

Research Article

Tournament Selected Glowworm Swarm Optimization Based Measurement of Selective Harmonic Elimination in Multilevel Inverter for Enhancing Output Voltage and Current

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In modern days Multi Level Inverters (MLIs) in the power industry receive a large interest. The MLIs with multilevel structures produces higher-power, higher-voltage inverters. Selective Harmonic Elimination (SHE) has become a popular one. It has been utilized widely studied during the past several decades for multilevel inverters as it has many merits like lesser switching losses and lesser Total Harmonic Distortion (THD). However, many researchers have failed to reduce the selective harmonic elimination time consumption and improve efficiency. A novel Tournament Selected Glowworm Swarm Optimization-Based Selective Harmonic Elimination (TSGWSO-SHE) approach is proposed in this paper for addressing these problems. The major aim of the TSGWSO-SHE approach is selecting optimal switching angles for removing the lower order harmonics. In the TSGWSO-SHE technique, initially, multilevel-inverters are created, and the modulation index is measured. Based on the modulation index, Switching Angles (SAs) are determined. Then several switching angles are initialized randomly. The objective function is determined for every switching angle. Using it detects and chooses the neighbouring switching angle with higher brightness by tournament selection and move to it. Lastly, the switching angle updates its position and finds the optimal switching angle. In this way, an optimal SA is selected during the process of selective harmonic eradication in MLI with higher efficiency and minimal time consumption. The efficiency of TSGWSO-SHE technique is simulated using parameters such as time of SHE, SHE efficiency and THD. Results prove that the proposed TSGWSO-SHE technique provides better SHE performance as compared to the existing studies. Experimental results demonstrate that the TSGWSO-SHE technique reduces the THD and SHE time by 46% and 33%, and the efficiency of selective harmonic elimination is increased by 13% compared to existing methods.

1. Introduction

Multilevel inverters employ average and higher voltage utilization. Use of SHE for voltage waveform by multilevel inverters has been studied broadly in the last decade. By harmonic eradication of the cascaded H-bridge MLI, the

SHE Pulse Width Modulation (PWM) method depends on hybrid Asynchronous PSO-Newton-Raphson (APSO-NR) algorithm was explained [1]. However, SHE time is not reduced by using the APSO-NR algorithm. To choose harmonic eradication in a single-phase seven-level inverter by minimum switches, a novel ant colony optimization

algorithm is presented in [2]. The algorithm is formulated in two phases. At the initial phase, ant colony optimization is carried out. In the second phase, the primary guess of the Newton–Raphson algorithm which is the solution attained from ACO is employed, but ant colony optimization does not reduce total harmonic distortion.

Similarly Bacterial Foraging Algorithm (BFA) is introduced in [3] to switch angles in the PWM inverter. The voltage harmonic elimination by output voltage regulation problem is addressed by optimization performance. However, the efficiency of the selective harmonic elimination is not improved. Artificial Neural Network (ANN) based solution was attained in [4] for determining angles and creating PWM signals. ANN generates optimum switching angles for each modulation index, but the output voltage is not improved.

The artificial Bee colony optimization is developed in [5] to solve the nonlinear equation of SHE with an extreme direct power resource. However, the computational complexity is not reduced. Likewise, a selective harmonic elimination system is introduced in [6] by using fuzzy logic to eradicate the higher magnitude harmonics by frequencies near the basic frequency of single-phase inverters in output voltage. However, selective harmonics elimination is not done efficiently using a selective harmonic elimination system.

An Imperialist Competitive Algorithm (ICA) also is introduced in [7] to eradicate undesired harmonics. DC-DC converter is employed for enhancing the SHE task. The algorithm designed reduces many harmonics where the entire harmonics output voltage is less. However, the output current is not improved using ICA. A novel SHE modulation method is presented in [8] to obtain multiple solutions to eliminate particular harmonics in modulation indices via changed NR and pattern generation methods, but the time of selective harmonic elimination is not reduced.

Similarly, a new DC-link balancing approach is introduced in [9] for a 7-level inverter fed by utilizing the photovoltaic scheme. The redundant state procedure is linked by SHE-PWM rather than the Space Vector (SV)-PWM. But the efficiency of selective harmonic elimination is not improved by using DC-link balancing method. The performance of the modular cascaded multilevel inverter dependent on Shunt Hybrid Active Power Filter (SHAPF) performance is studied in [10] to react power allowance and SHE below the deformed/uneven voltage grid condition within the average voltage levels, but time consumption is not minimized to exploit SHAPF.

In the existing techniques there are some issues identified such as higher time consumption for selective harmonic elimination, nonselection of the optimal switching angle, higher computational complexity, higher switching losses, lesser efficiency of selective harmonic elimination and higher THD rate. To address these issues, the proposed TSGWSO depends on the SHE approaches.

The contribution of the paper is given as follows.

