelity electrical signals that minimize harmonic content and distortion.* ***Problem***. *Among the modulation strategies, selective harmonic elimination pulse width modulation (SHE-PWM) is highly effective, but solving its nonlinear transcendental equations requires accurate numerical methods.* ***Goal***. *To improve the performance of the 7-level packed U-cell (PUC) inverter by applying the Newton–Raphson method to compute optimal switching angles for SHE-PWM, thereby minimizing total harmonic distortion (THD), improving waveform quality, and achieving a more compact and cost-effective design with fewer components.* ***Methodology***. *The Newton–Raphson iterative algorithm was implemented in MATLAB/Simulink to solve the nonlinear equations of SHE-PWM, and a hardware prototype of the 7-level PUC-MLI was fabricated and tested to validate real-world performance.* ***Results***. *The application of the Newton–Raphson algorithm significantly improved the system's performance. After implementation, the THD was reduced to 13.19 % in the simulation and 18.14 % in the hardware prototype, whereas both initially exhibited considerably higher THD levels.* ***Scientific novelty***. *The proposed method demonstrates the capability of the Newton–Raphson algorithm as a reliable numerical solution for selective harmonic elimination in the 7-level PUC MLI, ensuring rapid convergence and precise determination of switching angles.* ***Practical value***. *The study shows that significant harmonic reduction can be achieved without additional hardware or complex circuitry, making the approach applicable to other inverter topologies and suitable for advanced power electronic and renewable energy systems.* References 22, tables 4, figures 9.

Key words: **multilevel inverter, packed U-cell, selective harmonic elimination, Newton–Raphson algorithm, switching angle optimization, total harmonic distortion**.

Вступ. *Останнім часом багаторівневі інвертори (MLI) активно досліджуються для промислових застосувань та систем відновлюваної енергетики, оскільки вони здатні формувати високоякісні електричні сигнали з мінімальним рівнем гармонік і спотворень.* ***Проблема***. *Серед методів модуляції селективне усунення гармонік на основі широтно-імпульсної модуляції (SHE-PWM) є високоефективним, проте розв'язання відповідних нелінійних трансцендентних рівнянь потребує застосування точних чисельних методів.* ***Мета***. *Підвищення ефективності 7-рівневого багаторівневого інвертора з компактною U-коміркою (PUC) шляхом застосування методу Ньютона–Рафсона для визначення оптимальних кутів перемикання в SHE-PWM з метою зменшення сумарного коефіцієнта гармонічних спотворень (THD), покращення форми вихідної напруги та досягнення більш компактної й економічно ефективної конструкції з меншою кількістю компонентів.* ***Методика***. *Ітераційний алгоритм Ньютона–Рафсона реалізовано в середовищі MATLAB/Simulink для розв'язання нелінійних рівнянь SHE-PWM. Для підтвердження працездатності розроблено та експериментально досліджено апаратний прототип 7-рівневого PUC-інвертора.* ***Результати***. *Застосування алгоритму Ньютона–Рафсона суттєво покращило характеристики системи. Після його впровадження значення THD знижено до 13,19 % у моделюванні та до 18,14 % в експериментальному прототипі, тоді як початково ці значення були вищими.* ***Наукова новизна***. *Запропонований підхід демонструє ефективність методу Ньютона–Рафсона як надійного чисельного інструменту для селективного усунення гармонік у 7-рівневому багаторівневому PUC-інверторі, забезпечуючи швидку збіжність і точне визначення кутів перемикання.* ***Практична значимість***. *Показано, що зменшення гармонік може бути досягнуте без ускладнення апаратної частини чи використання додаткових елементів, що робить запропонований підхід придатним для інших топологій інверторів і перспективним для сучасних систем силової електроніки та відновлюваної енергетики.* Бібл. 22, табл. 4, рис. 9.

