NATURE INSPIRED MEMETIC OPTIMIZED SHEIN MULTILEVEL INVERTERS FOR OUTPUT VOLTAGE ENHANCEMENT

C. Udayakumar[1] **K. Sathiyasekar[2]**
[1]Research Scholar, Anna University, Chennai, India.
[2]Professor, S.A. Engineering College, Chennai, India.
[1]jkkn_udiyakumar88@yahoo.com and [2]sathiyasekar1989@yahoo.com

Abstract: *A multilevel inverter is a power electronic device for AC voltage level at output by multiple lower level DC voltages as input. The usage of multilevel inverters is increased since last decade. Total harmonic distortion (THD) of output voltage in multilevel inverters is reduced by optimal switching angle selection. But in existing methods, THD was not lessened to improve the output voltage performance. In order to address the above mentioned problem, Nature-Inspired Enhanced Memetic Optimization based Selective harmonic elimination (NIEMO-SHE) method is introduced in multilevel inverters. The key objective of NIEMO-SHE method is to identify the optimal switching angle for Selective harmonic elimination (SHE) in multilevel inverter. NIEMO-SHE method exploited the memetic optimization algorithm for finding the optimized switching angle to enhance the output voltage performance in multilevel inverter through eliminating the harmonic distortions. The multilevel inverter is designed and modulation index is computed. Then, the switching angles of multilevel inverter are calculated and the population of switching angle is initialized randomly. The memetic fitness function is measured in NIEMO-SHE method to perform the selection, crossover and mutation operation. Roulette wheel selection is carried out in NIEMO-SHE method to select the individual (i.e., switching angle) from the population after satisfying the memetic fitness function criterion. Then, ring crossover operation is performed to create new adapted ones for identifying the near optimal switching angles through performing the swapping process. Finally, adaptive levy mutation operation is carried out in NIEMO-SHE method for newly generated individuals to find the optimal switching angle. The process gets continual until criterion gets satisfied. By this way, the optimal switching angle is selected in NIEMO-SHE method for SHE with minimal time consumption and higher efficiency. Experimental evaluation of NIEMO-SHE method is carried out in terms of SHE time, SHE efficiency, and total harmonic distortion. The simulation results show that NIEMO-SHE method increases the performance of SHE efficiency reduces SHE time and THD when compared to state-of-the-art works.*

Keywords: *multilevel inverter, total harmonic distortion, roulette wheel selection, memetic fitness function, switching angle, adaptive levy mutation, ring crossover*

1. Introduction

An ant colony optimization based hybrid algorithm was introduced in [1] for SHE in multilevel inverter with minimum switches. The output voltage of multilevel inverter includes essential component with harmonics. But, the execution time was not reduced. A bat evolutionary optimization method was introduced in [2] for eradication of undesired harmonics in multilevel inverter with identical DC sources. SHE was employed for achieving the preferred components. But, the harmonic elimination failed to improve output voltage performance with lesser computational complexity.

For SHE, an optimized algorithm was presented in [3] through hybrid control mechanism using fmincon and Newton–Raphson iterative technique. To lessen THD, multi-level sequences and firing angles were exploited. It lessens the execution time and improves convergence rate. Though the execution time was reduced, the output voltage performance was not enhanced after harmonic elimination. The degrees of freedom in designed method enhances when number of switching angles enhanced. In [4], the imperialist competitive algorithm (ICA) was exploited to evade greater number of unnecessary harmonics. But, ICA failed to provide the better solution.

Artificial Bee Colony (ABC) optimization algorithm was introduced in [5] to address nonlinear equation of SHE pattern with unequal direct current sources. The fundamental component satisfaction and low-order harmonics removal were SHE switching pattern. But, the performance of ABC optimization algorithm was not enhanced during selective harmonic elimination. SHE pulse width modulation technique-based hybrid asynchronous PSO-Newton-Raphson (APSO-NR) algorithm was introduced in [6] for removal of undesired harmonics in cascaded H-bridge multilevel inverter. The designed algorithm was used in all levels with equal and non-equal DC sources. The ring topology-based APSO algorithm was combined with NR method. But, the performance was not enhanced using APSO-NR algorithm.

Particle Swarm Optimization Algorithm with Selective Harmonic Elimination-Pulse Width Modulation (SHEPWM) method was introduced in [7] for harmonic minimization of Cascaded H-Bridge Multi-Level Inverter. In SHEPWM method, PSO algorithm was used in finding the required switching angles to remove desired value of harmonics. However, the designed method failed to minimize the harmonic in effective way for improving the output performance of inverter.

A field programmable gate array (FPGA)-based real-time SHE pulse width modulation (SHE-PWM) scheme was introduced in [8] for voltage source inverter (VSI). The designed algorithm created switching angles by approximation of angles trajectories using simple variable coefficients-based polynomial equations. But, the harmonic elimination was not carried out in efficient manner. The hybrid optimization set of rules was designed in [9] to detect the reliable change angles in structure electrical converter (MLI). The angle square was employed to measure the low frequency harmonics. Hybrid algorithm combined the Particle swarm optimization (PSO), global search method with gradient search (GS) to improve the results. But, the execution time was not reduced as it combines two algorithms.

In [10], the issues of SHE pulse width modulation (SHE-PWM) or high power multilevel inverters was addressed. An objective function was created and eradicated the selective harmonics in efficient manner through managing the fundamental component. The exact solution was not exactly identified for improving the high power multilevel inverter performance.

The certain problems are identified from the above said literatures such as high execution time, failed to choose optimal switching angle with minimum time, computational complexity, improved voltage performance, high switching losses, high THD rate and so on. In order to address these issues, NIEMO-SHE method is introduced.

The main contribution of paper is described as follows,

- The key aim of NIEMO-SHE method is to select the optimal switching angle for SHE in multilevel inverter based on the objectives.