- (i) The main aim of the TSGWSO-SHE technique is to select optimal switching angles where the basic part is at the preferred value and to eradicate the lower

order harmonics for improving output voltage and current in the multilevel inverter.

- (ii) TSGWSO-SHE technique uses a tournament-selected glowworm swarm optimization algorithm for reducing harmonic distortion by eliminating the lower order harmonics. The Modulation Index (MI) is determined and SAs are computed. The number of glowworms, i.e., SAs, is considered arbitrarily. The OF is estimated for every glowworm. It identifies and chooses the neighboring glowworm with higher brightness through Tournament Selection (TS) and shift to it. The glowworm restores its position and analyses the excellent one.
- (iii) Thus, the optimal SA is identified to choose harmonic removal in a multilevel inverter to improve the performance of output voltage and current.

This paper is structured as follows. Section 2 presents works related to optimization techniques designed to choose selective harmonic removal in the multilevel inverter. Section 3 describes the proposed technique. In Section 4, comparative performance analysis is presented. Section 5 concludes the study.

2. Literature Survey

A harmony search on optimization is designed in [11] with the help of Artificial Neural Networks (ANNs) on the new 21-level inverter topology. Its depends on the music improvisation process, but the THD is not minimized using harmony search optimization. A cascaded H-Bridge multilevel inverter concept is introduced in [12], where switching angles are independent of the basic voltage. Polynomial term computes the relationship among switching angles and DC voltages, but the optimization technique is not used for discovering the optimal switching angle.

A Generalized Hopfield Neural Network (GHNN) dependent on SHE PWM was implemented in [13] for one phase inverter. It is introduced to remove fifth, seventh, eleventh and thirteenth order of harmonic, but the output current is not improved. MLI with a lesser amount of switches was introduced in [14] for system cost minimization. The nonlinear SHE equation is optimized through Genetic Algorithm (GA) software.

One phase 9-level cascaded H-Bridge MLI using FLC, and P&O is introduced in [15] for Photo Voltaic (PV) power generation, but lower-order harmonics are not eliminated efficiently. A novel altered Cascaded H-bridge (CHB) MLI by using SHE technique and passive LC filters is introduced in [16] for the enhancement of output voltage waveform. With SHE, a PWM technique is employed to handle the basic harmonic and to remove lower order harmonics in CHB multilevel inverter. However, the execution time is not minimized by the modified CHB multilevel inverter.

In the same way, a cuckoo evolutionary optimization method is introduced in [17] to eradicate the unwanted harmonics in multilevel inverters by using equivalent DC

origin. SHE is an effective technique for attaining basic parts and removing selection harmonics, but the computational time using this cuckoo evolutionary optimization is higher. A new variant of SO that depends on the SHE approach is introduced in [18] to lessen harmonics in MLI. Nevertheless, it does not reduce the time of selective harmonic elimination.

A two-phase adaptive algorithm is introduced in [19] for generating real-time optimal switching angles in the multilevel inverters. An optimal switching angle is computed offline by using a Real Coded Genetic Algorithm (RCGA), but selective harmonic elimination is not done efficiently. Likewise, a novel 5-level MLI using switch count is introduced in [20] for the standalone PV system. Firefly-Assisted Genetic Algorithm (FAGA) dependent on the SHE approach is introduced to minimize the harmonics, but the THD is not reduced for 5-level MLI. An optimized switching angle was introduced in [21] to take away unnecessary harmonics which comprise a low order value in the cascaded H-Bridge MLI. However, the convergence rate is not higher. Selective harmonic elimination is done in [22] with the help of PWM to eradicate the low-level harmonics. However, the optimized transition points on the time axis minimize the unwanted low-order harmonics. Further, MLI topologies are introduced in [23] to for application in dc-ac power transformation and thereby to get better power quality.

3. Proposed Methodology

Multilevel inverters are employed in power utilization for acquiring small total THD in average or higher voltage levels. The SHE method is essential in power electronic applications. It is a modulation technique used for attaining suitable switching instants to eliminate the small order harmonics. In it switch moments are identified through the preferred magnitude of basic and harmonics concealed. Different techniques are utilized for the multilevel inverter for attaining the low THD for enhancing the output voltage and current, but THD is not minimized by employing the existing methods. To address these problems, TSGWSO-SHE approach is introduced. The aim of the TSGWSO-SHE technique is used to identify optimal switching angles where the basic part is at the preferred value and to take away the harmonics which include a lower order. The architecture of the TSGWSO-SHE Technique is given in Figure 1.

Figure 1 explains the flow of the TSGWSO-SHE technique. In using TSGWSO-SHE technique, multilevel inverters are designed. Then the MI is determined and switching angles are computed. The number of glowworms is initialized randomly. Additionally, the Objective Function (OF) is calculated for every glowworm. In addition, it identifies and selects the neighboring glowworm with higher brightness by using tournament selection and shifting to into. Then the glowworm upgrades its point to finds the excellent one. In this way, selective harmonic elimination is carried out in a multilevel inverter for output voltage with current enhancement.

