# THD Comparison Of Modified SHE-PSO PWM With LS-PWM, PS-PWM, POD-PWM, APOD-PWM, NLC-PWM Techniques For 17 Level Inverter With Reduced Switch Count

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**Abstract:**

This paper focusing onthe comparison of total harmonics distortion (THD) of the output voltage is minimized by the help of a cascade multilevel inverter with reduced number of switches with un-equal DC sources using the conventional PWM techniques and modified SHE PWM using particle swarm optimization (PSO) algorithm. To address the issues of the multilevel inverters with better performance and efficiency there has been increased advancements with level shift PWM technique, phase shift PWM, POD PWM, APOD PWM and NLC PWM. The paper deals with the analysis of some such advancements like particle swarm optimization techniques and is contrasted to pulse width modulation technique in terms of total harmonic reduction, feasibility, switching pattern of PWM techniques and efficiency. Due to the conventional PWM techniques the complexity of the increased number of elements and harmonics can be reduced with the particle swarm optimization technique and can also determine the optimized switching angles in reducing the selected harmonics. The simulations of the analysis are carried out in the Matlab and the same are presented in the paper which are indeed proved to be better for PSO in contrast to conventional PWM techniques.

**Key words:** multi-level inverters (MLI), LS-PWM,PS-PWM, POD-PWM, APOD-PWM, NLC-PWM, particle swarm optimization, optimized switching angles, selective harmonic elimination.

## 1. Introduction:

In modern electrical and electronics the major drawback of the switches is generating the harmonics classified as voltage and current harmonics causing huge loss to the power system. In recent trends of advancements in multi-level inverters has been a wide area for development of new techniques in selective harmonic elimination, increased performance and efficiency.One such area is redefining the switching angles of the multi-level inverter for efficient performance. The ability of the multi-level inverters is to convert high voltages of AC from cascaded DC sources[1,2] thus making the MLI a part of the modern power grids in high power applications due to added benefits of reduced voltage stresses, filter sizes, various methods for operating of switching angles optimization[3-6] and different methods for harmonic elimination.

For elimination of harmonics from the switches of MLI a few techniques like sine triangle PWM[7] , Optimal Minimization of Total Harmonic Distortion[8] and Selective Harmonic Disposal Pulse Width Modulation[9] are carried out for symphonious end in the cascaded inverters. Modified SHE-PWM is a popular strategy for exchanging switching angles. This limits the THD from a voltagewaveform generated by a voltage-source inverter[10]. Most typically, the Newton-Raphson(NR)

technique is utilized whichadditionally takes care of the symphonious issue. SPWM strategy is extremely successful for noticing the inverter yield voltage however this technique can make high loss in switching actions.

Optimal minimization THD technique can just cycle to limit the THD, it can't consider the significance of lower and higher frequencies [11,12]. MODIFIED SHE-PWM is the best strategy to wipe out lower harmonics and exposed to low switching losses. It further develops power quality of output and also decreases the expense of channel[13]. The different techniques as NRmethod[14], Walsh functions[15] and Block-pulse [16] functions are engaged with the harmonic minimization process in MLI. These multiple of techniques of harmonic suppression have their own weakness. NR strategy requires initial speculations, disparity issues and gives no ideal arrangement. Walsh function and also Block-pulse strategy just settles direct conditions, on account of non-linear conditions which are troublesome to observe better results of switching.

Thus we need strategy to appropriate initial qualities to merge to a legitimate arrangement. As of late, non-conventional strategies dependent on transformative calculations, like Particle Swarm Optimization (PSO)[17], Bee Calculations[24] have been utilized for inverter harmonic elimination[18].

The Particle Swarm Optimization(PSO) strategy was planned in 1995 by Edward and Kennedy[14]. These calculations were motivated by social behavior of creatures like birds, tutoring fish. This strategy for advancement is based on the reason that people living in general public have an assessment that is essential for a bunch of convictions that are shared by every conceivable person. Every individual can alter his own perspective based on three variables:

- Information about the climate
- Recorded information or past encounters
- Recorded information or previous encounters ofpeople in your area or neighborhood.