Ключові слова: **багаторівневий інвертор, компактна U-комірка, селективне усунення гармонік, алгоритм Ньютона-Рафсона, оптимізація кута перемикання, сумарний коефіцієнт гармонічних спотворень.**

Introduction. The rapid expansion of renewable energy systems, electric vehicles, and distributed energy resources has created an increasing demand for highly efficient power conversion systems that ensure reduced losses and improved power quality. Multilevel inverters (MLIs) are widely recognized as promising solutions because they can synthesize nearly sinusoidal voltage waveforms from multiple voltage levels, thereby lowering device stress and suppressing harmonic distortion [1, 2].

These features make MLIs attractive for medium- and high-power applications where grid compliance and reduced electromagnetic interference are critical [3]. Among the existing MLI topologies, the packed U-cell (PUC) inverter offers significant advantages due to its ability to achieve multiple output voltage levels with fewer power electronic components, making it more compact, cost-effective, and modular. Compared to conventional topologies for instance, neutral point clamped (NPC) and cascaded H-bridge (CHB) converter structures, the PUC inverter demonstrates superior scalability, hardware simplicity, and reduced component count while maintaining high-quality output performance [4, 5]. In particular, the 7-level PUC (7-PUC) inverter provides a practical trade-off between hardware complexity and output waveform quality.

However, a major problem arises from its inherent harmonic distortion, especially low-order harmonics, which degrade voltage quality and shorten the lifetime of connected loads [6]. The selective harmonic elimination pulse width modulation (SHE-PWM) is a powerful modulation approach for minimizing harmonics by calculating optimal switching angles. However, solving the SHE nonlinear transcendental equations requires substantial computational effort, particularly for PUC topologies with asymmetric DC sources where the equations become more complex and convergence of numerical methods is less guaranteed [7]. Optimization techniques such as particle swarm optimization, genetic algorithms and ant colony optimization have been applied to SHE metaheuristic solutions for selective harmonic elimination in MLIs [8, 9], but they typically involve high computational costs and are unsuitable for real-time applications. Alternative control strategies have been explored for harmonic suppression. In [10] fuzzy logic control was proposed for harmonic mitigation in power converters, demonstrating effective reduction of low-order harmonics. In [11] was investigated power quality enhancement in inverter-based renewable energy systems through optimized control strategies. However, these approaches either require complex tuning

procedures or involve higher computational overhead compared to analytical methods In contrast, the Newton–Raphson (NR) method offers fast convergence and high accuracy when provided with good initial estimates, and has been effectively used in other inverter topologies such as CHB and NPC [12, 13]. However, the application of NR to 7-PUC inverters with asymmetric voltage sources remains underexplored, which represents a clear research gap.

This study investigates the application of the NR algorithm to the 7-level PUC inverter under asymmetric DC input conditions with a focus on solving the nonlinear switching angle equations of SHE-PWM. The subject of investigation includes the analysis of harmonic performance, algorithm convergence, and total harmonic distortion (THD) reduction in order to evaluate the feasibility and efficiency of this numerical approach for real-time inverter control.

The goal of this work is to improve the performance of the 7-level PUC inverter by applying the Newton–Raphson method to compute optimal switching angles for SHE-PWM, thereby minimizing THD, improving waveform quality, and achieving a more compact and cost-effective design with fewer components.

The main contributions of this study include:

1) formulation of the SHE-PWM problem for 7-PUC under asymmetric DC sources;

2) implementation of the NR algorithm in Simulink and hardware for computing switching angles and evaluating convergence.

This work demonstrates that the NR algorithm provides a computationally efficient solution with reduced processing demand, making it suitable for real-time applications on microcontrollers such as Arduino, based embedded inverter systems.

Methodology of packed U-cell MLI. The employed circuit topology is a compact and efficient MLI topology designed to generate superior output performance waveforms using a reduced number of components. The inverter comprises three cascaded U-cells, each composed of 2 complementary IGBT switches. The entire mechanism functions using six switches and two primary DC voltage sources [14].