3.1. Multilevel Inverter. The power electronic device with a higher potential to convert the DC power into AC power is termed as an inverter. The inverters drive the lightning load when the grid gets powered off. With technological advancements, inverters are employed in motor drives, Uninterrupted Power Supply (UPS), and power system utilization. A multilevel inverter creates the smooth sinusoidal waveform by DC voltage levels as input. Multilevel inverters develop into an attractive region in industrial utilization for higher power and voltage ranges. They are associated with sustainable energy sources for different higher power utilization.

MLIs are developing one as more approved beside single level inverter in the high-power utilization. By employing DC voltage levels, the multilevel output is combined. The switches are connected in sequences in multilevel inverters that permit the process at higher voltage level. Multilevel inverters present a huge improvement of harmonic decrease in output waveform, lacking the switching frequency or lessening the inverter output current. They are employed different industrial utilization like motor drives, sustainable energy, power conditioners, active filters, Flexible AC Transmission System (FACTS), higher voltage direct current lines, and so on.

Multilevel inverters obtain large awareness in both academy and industry. They are optimal solutions for attaining superior voltages by enhancing the harmonic spectrum. The multilevel inverter is an electronic power scheme that combines the output voltage with different DC voltages. The main aim of a multilevel inverter is to generate staircase output voltage with the existing DC current origin. The standard of the output current is enhanced by improving the quantity of energy levels.

MLIs are the collection of power semiconductors and capacitor power resources that generate voltages with stepped waveforms. By enhancing the number of stages in the inverter, output currents are introduced process with lesser harmonic distortions. A MLIs includes many metrics over a two-stage inverter that exploits the higher switching rate of PWM. The key characteristics of MLI are given as below.

3.1.1. Low dv/dt Stress. MLI creates the output voltages by lesser alteration to minimize the low dv/dt stresses.

3.1.2. Common-Mode (CM) Voltage. MLI creates less CM voltage. The anxiety in the compartments of the motor linked with the multi-level motor drive decreases.

3.1.3. Input Power. MLI collects the input power with low bias.

3.1.4. Switching Frequency. MLI involves the basic frequency and higher switching frequency PWM. Switching frequency is a smaller switch frequency using lesser switching loss with superior performance.

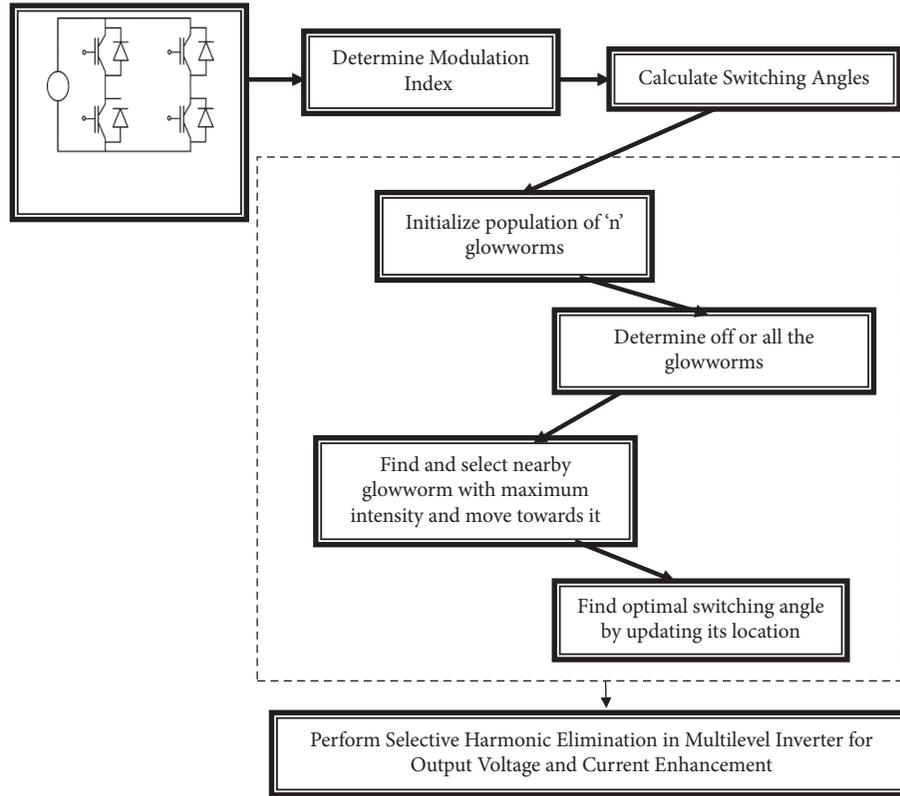


FIGURE 1: Architecture of TSGWSO-SHE technique.

A Seven Level Inverter comprises 12 switches and a series of switches. The output voltage waveforms of a multilevel inverter include an amount of level voltages. When the number of levels gets increased, the output of the THD gets reduced. The output waveform of seven-level inverters is shown in Figure 2.