- NIEMO-SHE method exploited memetic optimization algorithm for finding the optimized switching angle to improve the output voltage performance in multilevel inverter. The multilevel inverter is constructed and modulation index is calculated. After that, the switching angles of the multilevel inverter are computed. The population of switching angle is initialized randomly. Memetic fitness function is calculated for all switching angle to perform selection, crossover and mutation operation.

- Roulette wheel selection is carried out in NIEMO-SHE method to select the individual from the population after satisfying the memetic fitness function. Ring crossover is carried out to generate new adapted ones to find near optimal switching angles through performing the swapping process. Adaptive levy mutation is carried out in NIEMO-SHE method for newly generated individuals to obtain optimal switching angle. The process gets repeated until criterion gets satisfied.

By this way, the optimal switching angle is selected in NIEMO-SHE method for SHE with minimal time consumption and switching losses.

The rest of the paper is organized as: Section 2 reviews the related works of selective harmonic distortion in multi level inverter. Section 3 provides the brief explanation about proposed NIEMO-SHE method with neat diagram. In Section 4, simulation settings and result analysis is explained. Conclusion of the paper is given in section 5.

2. Related Works

A genetic algorithm optimization technique was introduced in [11] to find the switching angles for cascaded multilevel inverter. Artificial neural networks were employed to find switching angles for real-time application. The designed artificial neural network removed specified order harmonics while preserving the output constant. But, the designed technique failed to find the optimal switching angle for harmonic elimination.

For stand-alone solar photovoltaic system operation, a multilevel inverter was designed in [12]. It exploits pulse-width modulation (PWM) in multilevel inverter to modify DC voltage from battery storage to afford AC loads. An adaptive neuro fuzzy inference (ANFIS) to estimate optimum modulation index and switch angles necessitated for five level cascaded H-bridge inverter with enhanced inverter output voltage. However, selected switching angle failed to improve the performance of multilevel inverter.

Bio-inspired intelligent algorithms (BIAs) were introduced in [13] for addressing the complex equations. The principle process of nine BIA was discussed in inverters for harmonic elimination (HE). However, the output voltage was not improved by BIAs. 11-level cascade multilevel inverter by SHE was introduced in [14] using artificial neural networks to identify switching angles for each phase. The dc sources feeding multilevel inverter were taken based on the time variation and the switching angles were adjusted based on the dc source variation. But, the output voltage performance was not improved.

The mapping between modulation rate and

necessary switching angles was estimated in [15] using feed forward neural network. The suitable switching angles were identified through the neural network resulting in low-computational cost for real-time applications. But, the output voltage was not improved after harmonic elimination. A new switching strategy was presented in [16] for asymmetric multilevel inverters that developed an additional degrees of freedom to remove additional low-order harmonics. But, the computational complexity was not reduced using switching strategy

Teaching–learning-based optimization algorithm was introduced in [17] to identify optimum switching angles for create desired voltage with minimal THD. But, the time consumption was not lessened. Harmonic elimination capability of SHE technique was introduced in optimal minimization of THD (OMTHD). In [18], an improved OMTHD technique was introduced for n-level cascaded multilevel inverter with variable DC sources. However, the output voltage performance was not improved.

SHE equation was solved by deterministic and stochastic optimization methods in [19]. An effective algorithm was introduced to lessen THD with less computational complexity between all optimization algorithms. But, the efficiency was not improved using stochastic optimization methods. Simulated Annealing (SA) based technique was introduced in [20] to optimize the switching angles that lessen THD. But, the time consumption was not reduced.

3. Proposed Methodology

Multi-level inverters gained huge attention in distributed energy generation. Fuel cells, solar cells, wind turbines and batteries are linked to feed load through multilevel inverters without any voltage variation. Multilevel inverters have lesser switching frequency and switching losses. The multilevel inverter output is in stepped format with existence of harmonics. The switching process identifies the switching angles to produce fundamental voltage and eradicate higher order harmonics.

3.1 Problem Definition:

To acquire preferred fundamental output when eradicate low order harmonics, SHE techniques are employed in multilevel inverters for computation of switching angles. Harmonic elimination at fundamental frequency is suitable for high range of power generation and applications. Multilevel switching scheme affords opportunity with certain lower order harmonics by diverse instances where positive switches are became ON and OFF (i.e. varying the switching angles). Non-linear equations are exploited to calculate optimized switching angles. But, the non-linear equations undergo many issues in attaining the switching angles. Newton–Raphson (N-R) method was exploited for addressing equations. The key demerit of iterative method is depending on the initial guess and undergoes the divergence issues. The method is used for identifying all feasible solutions for modulation index 'M'. But, it is difficult and consumes large amount of time.

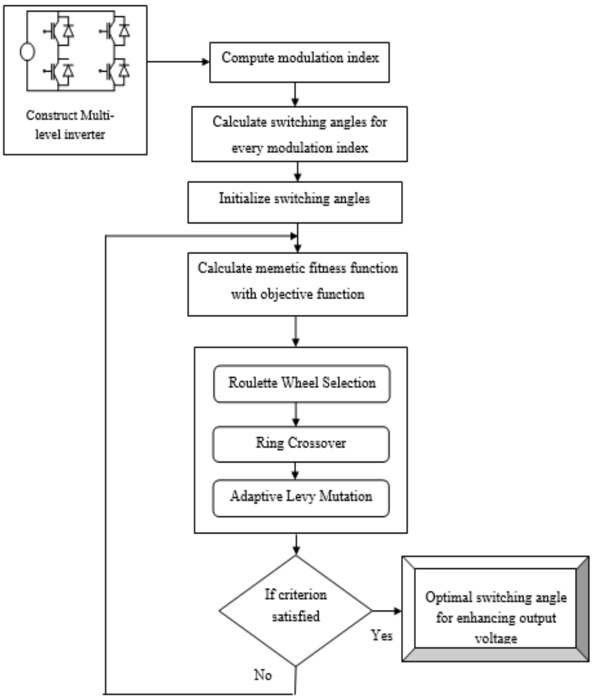

Figure 1 Architecture diagram of NIEMO-SHE Method

After performing the process, it checks whether the criterion is satisfied or not. The process gets repeated till it satisfies the criterion and discovers the optimal switching angle for SHE in multilevel inverter. The brief explanation about NIEMO-SHE method is given in forthcoming sections. Figure 1. Flowchart for fault detection process