The PUC converter was originally proposed by Al-Haddad in earlier studies and later adapted for 7-level configurations [15]. Figure 1 shows a configuration featuring 6 operational switches and 2 DC sources, namely the 1st and 2nd sources. The significant benefit of PUC lies in the total component count relative to other topologies. A reduced number of switches leads to diminished power losses, fewer gate drives and lower costs. The correlation between the quantity of voltage levels attained and the number of sources employed can be formulated as:

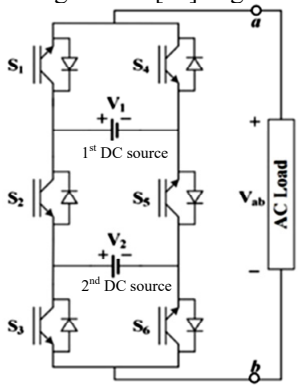

Fig. 1. 7-level PUC inverter

$$N_v = 2^{N_s+1} - 1; \quad (1)$$

$$N_p = 2^{N_s}; \quad (2)$$

where N_v is the number of voltage levels; N_p is the number of power switches; N_s is the number of DC voltage sources.

The PUC configuration achieves elevated voltage generation by reconfiguring the 2nd DC source (V_2) topology, with bottom switches (S_3 and S_6) inverted to suppress unwanted diode conduction. All feasible switching combinations are detailed in Table 2. The inverter produces 7 voltage levels ranging from 0 to 4*E* when V_1 equals $3V_2$. The maximum output voltage of 4*E* results from the series combination of both DC sources.

Table 1

Switching states for 7-PUC inverter

Switching states	S_1	S_2	S_3	S_4	S_5	S_6	Voltages
1	1	0	1	0	1	0	V_1+V_2
2	1	0	0	0	1	1	V_1
3	0	0	1	1	1	0	V_2
4	0	0	0	1	1	1	0
5	1	1	0	0	0	1	$–V_2$
6	0	1	1	1	0	0	$–V_1$
7	0	1	0	1	0	1	$–V_2–V_1$

The study utilizes the SHE-PWM on a 7-PUC inverter to target specific low-order harmonics, primarily the 5th and 7th thereby improving spectral purity by limiting THD. To accomplish this, it is essential to identify 3 switching angles. A notable advantage of the PUC is its utilization of fewer components compared to alternatives such as the CHB, resulting in diminished power losses, reduced gate drive requirements and lower system costs. In this method, 3 switching angles (α_1, α_2, α_3) are determined within the 1st quarter-cycle of the fundamental waveform to shape the stepped output. To ascertain these angles, it is essential to resolve several nonlinear transcendental equations through Fourier analysis. This is subsequently followed by the implementation of the NR method to achieve a prompt and precise solution [16, 17].

The notable advantage of PUC is its reduced component count compared to alternative topologies, such as the CHB, fewer switches result in diminished enhanced efficiency through reduced losses, fewer control circuits, and lower financial investment in the system. The voltage magnitudes produced at the output of the single-phase inverter topology seen in Fig. 1 are enumerated in Table 1. There are 8 possible states, in which S_4, S_5 and S_6 work in reverse with respect to the switches S_1, S_2 and S_3 are controlled in a manner that prevents short circuits across the DC buses. It is important to note that switches S_4, S_5 and S_6 function as complementary pairs to S_1, S_2 and S_3, respectively. As a result, each switch pair (S_1, S_4), (S_2, S_5) and (S_3, S_6) is designed to avoid simultaneous conduction [18]. While the PUC can generate multiple discrete voltage magnitudes from various DC sources, achieving the maximum output voltage V_{ab}. The output voltage V_{ab} can generate 7 distinct levels [19].

Selective harmonic elimination. Various control procedures govern output voltage profiles in converter stages, primarily categorized into 2 types:

- low-frequency switching modulation techniques including phase disposition, phase opposition disposition and SHE;
- high-frequency switching methods employing PWM [20].

SHE decreases switching losses and noise levels, facilitating the use of smaller output filters. It operates by waveform symmetry and advances in a sequentially increasing manner. The design offers a lower number of circuit elements, thereby minimizing power losses and gate drive requirements.