The output waveform is examined in THD and is represented as

$$\text{THD (\%)} = \left[\left(\frac{1}{a_1^2} \sum_{n=5}^{\infty} a_n^2 \right)^{1/2} \right] * 100. \quad (1)$$

Equation (1), the THD is calculated. THD is the amount used to classify harmonic contents in the output concerning the basic. It is a nonlinear transcendental mathematical statement.

3.2. Tournament Selected Glowworm Swarm Optimization (TSGWSO). The TSGWSO-SHE technique is a type of swarm intelligence development technique that depends on the behaviour of glowworm. The glowworms behaviour patterns modify the strength of Lucifer in release and glow at the diverse powers. The TSGWSO algorithm agents are considered as glowworms i.e., switching angles that transmit the luciferin's luminescence. Each glowworm exploits the luciferin i.e., neutral basis to transmit data from the current place to the closets. The glowworms get involve in the intense luciferin surrounding. They depend upon the variable neighborhood to identify and select the neighbors by using

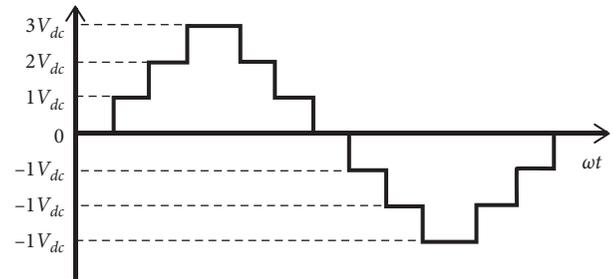


FIGURE 2: Output Waveform for seven-level inverter.

tournament selection. After selecting the neighbors, it performs the actions.

Every glowworm plays a tournament selection technique for selecting the surrounding with high luciferin value and moves into it. It comprises the dynamic result gap with the luciferin higher apart and space within the dynamic result area. The glowworm updates its places to glowworm within the dynamic result area and the decision space radius. TSGWSO algorithm consists of the two key ideas:

- (i) The agents glow to the intensities proportional for the objective task optimization. Glowworms of brighter intensities get attracted by glowworms of lesser intensity.
- (ii) TSGWSO algorithm involves the dynamic decision range where the distant glowworm effect is discounted while the glowworms have enough closest places.

In the TSGWSO-SHE technique, all glowworm include the limited-result area cleared by radial sensor choice. All glowworms find their closest place in the limited result area and get involved by the brighter glow of extra glowworms by neighborhood set. Limited-result area volume is unstable, which gets influenced by their closest places. When closest places have a lower thickness, the limited-result area increases to find and select their closest place. If not, the limited-result area is minimized. At last, the action of glowworms leads to the gathering of optimal solutions. TSGWSO algorithm performs the following process to find excellent glowworms.

3.2.1. *Deployment of Glowworm Phase.* The glowworms i.e. switching angles are scattered in the objective gap in this part. All the glowworm include the identical size of luciferin.

The glowworm location and every glowworm launches the parallel luciferin rate based on function rate through the primary iteration. A rate get changed regularly with the function rate in the existing position. Each glowworm loads to the preceding luciferin stage during the luciferin update phase. A luciferin quantity depends upon the calculated rate in the sensed form. The fraction of luciferin rate is removed for imitating decay in luciferin by time. Each glowworm changes the luciferin rate constant by employing objective function rate in the current position. This luciferin update rule can be formulated as

$$LE_i(T) = (1 - \rho) * LE_i(T - 1) + \gamma * OF_i(T), \quad (2)$$

$$OF_i(T) = \min_{\delta_i} \left\{ \left(\frac{100 * (V_1^* - V_1)}{V_1^*} \right)^4 + \sum_{i=2}^S \frac{1}{h_s} \left(50 * \frac{V_{h_s}}{V_1} \right)^2 \right\}. \quad (3)$$

In equation (2), “ ρ ” represents the luciferin decay steady. “ γ ” denotes luciferin’s increasing fraction. “ $LE_i(T - 1)$ ” symbolizes the previous luciferin level for glowworm. “ $OF_i(T)$ ” denotes the objective task rate in glowworm. “ i^{th} ” is the position in the time instant “ T ”.

varied. The first appropriate glowworm from the tournament is chosen with the probability and the next appropriate glowworm selection probability is computed as

$$P * (1 - P). \quad (6)$$

3.2.2. *Movement-phase.* Every glowworm takes result with tournament mechanism to move the adjacent by luciferin rate superior to own. TS is employed for determining the best glowworm using the objective function. Manhattan Distance (MD) is calculated based on the current and the neighboring glowworm positions. It is given by