3.2 Multilevel Inverter for Selective Harmonic Elimination:

Multilevel inverter is exploited for high power utility applications. The multilevel inverter creates the sinusoidal waveforms with low level harmonics to minimize the distortion. The benefits of multilevel inverter are superior power and voltage ratings, electromagnetic compatibility, minimal switching losses, improved efficiency and voltage capability, lesser THD. An ac voltage is synthesized from various dc sources through cascading the individual inverter. The main problem for switching scheme is determination of switching angles to generate desired fundamental voltage while not generating the higher-order harmonics. The multilevel inverter is the process of eliminating the harmonics from the output voltage. The output voltage of inverter addresses the maximum THD problems. The cascaded multilevel inverter includes single-phase full bridge inverters connected in series connection. The multilevel inverter synthesizes the required ac output voltage from diverse dc sources linked to individual inverter units. The circuit diagram of cascaded multilevel inverter and is explained in figure 2.

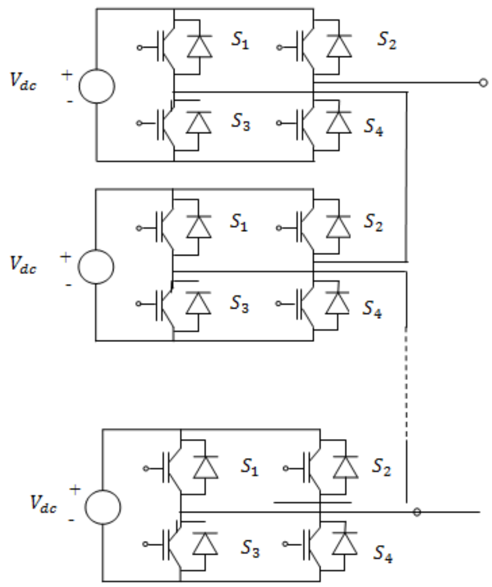

Figure 2 Circuit Diagram of Multilevel Inverter

Figure 2 explains the circuit diagram of multilevel inverter. Every inverter constructs different output voltage ‘+V_dc’, ‘0’ and ‘+V_dc’by joining dc source to ac output with four switches ‘S_1, S_2, S_3and S_4’.Synthesized ac output voltage waveform is sum of each inverter outputs. The number of output-phase voltage levels of multilevel inverter is ‘2S+1’,here‘S’ signify number of dc sources. The output waveform of multilevel inverter is explained in figure 3.

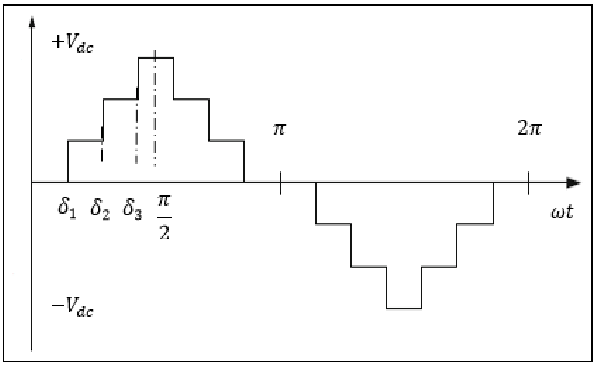

Figure 3 Output voltage waveform of multilevel inverter

In power, quality elements are harmonic contents inside the electrical system. Harmonics are divided as two kinds, i.e. voltage harmonics and current harmonics. Current harmonic are produced via harmonics included in voltage supply and based on kind of load (i.e., resistive, capacitive, and inductive). Load harmonics is owing to overheating of magnetic cores in transformer and vehicles. With non-sinusoidal voltage and non-sinusoidal current waveforms, source harmonics are created by power supply. Frequency of each harmonic component is multiple of its basic frequency. The output voltage waveform ‘V (ωt)’ of multilevel inverter is denoted in fourier series as,

$$V(\omega t) = \sum_{n=1}^{\infty} V_n \sin n\omega t \quad (1)$$

From (1), $2\pi\ V_n$ denotes the amplitude of n^{th} harmonic component. The switching angles are limited ωt between the range ‘$0 < \delta_1 < \delta_1 \ldots\ldots < \delta_m < \frac{\pi}{2}$’. After that, V_n gets changed into A_n and it is given by,

$$A_n = \frac{4V_{dc}}{n\pi} \sum_{k=1}^{L-1} \cos n\delta_k \qquad (2)$$

For all odd n

$$A_n = 0 \quad \text{For all even n} \qquad (3)$$

From (2) and (3), ‘L’ denotes the number of levels, ‘V_{dc}’ symbolizes the dc voltage, ‘δ_k’ represents kth switching angles. Switching angles for L-level inverter requires solving the $\frac{L-1}{2}$equations with nonlinear terms. It is possible to exploit conventional techniques such as Newton Raphson method to find switching angles. When the level increases, the techniques become less effective due to the large number of local minima.