Equation (3) ensures that the switching angles (α_1, α_2, α_3) are properly ordered within one quarter of the output waveform. This constraint maintains the

waveform's symmetry and guarantees correct pulse positioning. It is essential for achieving accurate harmonic elimination using SHE techniques:

$$0 < \alpha_1 < \alpha_2 < \alpha_3 < 90°. \quad (3)$$

Equation (4) defines the modulation index m with respect to the magnitude of the fundamental voltage V_1 relative to the maximum and represents the V_{dc} which is the total direct current supply voltage provided to the inverter:

$$m = \frac{\pi V_1}{4 + 3V_{dc}} =< 3m = \frac{\pi V_1}{4V_{dc}}. \quad (4)$$

Equations (5)–(8) represent the SHE conditions, where the switching angles $\alpha_1 - \alpha_3$ are calculated to achieve the desired modulation index m while eliminating the 3rd, 5th and 7th harmonics from the inverter output voltage:

$$\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3) = 3m; \quad (5)$$

$$\cos(3\alpha_1) + \cos(3\alpha_2) + \cos(3\alpha_3) = 0; \quad (6)$$

$$\cos(5\alpha_1) + \cos 5(\alpha_2) + \cos(5\alpha_3) = 0; \quad (7)$$

$$\cos(7\alpha_1) + \cos(7\alpha_2) + \cos(7\alpha_3) = 0. \quad (8)$$

The resolution of the SHE equations is a significantly non-linear endeavor, as it produces a transcendental system. Traditional methods, such as sequential and recursive algorithms, particularly the NR method, are frequently favored; however, as inverter levels increase, the task becomes more challenging, necessitating more accurate initial estimates [21].

The Newton–Raphson approach is a commonly employed iterative technique for resolving nonlinear equations. It is especially efficacious when an accurate initial estimate is supplied. The approach relies on the Taylor series expansion and linear approximation of the function in question [22]. The standard formulation of the NR method is expressed as:

$$X_{x+1} = X_n - \frac{f(x_n)}{f'(x_n)}, \quad (9)$$

where X_n is the current approximation; X_{n+1} is the next approximation; $f(x_n)$ is the function value at x_n; $f'(x_n)$ is the derivative of the function at X_n.

In the context of SHE, the target is to find the switching angles that resolve the system of nonlinear mathematical models $f^k(\alpha) = 0$. The NR method requires the computation of the Jacobian matrix $\boldsymbol{J}$ of the equations system, which consists of the partial derivatives of the nonlinear functions corresponding to each switching angle

The proposed NR technique begins by selecting a random initial estimate for the switching angles within the range of 0–90°, where the iteration count is denoted as $\boldsymbol{J}$ and the tolerance as ε. The optimization process for determining the switching angles is structured as follows.

1) *Initialization*. Formulate a preliminary set of estimations for switching angles.

2) *Jacobian calculation*. Determine the parameters for the constraint equations and compute the Jacobian matrix $\boldsymbol{J}$ for the nonlinear system The Jacobian matrix $\boldsymbol{J}$ represents the partial derivatives of the constraint equations $f = [f_1(\alpha), f_2(\alpha),..., f_n(\alpha)]$ with respect to the switching angles $\alpha = [\alpha_1, \alpha_2,..., \alpha_n]$, where $f(\alpha)$ is the system of nonlinear equations for harmonic elimination.

The correction vector $\Delta\boldsymbol{\alpha}$, corresponding to n unknowns in the k-th iteration, is obtained using (10), (11). Here $\boldsymbol{J}^{-1}$ is the inverse of the Jacobian matrix; α^i is the current estimate of switching angles at iteration i, which is then updated as $\alpha^{i+1} = \alpha^i + \Delta\alpha$

$$\boldsymbol{J} = \begin{matrix} \frac{\partial f_1}{\partial \alpha_1} & \cdots & \frac{\partial f_1}{\partial \alpha_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial f_m}{\partial \alpha_1} & \cdots & \frac{\partial f_m}{\partial \alpha_m} \end{matrix}. \quad (10)$$

$$\Delta\boldsymbol{\alpha} = -\boldsymbol{J}^{-1} \times f(\alpha^i). \quad (11)$$

3) *Convergence check*. Continue the iteration while the tolerance ε remains smaller than $\Delta\boldsymbol{\alpha}$. The process terminates once the tolerance equals or exceeds $\Delta\boldsymbol{\alpha}$.