The third best glowworm with the probability is chosen as

$$P * (1 - P)^2. \quad (7)$$

$$\text{Manhattan distance} = \sqrt{\sum_{i,j=1}^n (g_j - g_i)^2}. \quad (4)$$

Correspondingly, the entire best glowworm is chosen along with the selection probability. When the size of the tournament is high, weak glowworm comprises the lesser possibility for tournament selection. After selection, the glowworm has involved at neighbors that glow brighter. For each glowworm, the chance of moving for a neighbor “ q ” can be represented as

In equation (4), where “ g_i ” denotes the current position of glowworm and “ g_j ” represents the neighboring glowworm position. When the distance is lesser, it has a higher fitness value. Tournament selection is a method used for randomly choosing glowworms from a population with higher fitness. For every tournament, the winner is selected with the best fitness. The glowworm selection is used to create successive generations. By applying the selection approach, the fitness of each glowworm is calculated. The selection of each glowworm is carried out with probability and it is formulated as,

$$P = \frac{F_i}{\sum_{j=1}^n F_j}. \quad (5)$$

Equation (5), the tournament selection Probability (P) of every glowworm and F_i represent the average fitness of the population in j^{th} glowworm. When the population generation changes, fitness value and selection probability get

$$N_i(t) = \{q: D_{iq}(T) < R_d^i(T)\}, LE_i(T) \quad (8)$$

$$= LE_q(T),$$

$$\rho_{iq}(T) = \frac{LE_q(T) - LE_i(T)}{\sum_{k \in N_i(T)} LE_q(T) - LE_i(T)}. \quad (9)$$

Equations (8) and (9), “ T ” point out the index value of time. “ $D_{iq}(T)$ ” shows the Euclidian gap among glowworms “ i ” with “ q ” to the time “ T ”. “ $LE_q(T)$ ” illustrates luciferin stage by the glowworm “ q ” in time instant “ T ”. “ $R_d^i(T)$ ” signifies uneven local-result variety by glowworm “ i ” in the period “ T ”. “ R ” symbolizes the range of radial in luciferin sensor. Each glowworm updates its location by

$$X_i(T + 1) = X_i(T) + S_s \left(\frac{X_q(T) - X_i(T)}{X_q(T) - X_i(T)} \right). \quad (10)$$

In equation (10), “ S_s ” denotes the step size and “ $|X_q(T) - X_i(T)|$ ” indicates Euclidean utilizes glowworms.

Local decision range update rule:- To conclude the position of glowworms that depends upon local detail, it is measured as a strong function in the radial sensor choice. The glowworm’s dynamic decision space is based on the decision space in the existing radius and connected sensor of luciferin of radial range. The dynamic glowworm of decision space radius is represented by

$$R_d^i(T+1) = \min\{R, \max\{0, R_d^i(T) + \beta N_T - |N_i(T)|\}\}. \quad (11)$$

Equation (11), “ β ” represents a constant parameter. “ N_t ” illustrates the clear threshold parameter. Thus, the best glowworm is identified using the TSGWSO algorithm efficiently. The step-by-step process of the TSGWSO algorithm is explained in Algorithm 1.

The Algorithm 1 describes the step-by-step process of TSGWSO to choose the best SA with lower time complexity. In the TSGWSO algorithm, agents are considered as SAs. Each glowworm computes objective function and transmits its current position information to the neighbors. The neighboring location is identified using the tournament selection process. The brighter objective function neighbors with lesser objective function nodes are attracted. The probabilistic concepts for moving to the neighbor with a higher OF are decided by each glowworm. The switching angle is updated by position and it the avoids THD of multilevel inverters to eliminate selective harmonic by selecting the optimal switching angle. In this manner, selective harmonic elimination time is reduced using the TSGWSO algorithm.

4. Simulation Settings

The experimental settings of the proposed TSGWSO-SHE technique and the two existing methods, namely asynchronous PSO-Newton-Raphson algorithm [1] and ACO-based hybrid algorithm [2] are carried out using MATLAB/Simulink environment. To evaluate the performance of the technique, the metrics like elimination time of THD and efficiency of selective harmonic elimination are used. The same amount of switching angles are achieved by the 7-level multi-level inverter, three SHE equations must address the issues. The fundamental voltage and the remaining two remove the order of 5th and 7th harmonic components generated by one switching angle. In the attained solution, the value of arbitrary modulation index varies from 0 to 1. The simulation parameters are shown in Table 1.

4.1. Simulation Result Analysis of Total Harmonic Distortion. The HD determines the harmonic deformation of the signal by taking the ratio for summation of the power amplitude of all the harmonic components to the power of basic frequency computed by THD rate. It is measured in percentage (%) and computed as,

$$\text{THD (\%)} = \left[\frac{1}{V_1} \sum_{n=5,7}^{\infty} \sqrt{(V_n^2)} \right] * 100. \quad (12)$$

In equation (12), “ V_n ” symbolizes the amplitude of the harmonic n^{th} order and “ V_1 ” signifies the amplitude of basic frequency. When the THD is lesser, the method is more effective.