Let us consider that seven level inverter is chosen to eradicate low-order harmonics. It comprises three variables δ_1,δ_2,δ_3 and all voltage sources are equal. For removing the fifth and seventh harmonics, three nonlinear equations are given as:

$$A_1 = \frac{4V_{dc}}{\pi}(\cos\delta_1 + \cos\delta_2 + \cos\delta_{3k}) \qquad (4)$$

$$A_5 = \frac{4V_{dc}}{5\pi}(\cos 5\delta_1 + \cos 5\delta_2 + \cos 5\delta_3) \qquad (5)$$

$$A_7 = \frac{4V_{dc}}{7\pi}(\cos 7\delta_1 + \cos 7\delta_2 + \cos 7\delta_3) \qquad (6)$$

From (4), (5) and (6), ‘A_1’ denotes the amplitude of the fundamental voltage. ‘A_5’ and ‘A_7’ are voltage at the 5^{th} and 7^{th} level inverter. After that, ‘A_1’ is equated to modulation index. ‘A_5’ and ‘A_7’ are set to zero to eradicate the fifth and seventh order harmonics.

$$\frac{4V_{dc}}{\pi}(\cos\delta_1+\cos\delta_2+\cos\delta_{3k})=M \quad (7)$$

$$\frac{4V_{dc}}{5\pi}(\cos 5\delta_1+\cos 5\delta_2+\cos 5\delta_3)=0 \quad (8)$$

$$\frac{4V_{dc}}{7\pi}(\cos 7\delta_1+\cos 7\delta_2+\cos 7\delta_3)=0 \quad (9)$$

From (7), (8) and (9), modulation index is calculated for attaining different switching angles. Modulation index (M) depicts relation among fundamental voltage 'V_1' and maximum dc voltage 'V_{dc}'. It is given by,

$$M=\frac{\pi * V_1}{4 * s * V_{dc}} \quad (10)$$

$$s=\frac{L-1}{2} \quad (11)$$

From (10) and (11), 's' denotes the degree of freedom. '$(s-1)$' harmonics are eliminated with the's' number of switching angles. The non-linear equations afford multiple solutions as modulation gets varied for multilevel inverter and major complexity is discontinuity at certain points where no set of solution is obtainable. In addition, the optimal switching angle is not identified for eradicate harmonics. The complexity of finding the solution of the non-linear equations is avoided by converting SHE problem to optimization problem. THD of the output voltage are calculated using,

$$THD(\%)=\left[\frac{1}{A_1}\sum_{n=5,7}^{\infty}\sqrt{\left(A_n{}^2\right)}\right]*100 \quad (12)$$

From (12), 'A_n' represents amplitude of harmonic n^{th} order and 'A_1' denotes the amplitude of the fundamental frequency. The voltage THD is taken as the objective function $F(\delta)$ in enhanced memetic algorithm. For minimizing the overall THD in output voltage waveform, objective function '$F(\delta)$' has to be lessened with limitations of selective harmonic elimination. The problem is computed as,

$$\text{Minimize }(\delta)=A(\delta_1,\delta_2,\ldots\ldots,\delta_m)\;;$$
$$0<\delta_1<\delta_2\ldots\ldots<\delta_m<\frac{\pi}{2} \quad (13)$$

$$A_1=M; A_5\le\varepsilon_1; A_7\le\varepsilon_2; A_n\le\varepsilon_n \quad (14)$$

From (14), 'ε_1,ε_2,...,ε_n' are permissible limits of individual harmonics. After finding the switching angle and THD, the optimization process is carried out to select the optimal one for harmonic elimination in multilevel inverter.

3.3 Memetic Optimization for Switching Angle Selection:

Memetic Algorithm (MA) is a class of stochastic global search heuristics where the evolutionary algorithms-based techniques are joined with problem specific solvers. MA is a search heuristic that imitates the natural evolution process. The heuristic is employed to obtain the better solutions for addressing the optimization problems. Memetic algorithm generates the solutions to the optimization issues by natural evolution like inheritance, mutation, selection and crossover. Initially, the switching angles is randomly generated and taken as initial population of n−bit chromosomes. With the random values, individual harmonics are computed. After that, memetic fitness, selection, crossover and mutation process is carried out to find the optimized power output. Finally, the optimized maximum power output power is sent to the operator to take the decision. The flow process of NIEMO-SHE method is explained in figure 4.

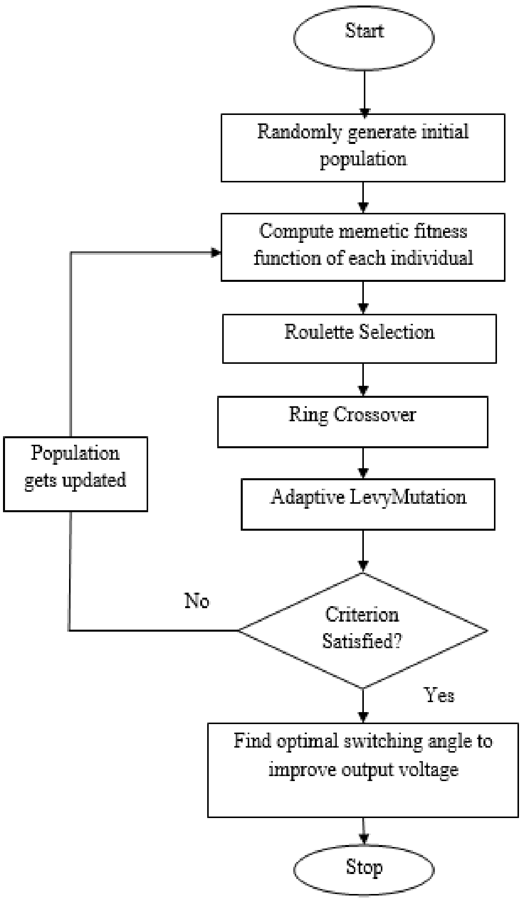

Figure 4 Flow Process of NIEMO-SHE method

Population Initialization:

In population initialization, the population is randomly created after minimizing objective function with randomly chosen individual switching angle. The generated switching angles are the distributed uniformly between the lower and upper limits.