4) *Angle update*. Update the switching-angle vector $\boldsymbol{\alpha}$ according to (12), then repeat from Step 3 until convergence is achieved .The convergence criterion is defined as $\|\Delta\alpha\| \le \varepsilon$, where $\| \|$ denotes the Euclidean norm and ε is the specified tolerance value.

$$a^{i+1} = a^i + \Delta\alpha. \quad (12)$$

The NR algorithm is employed to determine the optimal switching angles for the SHE-PWM technique through an iterative numerical procedure.

The process begins with an initial estimation of the switching angles, followed by the computation of the Jacobian matrix, which represents the partial derivatives of the nonlinear system equations. A correction vector $\Delta\boldsymbol{\alpha}$ is subsequently calculated and applied to update the switching angles iteratively until the convergence criterion, defined by a specified tolerance ε, is satisfied. Upon convergence, the resulting set of switching angles is considered optimal, effectively minimizing the THD in the inverter output voltage.

The following organizational layout shown in Fig. 2 is intended to utilize the NR technique for solving the mathematical complexity associated with SHE.

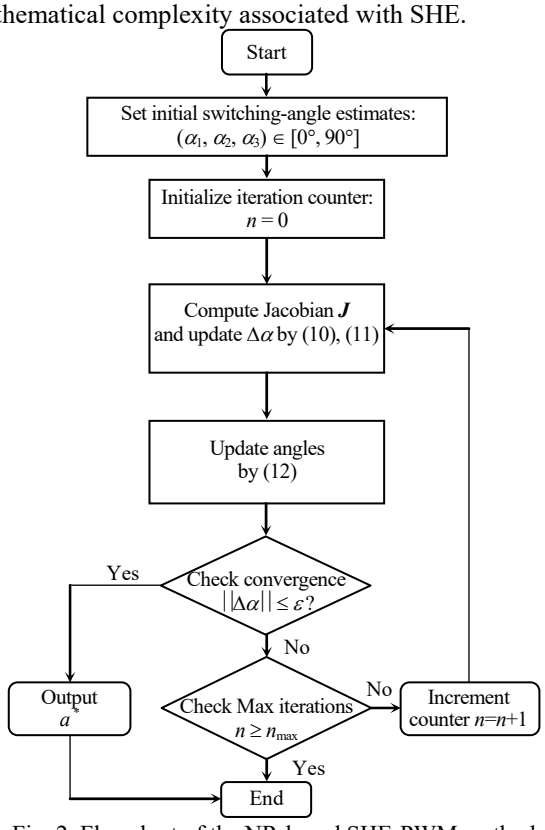

Fig. 2. Flowchart of the NR-based SHE-PWM method

Simulation results. To validate the proposed SHE-NR technique, comprehensive simulations were conducted to evaluate harmonic suppression performance,

switching angle optimization, and THD reduction. The NR method solves the nonlinear equations required to determine optimal switching angles that eliminate specific harmonics while maintaining fundamental voltage across 33 V and 11 V DC links. The following subsections present the detailed analysis and results.

This work utilized the SHE methodology in conjunction with the NR iterative method to ascertain the optimal switching angles for a MLI. The preferred due to its advantages that can easily solve non-linear equations, with special mention of its fast rate of convergence and precision. The following features are essential in the case of the inference of the SHE process, which is nothing but the reduction of lower-order harmonics (for example, the 5th and 7th) from the output voltage waveform by keeping the desired fundamental component. The NR method will, through iterations of an indirect procedure, minimize the discrepancy between the found and the desired harmonic components, and thus the time it takes for convergence to be realized.