Table 2 depicts the simulation measurement of the THD using the three methods like TSGWSO-SHE Technique, asynchronous PSO-Newton-Raphson algorithm and ACO based hybrid algorithm. The Table 2 shows that the THD of TSGWSO-SHE is lesser than the other two existing methods. The graphical representation of THD is given in Figure 3.

Figure 3 explains the total harmonic distortion result versus the varied number of modulation index ranges. The Figure 3 gives the modulation index in the “X-axis” and the total harmonic distortion is considered “Y-axis.” In Figure 3, the blue colour symbolizes the total harmonic distortion in TSGWSO-SHE technique, the red colour describes the total harmonic distortion in APSO-NR algorithm and the green colour describes the total harmonic distortion of Asynchronous PSO-Newton-Raphson Algorithm [1] and ACO based hybrid algorithm [2]. The total harmonic distortion of the TSGWSO-SHE technique is lesser due to the use of the tournament-selected glowworm swarm optimization algorithm. The current location information to the neighbors is transmitted, and each glowworm’s objective function is computed. The neighboring location is identified using the tournament selection process. The neighbors with brighter objective function get attracted by lesser objective function nodes. To move the neighbor with a higher objective function, each glowworm decided by the probabilistic mechanism. The optimal glowworms are chosen for the elimination of selective harmonic to avoid the total harmonic distortion of multilevel inverters and to update the glowworm’s position.

For simulation, the proposed TSGWSO-SHE technique gets ten dissimilar modulation index values and thereby minimize the THD. When the modulation index is 0.5, the total harmonic distortion of the TSGWSO-SHE technique is 8%, while total harmonic distortion of asynchronous PSO-Newton-Raphson algorithm and ACO-based hybrid algorithm is 12% and 15% respectively. The total harmonic distortion of the TSGWSO-SHE technique is reduced by 40% and 52% compared to the existing asynchronous PSO-Newton-Raphson algorithm [1] and ACO based hybrid algorithm respectively [2].

4.2. Impact of Selective Harmonic Elimination Time. The complexity m is measured as time. The Selective Harmonic Elimination Time (SHET) is the time taken for eliminating the selective harmonics to improve the output voltage results. SHET refers to a variation between the beginning time and the finishing time of the selective harmonic elimination process in a multilevel inverter. It is measured in milliseconds (ms) and given by,

$$\text{SHET} = \text{ending time} - \text{starting time of SHE}. \quad (13)$$

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\\ Tournament Selected Glowworm Swarm Optimization Algorithm
Input: Number of SAs
Output: Find Optimal SA for SHE
Step 1: Begin
Step 2: For each SA
Step 3: Evaluate OF
Step 4: Determine the probability of movement
Step 5: if (Neighbor SA > current SA) then
Step 6: Movement takes place to neighboring
Step 7: Neighboring SA is identified by the tournament selection
Step 8: else
Step 9: No movement occurs
Step 10: End if
Step 11: updates location of SA
Step 12: End for
Step 13: Select the optimal SA for selective harmonic elimination
Step 14: End
    