Memetic Fitness Calculation:

Memet

$$Memetic\ Fitness\ (mf_i)\ =$$

$$\min_{\delta_i}\left\{\left(\frac{100*(V_1{}^{*}-V_1)}{V_1{}^{*}}\right)^4+\sum_{i=2}^{S}\frac{1}{h_s}\left(50*\frac{V_{h_s}}{V_1}\right)^2\right\} \quad (15)$$

From (15), '$V_1{}^{*}$' symbolize the essential components, 'S'signify number of switching angles and 'h_s'symbolizes order of Sth harmonic at output of multilevel inverter. Switching angles are collected where the low-order odd harmonics are eliminated and magnitude of harmonic reaches the desirable value. When the fundamental value varies more than 1%, then 1st term fines their power of 4.

Roulette Selection:

After calculating the fitness value, selection process is carried out to choose the individual (i.e., switching angle) with minimum fitness value. In NIEMO-SHE method, the roulette wheel switching angle selection is used for selecting the individual based on the fitness value. Let us take a wheel for choosing the best individuals (i.e., minimum fitness value switching angle)from population.

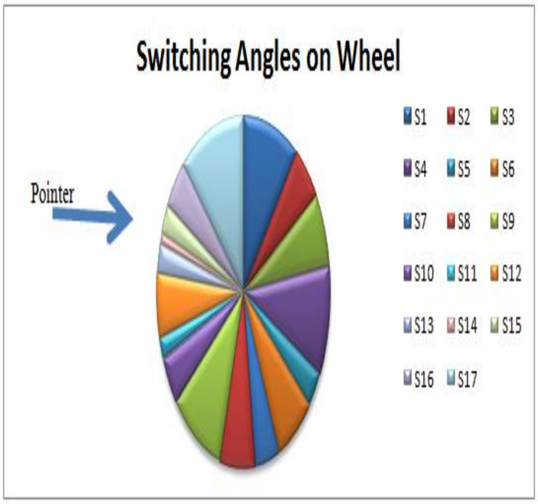

Figure 5 Roulette wheel switching angle selection

The wheel is divided into 'S' number of segments in which the 'S' is the number of switching angles in population. For selection process, all the switching angles are placed on the roulette wheel depends on fitness value. The selection of best individual is described in figure 5.

Figure 5 describes the individual selection using roulette wheel with the wheel pointer. The different segment color represents the fitness value of the different switching angles (i,e., S1, S2, S3, …., S17). For selecting the switching angle, the roulette wheel is rotated. The switching angle indicated by the wheel pointer is chosen and it has minimum fitness function. The selection probability of the best individuals from population is given as,

$$S_p=\frac{mf_n}{\sum_{i=1}^{n} mf_i} \quad (16)$$

From (16), 'S_p'represents the selection probability, 'mf_i'represents the fitness of switching angle 'n' in population 'i'. 'n' denotes the number of switching angles in the population. After that, the switching angles with lesser fitness are chosen for crossover operation.

Ring Crossover:

Crossover process is performed for identifying the new and best solutions. The crossover operation creates two new offspring through swapping the two parents (i.e., individuals). In NIEMO-SHE method, the ring crossover employs the fitness value of two parents to identify the direction of search. The ring operator comprises four steps for generating the two off springs from two parent individuals. At initial step, two parent individuals'p' and 'q' are described.

$p \rightarrow 10010110$; $\quad q \rightarrow 10010110$

After that, the two parents are joined to form the ring. Then, a random cut point is used in any point of the ring. After cutting, one offspring is generated in clockwise direction and another one is generated in anticlockwise direction. In final step, the offspring's are obtained with two parent individuals.

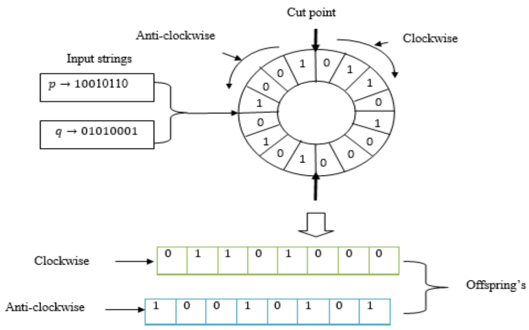

Figure 6 Ring crossover

From figure 6, the process of ring crossover is explained to produce the two offspring from parent individuals. The crossover is carried out depending on the combination of two parent solutions to produce two new individuals. The length of ring is same as the total length of two parents and the off spring are produced with random cut point. Crossover process helps to identify the optimal switching angle. Consequently, the ring crossover process failed to create the diversity within population of switching angles. As a result, the diversity is preserved through bio-inspired mutation operator.

Adaptive Levy Mutation:

After generating the offspring's, mutation process is carried out. Mutation is defined as the process of random variation in the given string. It is used to preserve the genetic diversity from one generation to the next generation. The proposed NIEMO-SHE method uses adaptive levy mutation for randomly interchanging the bit to obtain better solution. The mutation operator considers the newly generated offspring from the ring crossover and flips the bits '1' to '0' or '0' to '1' at random position. In NIEMO-SHE method, the levy density probability density function is formulated as,

$$f_L(x) = \frac{1}{\pi}\int_0^{\infty} e^{-\gamma q^{\alpha}} \cos(qx)dq \qquad (17)$$

From (17), 'α' and 'γ' represents parameters classifying the distribution. The bit flip mutation is showninfigure7.