Figure 3 and Table 4 present a comprehensive dual-perspective analysis of THD in MLI operation, evaluating performance under varying modulation indices and switching angle configurations. Figure 3 shows an inverse relationship between modulation index (MI) and THD across the range of 0.35 to 1.05, where THD decreases non-linearly from approximately 48 % to 13.91 %, with the steepest reduction occurring below MI = 0.7 and local extrema observed at MI ≈ 0.6 and MI ≈ 0.7 reflecting complex harmonic interactions in PWM strategies. Table 4 illustrates THD variation as a function of 3 independent switching angles (α_1, α_2, α_3) ranging from 11° to 90°, where all 3 parameters exhibit positive correlation with THD, increasing from approximately 13.19 % to 49 %. The SHE-NR optimization algorithm successfully identifies the optimal switching angle combination (α_1 = 12.57°; α_2 = 23.81°; α_3 = 54.33°), achieving minimum THD of 13.19 %, which represents substantial improvement over arbitrary angle selection.

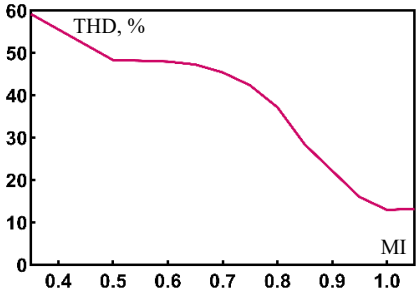

Fig. 3. THD vs modulation index MI

Table 2

SHE-NR switching angles at various MI

Modulation index MI	Switching angles α_1, α_2, α_3		
0.35	46.30	82.37	89.94
0.50	40.77	65.82	89.36
0.55	39.77	62.13	86.57
0.60	39.43	58.58	83.10
0.65	39.39	55.52	78.90
0.70	38.34	53.53	73.96
0.75	34.89	54.46	68.55
0.80	29.24	54.44	64.48
0.85	22.77	49.38	64.56
0.95	13.82	37.19	61.92
1.00	11.68	31.18	58.58
1.05	12.57	23.81	54.33

The parallel upward trajectories in Fig. 3 and the monotonic decrease in Table 4 collectively validate the SHE-NR technique's effectiveness in minimizing harmonic distortion, thereby reducing inverter losses and enhancing output waveform quality for multilevel converter applications. Figure 4 shows the correlation between the MI and the corresponding switching angles. As the MI increases, the inverter strives to deliver higher amplitude of fundamental voltage while maintaining harmonic cancellation, thereby resulting in reduced switching angles.

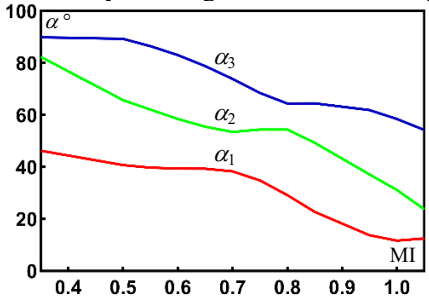

Fig. 4. Switching angles vs modulation index

Figure 5 shows the suppression of low-order harmonics (5th and 7th), with the FFT analysis of THD, which shows a reduction from 59.21 % (MI = 0.35) to 13.19 % (MI = 1.05). The transitory increase in THD to 45.46 % at MI = 0.7 (see Table 2), is associated with the overlapping switching angles. This indicates that SHE-PWM is highly sensitive to the selection of angle. Both outcomes substantiate the notion that the NR method enhances harmonic suppression and waveform fidelity.

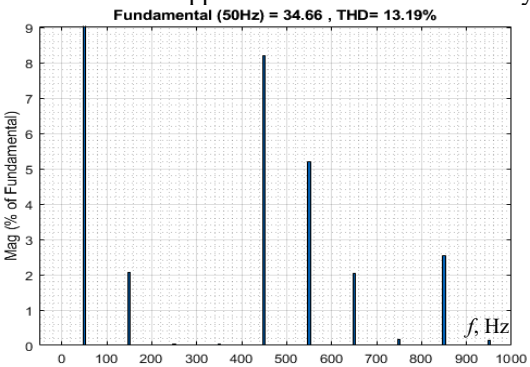

Fig. 5.THD vs switching angle

In Fig. 6, the output waveforms of the topology are shown, obtained using SHE-PWM based on the NR method, where 7-level voltages are produced and harmonic distortion is effectively minimized through selective elimination of low-order harmonics.