```

ALGORITHM 1: Tournament Selected Glowworm Swarm Optimization Algorithm.

TABLE 1: List of simulation factors.

Parameters	Values
DC sources	100 V each
Switching rate	50 Hz
Basic frequency	50 Hz
Iteration count	200
Population initialization	$0 \leq \alpha_1 < \alpha_2 < \alpha_3 \leq \pi/2$
Modulation index	$0 \leq M \leq 1$
Difference between switching angles	10^{-15}

TABLE 2: Comparison of total harmonic distortion (%).

Modulation index (M)	Total harmonic distortion (%)		
	TSGWSO-SHE technique	APSO-NR algorithm	ACO based hybrid algorithm
0.1	21	28	32
0.2	18	24	25
0.3	15	18	20
0.4	11	15	19
0.5	8	12	15
0.6	6	10	14
0.7	4	8	11
0.8	5	11	15
0.9	3	9	12
1.0	2	6	9

Equation (13), the selective harmonic elimination time is determined. When the selective harmonic elimination time is lesser, the technique is more effective.

Table 3 explains the performance results of SHET using the proposed TSGWSO-SHE Technique and the existing Asynchronous PSO-Newton-Raphson algorithm and ACO-based hybrid algorithm with respect to various modulation index values. Table 3 makes clear that the SHET of the proposed TSGWSO-SHE is very minimal compared to the other state-of-the-art methods. The graphical results of SHET using the three methods shown in Table 3.

Figure 4 explains the results of selective harmonic elimination time results for various modulation indexes ranging from 0.1 to 1. In it the modulation index is

considered as the “X-axis, SHET is given as the “Y-axis. From Figure 4, the blue colour symbolizes the selective harmonic elimination time in the TSGWSO-SHE technique, the red colour represents as selective harmonic elimination time in the APSO-NR algorithm, green colour indicate selective harmonic elimination time in the asynchronous PSO-Newton-Raphson algorithm [1] and ACO depends on the hybrid algorithm [2]. The selective harmonic removal time of the TSGWSO-SHE technique is lesser due to the tournament-selected glowworm swarm optimization algorithm. The information about the current location to neighbors has been transmitted and then the objective function of every glowworm is calculated. The brighter objective function neighbors are attracted in

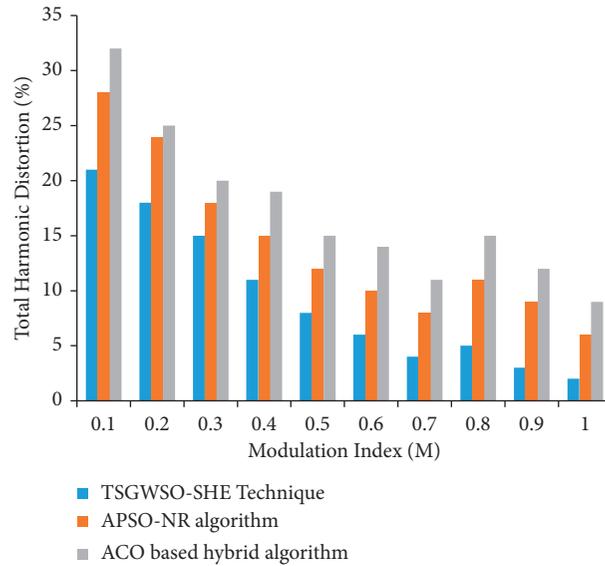


FIGURE 3: Result of total harmonic distortion.

TABLE 3: Comparison of selective harmonic elimination time.

Modulation index (M)	Selective harmonic elimination time (ms)		
	TSGWSO-SHE technique	APSO-NR algorithm	ACO based hybrid algorithm
0.1	36	55	61
0.2	39	59	64
0.3	42	63	67
0.4	40	60	65
0.5	38	57	62
0.6	37	54	57
0.7	41	58	60
0.8	45	62	65
0.9	48	65	69
1.0	52	68	73

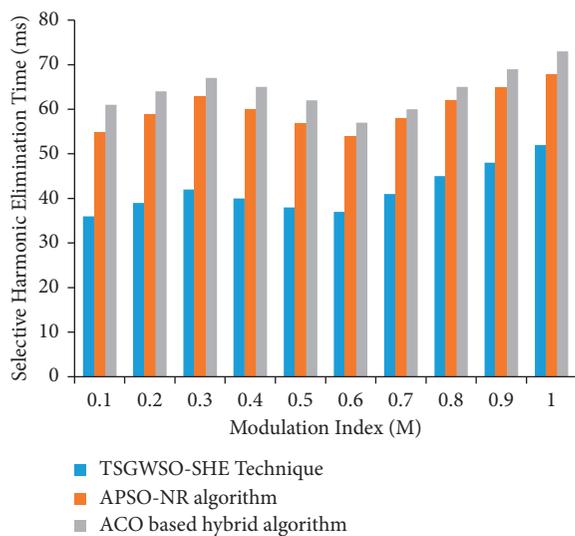


FIGURE 4: Measure of selective harmonic elimination time.

lesser objective function nodes. To move the neighbor with a high objective function, decisions are taken by each glowworm. The optimal glowworms are chosen for the

elimination of selective harmonic to avoid the total harmonic distortion of multilevel inverters and to update the glowworm's position.

During simulation, the proposed TSGWSO-SHE technique takes ten different modulation index values as input to minimize the SHET. While getting the modulation index of 0.2 as input, the selective harmonic elimination time of the TSGWSO-SHE technique is 39 ms while the selective harmonic elimination time of the asynchronous PSO-Newton-Raphson algorithm and the ACO based hybrid algorithm is 59 ms and 64 ms, respectively. The SHET of the TSGWSO-SHE technique is lessened by 31% as compared to the traditional PSO-Newton-Raphson algorithm [1] and 35% as compared to the ACO based hybrid algorithm [2].

4.3. Impact of Selective Harmonic Elimination Efficiency.

The Selective Harmonic Elimination Efficiency (SHEE) is described as the rate of eliminating the selective harmonics accurately for increasing the performance of the output voltage. It is measured in percentage (%). When the efficiency of the selective harmonic elimination is higher, the technique is said to be more effective.

TABLE 4: Comparison of the efficiency of Selective Harmonic Elimination Efficiency.

Modulation index (M)	Selective harmonic elimination efficiency (%)		
	TSGWSO-SHE technique	APSO-NR algorithm	ACO based hybrid algorithm
0.1	90	83	77
0.2	93	85	79
0.3	92	82	76
0.4	93	83	79
0.5	95	85	82
0.6	97	88	85
0.7	94	86	83
0.8	95	87	86
0.9	93	85	84
1.0	97	90	87

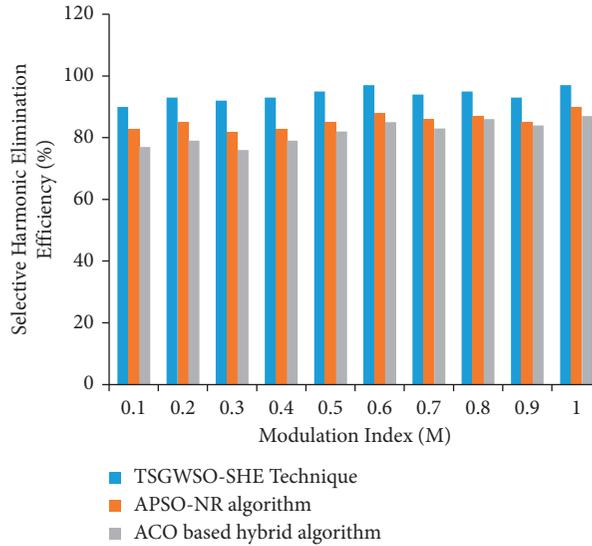