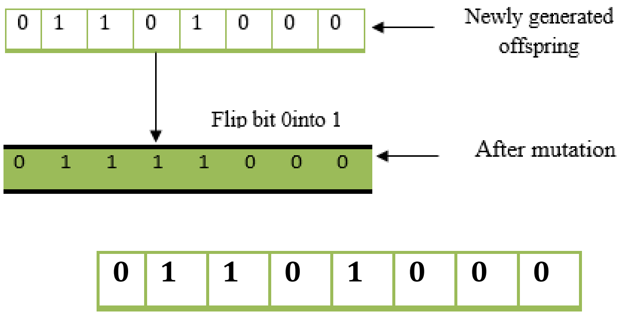

Figure 7 Adaptive Levy Mutation

Figure 7explains the process of levy mutation to attain the new solution by randomly changing the bit '0' into '1'. The previous selected individual is substituted with the new individual.

Termination condition:

Termination condition denotes the end point of the algorithm. The memetic algorithm gets terminated when the maximum iteration is reached. The process gets repeated till it reaches the maximum iteration count by updating the population. The algorithmic process of Nature-Inspired Enhanced Memetic Optimization based SHE in multi-level inverter is shown in below,

\\ Nature-Inspired Enhanced Memetic Optimization based SHE Algorithm

Input: Number of switching

angles'$\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \ldots \delta_n$'

Output: Find optimal switching angle for SHE

Step 1:Begin

Step 2: Initialize number of switching

angles$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \ldots \alpha_n$

Step 3:For each 'α'

Step 4:Calculate the memetic fitness FF

Step 5: Perform Roultee Wheel Selection Process

Step 6:Swap two individuals to generate new off

spring by ring crossover

Step 7:Perform Adaptive Levy mutation process

Step 8: Replace old individual

Step 9:ifcriterion satisfied then

Step 10:Select optimal switching angle

Step 11:else

Step 12:Go tostep4

Step 13:end if

Step 14:end for

Step 15:end

Algorithm 1 Nature-Inspired Enhanced Memetic Optimization based SHE Algorithm

Algorithm 1 describes the process for choosing optimal switching angle in multilevel inverter for harmonic elimination. At first, the numbers of switching angles are initialized. After that, memetic fitness functions are computed to measure the fitness of the individual switching angle. Then, roulette wheel selection is carried out for choosing the best individual from population depends on memetic fitness function. Ring crossover process is carried out to generate the new offspring through swapping process. The adaptive levy mutation is carried out to flip the input bit arbitrarily. Then, it checks whether the criterion gets satisfied or not. The process gets continual until an optimal switching angle is chosen for selective harmonic elimination. Consequently, the optimization process helps to improve the output voltage and output current performance in multilevel inverters.

4. Simulation Settings

The proposed scheme simulated for single phase 7-level multilevel inverter with reduced switch topology in MATLAB/Simulink environment. In 7-level multi-level inverter, to accomplish similar number of switching angles, the three SHE equations are needed to resolve. One switching angle produces fundamental voltage and remaining two eradicates 5th and 7th order harmonic components. The solutions were estimated with arbitrary modulation index value ranges from 0 to 1. The tabulation for simulation parameters are listed in table 1.

Table 1 Tabulation for Simulation Parameters

Parameter	Values
DC Source for 7-Level Inverter	100 v each
Switching Frequency	50Hz
Fundamental Frequency	50Hz
Number of Iterations	200
Initialization of population	$0 \le \delta_1 \le \delta_2 \le \delta_3 \le \frac{\pi}{2}$
Modulation Index	$0 \le M \le 1$
Difference between switching angles	10^{-15}

With help of modulation index, the witching angles are simulated for the proposed method as shown in figure 8. Figure 8 show that three switching angles for different modulation index ranging from 0 to 1.

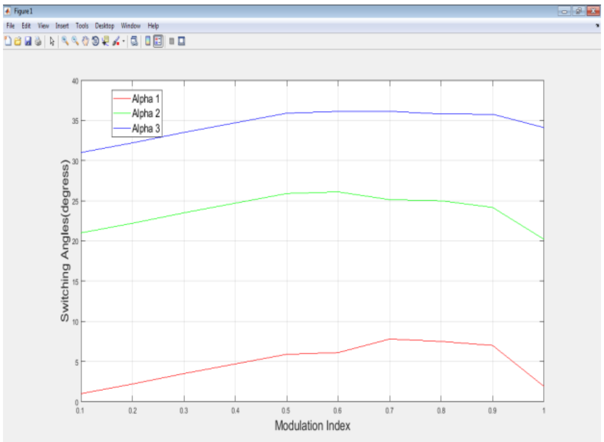

Figure 8 Switching angles (degrees) for different Modulation Index

From figure 8, the switching angles are determined. After that, NIEMO-SHE Method is introduced to choose optimal switching angle for SHE in multilevel inverter. The effectiveness of NIEMO-SHE Method is evaluated along with the metrics such as total harmonic distortion, SHE time and SHE efficiency.

4.1 Impact of Total harmonic Distortion

THD is measure of harmonic distortion exist in signal. THD rate is evaluated as ratio of sum of powers amplitude of each harmonic component to power of fundamental frequency. It is measured in terms of percentage (%). THD is formulated as,

$$THD(\%) = \left[\frac{1}{A_1}\sum_{n=5,7}^{\infty}\sqrt{\left(A_n{}^2\right)}\right] * 100 \qquad (18)$$

From (18), 'A_n' represents amplitude of harmonic n[th] order and 'A_1' denotes the amplitude of the fundamental frequency. When the THD is lesser, the method is said to be more efficient.