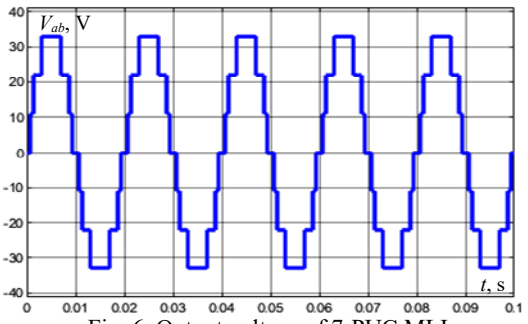

Fig. 6. Output voltage of 7-PUC MLI

As illustrated in Fig. 6, optimal switching angles are iteratively calculated by the NR algorithm to achieve harmonic cancellation, while the desired fundamental component is maintained, resulting in superior power

quality with minimal switching losses suitable for high-power applications.

Hardware testing and practical implementation. The experimental prototype (Fig. 7) consists of a 7-level PUC MLI with 2 DC sources configured in a 3:1 ratio (33 V and 11 V). The power stage includes IGBT switching devices with gate drivers, heat sinks for thermal management, and snubber circuits for protection. An Arduino microcontroller serves as the digital controller, executing pre-calculated SHE-PWM switching angles derived from the NR algorithm. Gate driver circuits with optocouplers provide electrical isolation between control and power stages. The measurement setup includes a GW Instek PSS-3203 programmable DC supply, digital oscilloscope for waveform capture, and FFT analyzer for harmonic spectrum analysis (Table 3).

Table 3

Component list

Components	Specification
Optocoupler	IC FOD 3182
Microcontroller	Arduino
Gate drive power supply	GW Instek PSS-3203, PSW 30-36
IGBT switches	SGL160N60UFD
Converts	Hi link 220V to 12V
Passive heat exchanger	Heat sink

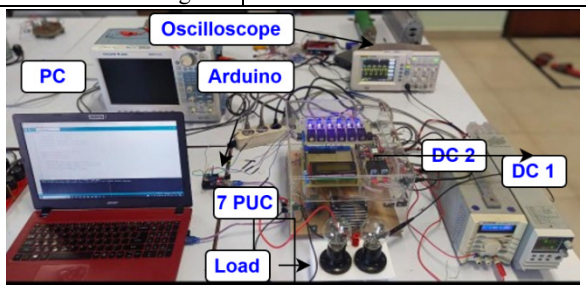

Fig. 7. Experimental setup layout and configuration

The NR algorithm was executed offline in MATLAB to calculate optimal switching angles for harmonic elimination. The computed angles were stored as lookup tables in the Arduino's memory, mapping different modulation indices to their corresponding switching angles. During real-time operation, the Arduino retrieves the appropriate angles based on the desired output voltage and generates precise PWM pulses with microsecond-level timing accuracy. These control signals are processed through gate driver circuits to trigger the IGBT switches at the calculated instants. The PUC topology configuration strategically switches the two DC sources to produce seven distinct voltage levels: 0, ±11 V, ±22 V, ±33 V, ±44 V. This switching sequence synthesizes a stepped quasi-sinusoidal waveform that inherently suppresses the specified 5th and 7th harmonics while retaining the desired fundamental voltage as depicted in Fig. 8.