FIGURE 5: Measure of Selective harmonic Elimination Efficiency.

Table 4 explains the efficiency of the selective harmonic elimination of three different techniques, namely TSGWSO-SHE technique, Asynchronous PSO-Newton-Raphson algorithm, and ACO based hybrid algorithm based on the diverse modulation index values that are taken as the input. It shows that the SHEE of the proposed TSGWSO-SHE is higher than the other two conventional techniques. The result of SHEE is presented in Figure 5.

Figure 5 describes the results of the efficiency selective harmonic elimination with respect to different modulation index ranges. It shows that the modulation index is considered in the “X”-axis and the selective harmonic elimination efficiency is given in the “Y”-axis. In Figure 5, the blue colour represents the efficiency of selective harmonic elimination of the TSGWSO-SHE technique where the red colour and green colour line denote the selective harmonic elimination efficiency of the asynchronous PSO-Newton-Raphson algorithm [1] and ACO depends on the hybrid algorithm [2]. The elimination of selective harmonic efficiency of the TSGWSO-SHE technique is higher with the tournament-selected glowworm swarm optimization algorithm. The objective function of every glowworm is calculated. The brighter objective function neighbors get attracted by lesser objective function nodes. To move the neighbor

with a higher objective function, each glowworm is decided by using probabilistic mechanism. The optimal glowworms are chosen for the elimination of selective harmonic for avoiding the total harmonic distortion of multilevel inverters and for updating the position of the glowworm. In this manner, the efficiency of selective harmonic elimination gets improved.

In the present study, the proposed TSGWSO-SHE technique considers ten different modulation indexes during the simulation evaluation process to improve the SHEE. While considering the modulation index value of 0.9, the efficiency of the selective harmonic elimination of TSGWSO-SHE technique is 93% while that of the Asynchronous PSO-Newton-Raphson algorithm and ACO based hybrid algorithm is 85% and 84% respectively. The SHEE of the proposed TSGWSO-SHE technique gets decreased by 10% and 15% as compared to the conventional asynchronous PSO-Newton-Raphson algorithm [1] and ACO based hybrid algorithm [2].

Table 5 shows the comparative result of Total Harmonic Distortion, Selective Harmonic Elimination Time, Selective Harmonic Elimination Efficiency using the proposed and the existing methods. The proposed TSGWSO-SHE technique reduces the Total Harmonic

TABLE 5: Overall comparison of the existing techniques with the proposed technique.

Parameters	TSGWSO-SHE technique (%)	APSO-NR algorithm (%)	ACO based hybrid algorithm (%)
Total harmonic distortion (%)	9	14	17
Selective harmonic elimination time	42	60	64
Selective harmonic elimination efficiency	94	85	82

Distortion by 9%, Selective Harmonic Elimination Time by 42% and the Selective Harmonic Elimination Efficiency is enhanced by 94%.

5. Conclusion

In this paper, an efficient TSGWSO-SHE method is designed for the multilevel inverter. In the TSGWSO-SHE technique, multilevel inverters are designed, and the modulation index is calculated. Then the, switching angles are computed. The number of SAs is initialized and the objective function is determined for every SA. It detects and selects the neighboring switching angle with higher brightness by tournament selection. Finally, the switching angle updates its position and identifies the optimal switching angle. In this way, an optimal SA is selected during the selective harmonic elimination process in a multilevel inverter for output voltage and current enhancement with improved efficiency and lower amount of time consumption. The effectiveness of the TSGWSO-SHE technique is analyzed by using the parameters such as THD, SHDE and SHDT. The proposed TSGWSO-SHE technique presents the improved performance of selective harmonic distortion in multilevel inverters. The simulation results demonstrate that the TSGWSO-SHE technique presents better results with reduced SHDE and higher SHDE for output voltage as compared to the existing works.

Data Availability

The data will be provided based on the request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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