Modulation Index (M)	Total Harmonic Distortion (%)		
	NIEMO-SHE Method	Ant Colony optimization based hybrid algorithm	Bat evolutionary optimization method
0.1	31	35	36
0.2	24	28	29
0.3	19	22	24
0.4	15	19	23
0.5	12	17	21
0.6	10	15	19
0.7	9	12	22
0.8	8	16	20
0.9	7	14	17
1.0	6	11	15

Table 2 Tabulation for Total Harmonic Distortion

Table 2 explains the THD of three different methods, NIEMO-SHE Method, Ant colony optimization based hybrid algorithm and Bat evolutionary optimization method for diverse modulation index ranging from 0 to 1. From the table, it is clear that, the THD of NIEMO-SHE Method is lesser than other two existing methods. The graphical representation of THD is given in figure 9.

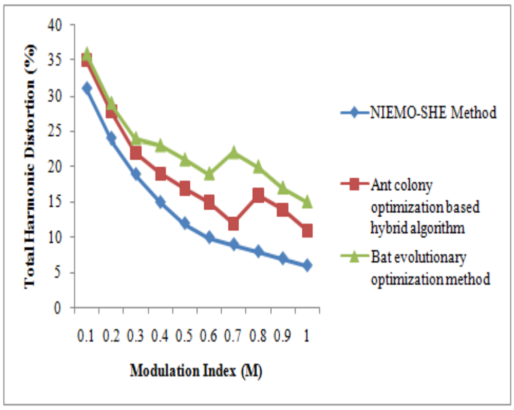

Figure 9 Measure of Total Harmonic Distortion

Figure 9 illustrates the performance of THD of different modulation index values. In the above graph, ten different modulation index values are considered in 'X' axis and the THD is taken in 'Y' axis. From the above figure, the blue colour line represents the THD of NIEMO-SHE Method where red colour and green colour represents the THD of

Ant colony optimization based hybrid algorithm [1] and Bat evolutionary optimization method [2]. From figure, it is clear that the THD using NIEMO-SHE Method is comparatively lesser than existing Ant colony optimization based hybrid algorithm [1] and Bat evolutionary optimization method [2].This is because of memetic optimization algorithm for finding the optimized switching angle to enhance the output voltage performance in multilevel inverter. For multi-level inverter, the modulation index and switching angles of multilevel inverter is measured. The population of switching angle is initialized and memetic fitness function is calculated for all switching angle to perform selection, crossover and mutation operation to identify the optimal switching angle for SHE with minimal total harmonic distortion.

Let us consider, ten different modulation index are taken for conducting the simulation experiment to reduce the harmonic distortion. When the modulation index is 0.9, THD of NIEMO-SHE method is 7% while THD of Ant colony optimization based hybrid algorithm and Bat evolutionary optimization method is 14% and 17% respectively. The THD of NIEMO-SHE method is reduced by 29% and 41% compared to existing Ant colony optimization based hybrid algorithm [1] and Bat evolutionary optimization method [2].

4.2 Impact of SHE Time

SHE time is defined as amount of time consumed for SHE to improve the output voltage performance. It is defined as difference of starting time and ending time of selective harmonic elimination. It is measured in terms of milliseconds (ms). It is mathematically formulated as,

SHET=Ending time-starting time of harmonic elimination (19)

From (19), the SHE time is computed. When the SHET is lesser, the method is said to be more efficient.

Modulation Index (M)	SHE Time (ms)		
	NIEMO-SHE Method	Ant colony optimization based hybrid algorithm	Bat evolutionary optimization method
0.1	56	65	70
0.2	59	67	72
0.3	61	70	75
0.4	58	68	73
0.5	55	64	70
0.6	52	63	69
0.7	56	66	72
0.8	59	69	75
0.9	63	72	79
1.0	65	76	82

Table 3 Tabulation for SHE Time

Table 3 describes the SHE time of three different methods, NIEMO-SHE Method, Ant colony optimization based hybrid algorithm and Bat evolutionary optimization method for different modulation index ranging from 0 to 1. From the table, it is clear that, the SHE time of NIEMO-SHE Method is lesser than other two existing methods. The graphical representation of SHE time is given in figure 10.

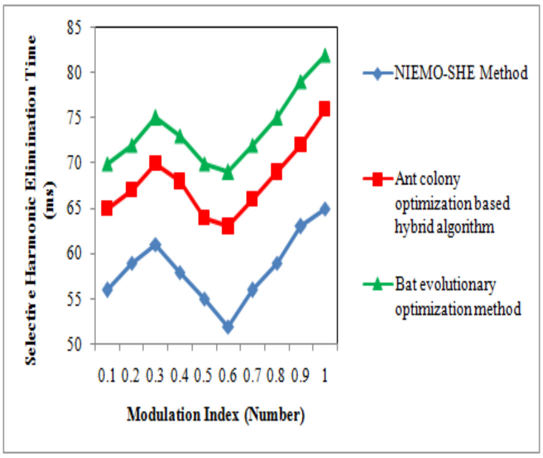

Figure 10 Measure of SHE Time

Figure 10 illustrates the performance of SHE time of different modulation index values. In the above graph, ten different modulation index values are taken in 'X' axis and the SHE time is taken in 'Y' axis. From the above figure, the blue colour line represents the THD of NIEMO-SHE Method where red colour and green colour represents the THD of Ant colony optimization based hybrid algorithm [1] and Bat evolutionary optimization method [2]. From figure, it is clear that the SHE time using NIEMO-SHE method is comparatively lesser than existing Ant colony optimization based hybrid algorithm [1] and Bat evolutionary optimization method [2]. This is because NIEMO-SHE method exploited memetic optimization algorithm for identifying the optimized switching angle to improve the output voltage performance in multilevel inverter. The modulation index is computed and the switching angles of multilevel inverter are determined. The population of switching angle is initialized randomly and the memetic fitness function is computed for all switching angle to execute the selection, crossover and mutation operation. These operations are carried out in NIEMO-SHE method to discover optimal switching angle for SHE with minimal time consumption.