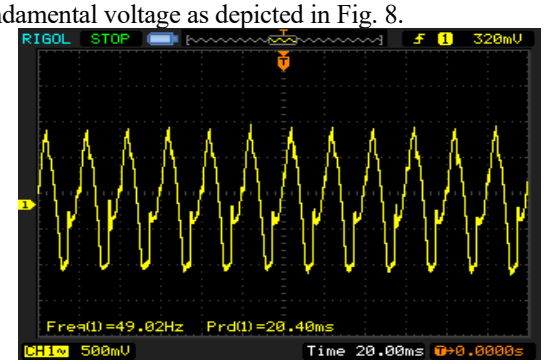

Fig. 8. Experimental output voltage of 7-PUC MLI

Oscilloscope measurements confirm a 7-level stepped waveform with ±44 V peak amplitude and 50 Hz fundamental frequency. The waveform exhibits smooth transitions between voltage levels with symmetric positive and negative half-cycles. FFT analysis reveals the harmonic spectrum with the fundamental component at 100 % reference magnitude as illustrated in Fig. 9. The 5th and 7th harmonics are successfully suppressed to below 3 %, compared to typical values of 15–20 % and 10–15 % in conventional PWM methods. Higher-order harmonics (11th and 13th) remain at approximately 8 % and 6 % respectively, as they were not targeted for elimination in this implementation. The measured THD is 18.14 %, representing a significant improvement over square wave inverters which typically exhibit THD around 45 %, validating the effectiveness of the SHE-PWM approach in reducing low-order harmonics.

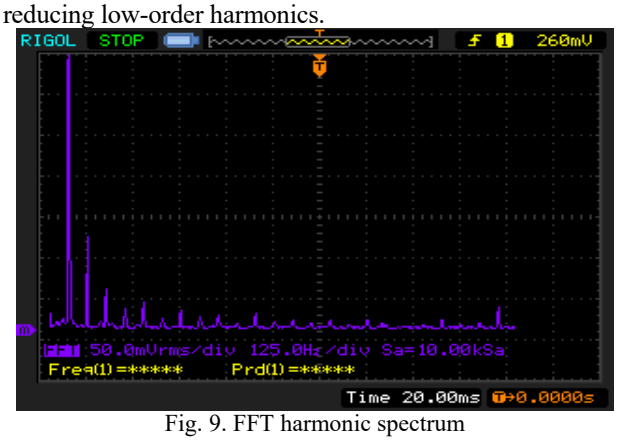

Fig. 9. FFT harmonic spectrum

The experimental results exhibit strong agreement with the theoretical predictions across multiple performance metrics, as presented in Table 4. The voltage levels match the theoretical formula with 100 % accuracy, confirming proper implementation of the PUC topology. Targeted harmonics (5th and 7th) are reduced to below 3 %, validating the NR optimization effectiveness. The measured THD of 18.14 % shows reasonable deviation from theoretical predictions (12–15 %) due to practical non-idealities including switching dead-time (typically 1–2 μs), device voltage drops (≈2–3 V), finite rise/fall times, component tolerances (±5 %), and DC supply ripple (<1 %). The fundamental voltage exhibits linear control with modulation index variation, confirming the expected relationship between control input and output amplitude. These results validate the practical feasibility of SHE-PWM-based harmonic elimination in MLIs using Arduino implementation, demonstrating effective reduction of low-order harmonics while maintaining acceptable power quality for practical applications.

Table 4

Comparison of THD between simulation and hardware results

Type	THD, %
Simulation results	13.19
Hardware results	18.14

Conclusions. The Newton–Raphson algorithm was successfully applied to compute optimal switching angles for selective harmonic elimination pulse width modulation in 7-level packed U-cell MLIs, demonstrating rapid convergence in solving nonlinear transcendental equations and effectively eliminating the 5th and 7th harmonics.

Simulation results achieved a THD of 13.19 % at a modulation index of 1, while hardware testing validated

practical feasibility with a THD of 18.14 %, confirming acceptable power quality for grid-connected applications.

The 7-PUC topology provides significant advantages including reduced component count compared to CHB and NPC configurations, resulting in a more compact and cost-effective design.

The Newton–Raphson method offers a computationally efficient solution suitable for real-time implementation on resource-constrained embedded systems such as Arduino-based microcontrollers, providing a viable path for improving power quality in MLIs.

The proposed approach is applicable for renewable energy integration, with future work recommended to focus on experimental validation under varied operating conditions and extension to higher-level inverter topologies.

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Conflict of interest. The authors declare that they have no conflict of interest.

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