Let us consider, ten different modulation index are taken for improving the output voltage through eliminating the selective harmonic elimination. When the modulation index is 0.6, SHE time of NIEMO-SHE method is 52ms while SHE time of Ant colony optimization based hybrid algorithm and Bat evolutionary optimization method is 63ms and 69ms respectively. The SHE time of NIEMO-SHE method is reduced by 14% and 21% compared to existing Ant colony optimization based hybrid algorithm [1] and Bat evolutionary optimization method [2].

4.3 Impact of SHE Efficiency

SHE efficiency is defined as the rate of eliminating the selective harmonics in accurate manner for improving the output voltage performance. It is measured in terms of percentage (%).When the SHE efficiency is higher, the method is said to be more efficient.

Table 4 describes the SHE efficiency of three different methods, NIEMO-SHE Method, Ant colony optimization based hybrid algorithm and Bat evolutionary optimization method for different modulation index ranging from 0 to 1. From the table, it is clear that, the SHE efficiency of NIEMO-SHE Method is lesser than other two existing methods. The graphical representation of SHE efficiency is shown in figure 11.

Modulation Index (M)	SHE Time (%)		
	NIEMO-SHE Method	Ant colony optimization based hybrid algorithm	Bat evolutionary optimization method
0.1	86	78	70
0.2	91	80	72
0.3	89	81	74
0.4	89	82	75
0.5	90	80	73
0.6	91	79	71
0.7	90	82	74
0.8	91	84	76
0.9	90	83	75
1.0	92	85	77

Table 4 Tabulation for SHE Efficiency

Figure 11 illustrates the performance of SHE efficiency of different modulation index values. In the above graph, ten different modulation index values are taken in 'X' axis and the SHE efficiency is taken in 'Y' axis.

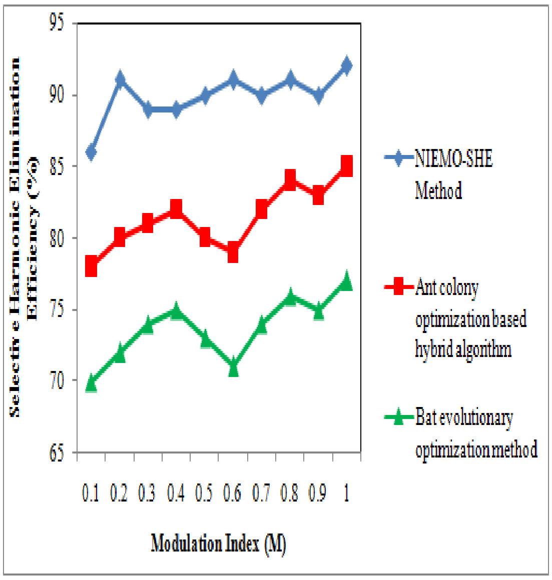

Figure 11 Measure of SHE Efficiency

From the figure, the blue colour line represents the SHE efficiency of NIEMO-SHE Method while the red colour and green colour represents the SHE efficiency of Ant colony optimization based hybrid algorithm [1] and Bat evolutionary optimization method [2]. From figure, it is clear that the SHE efficiency using NIEMO-SHE method is comparatively higher than existing Ant colony optimization based hybrid algorithm [1] and Bat evolutionary optimization method [2]. The SHE efficiency is higher due to the usage of memetic optimization algorithm. The memetic algorithm finds the optimal switching angle and eliminates the selective distortion in multilevel inverter for enhancing the output voltage performance. The modulation index is calculated for given multilevel inverter. With help of modulation index, the switching angles of multilevel inverter are determined. The population of switching angle is initialized and memetic fitness function is calculated for selection, crossover and mutation operation. These operations are performed in NIEMO-SHE method to identify the optimal switching angle for SHE with better efficiency.

Let us consider, ten different modulation indexes are taken for improving the output voltage through eliminating the selective harmonic elimination. When the modulation index is 0.8, SHE efficiency of NIEMO-SHE method is 91% while SHE time of Ant colony optimization based hybrid algorithm and Bat evolutionary optimization method is 84% and 76% respectively. The SHE efficiency of NIEMO-SHE method is reduced by 10% and 22% compared to existing Ant colony optimization based hybrid algorithm [1] and Bat evolutionary optimization method [2].

5. Conclusion

NIEMO-SHE method is introduced for improving output voltage performance in multilevel inverters. NIEMO-SHE method identifies the optimal switching angle for selective harmonic elimination. NIEMO-SHE method used the memetic optimization algorithm for finding the optimized switching angle for eliminating the harmonic distortions. The multilevel inverter gets designed and modulation index is calculated. Switching angles of multilevel inverter are determined and the population of switching angle gets initialized randomly. The memetic fitness function measured in NIEMO-SHE method for executing the selection, crossover and mutation operation. Roulette wheel selection is carried out in NIEMO-SHE method selects switching angle after satisfying the memetic fitness function criterion. Ring crossover operation produces new adapted ones for identifying the near optimal switching angles through swapping process. Adaptive levy mutation operation finds the optimal switching angle for newly generated individuals. The process gets repeated until it finds optimal solution for eliminating the selective harmonic distortion with higher efficiency and minimal time. The performance of NIEMO-SHE method is tested with the metrics such as total harmonic distortion, selective harmonic distortion efficiency and selective harmonic distortion time. With the simulations conducted for all methods, the proposed NIEMO-SHE method presents better performance on selective harmonic distortion in multilevel inverters when compared to state-of-the-art works. The simulations results demonstrates that NIEMO-SHE method provides better performance with reduction of selective harmonic distortion time and improvement of selective harmonic distortion efficiency for output voltage enhancement when compared to the state-of-the-art works.

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