The PSO[19] method is like a hereditarycalculation that begins with a arbitrary populace grid. In contrast to hereditary calculations, PSOhas no administrators like hybrid and transformation. The lines in the lattice are called particles. These contain the variable qualities. Every molecule continues on the expense surface with a given speed. These particles update their speed and position dependent on best available nearby and global arrangements

Thus in this paper the PSO method with selective harmonic elimination(MODIFIED SHE - PSO)[20] is contrasted with the conventional level shift PWM (LS-PWM), phase shift PWM(PS-PWM), phase opposition disposition PWM (POD-PWM), anti-phase opposition disposition PWM (APOD-PWM) and nearest level control PWM (NLC-PWM) to observe the results for two inverter namely: 17 level MLI and 53 level MLI. The various observations such as harmonics, switching patterns, efficiency, performance issues[25] are studied in further sections. The results and observations of the MODIFIED SHE-PSO of 17level MLI are contrasted with the results of 17 level MLI of LS-PWM, PS-PWM, POD-PWM, APOD-PWM and NLC-PWM

## 2. COMPARITIVE ANALYSIS

### 2.1 17 level MLI with LS-PWM, PS-PWM, POD-PWM, APOD-PWM and NLC-PWM:

This 17 level MLI connects 10 switches and 4 dc sources generating 17 levels of voltages without any need fro inductor, capacitor, freewheeling diodes. The structure allows us draw maximum of 8Vdc and min of -8Vdc in 17 levels ($8V_{dc}$, $7V_{dc}$, $6V_{dc}$, $5V_{dc}$, $4V_{dc}$, $3V_{dc}$, $2V_{dc}$, $V_{dc}$, 0, $V_{dc}$, $-V_{dc}$, $-2V_{dc}$, $-3V_{dc}$, $-4V_{dc}$, $-5V_{dc}$, $-6V_{dc}$, $-7V_{dc}$ and $-8V_{dc}$). The magnitude of voltage level in main model is given by:

$$V_{dc,main} = (N_{sm} + 1)V_{dc,sub}$$

The proposed configuration of the 17 level MLI is depicted in fig.1 as shown below which has reduced number of switches free of other supporting elements.

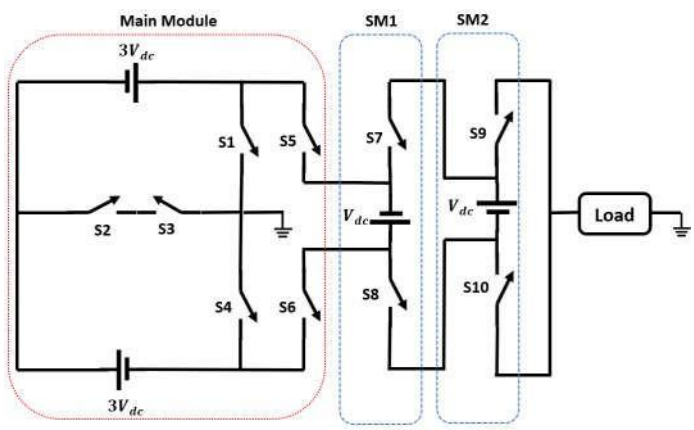


Fig.1 proposed 17 level MLI

The significant power loss of switches in MLIs are due to switching losses and conduction losses[19].Conductionpower losses are more viable in low switching frequencies, though the switching power loss is overwhelming in high frequencies. Conduction loss of IGBT with antiparallel diode is for the on-state condition of resistance and voltages of the two semiconductors and diode. Let Vs is on-state voltage, Rs is the semiconductor resistance, $V_d$ is diode voltage, Rd is resistance of diode. The conduction loss of diode as $P_{CD}$ and semiconductor $P_{cs}$ are: [21]

$$P_{CD}(t) = V_d i(t) + R_d i^2(t)$$
$$P_{CS}(t) = V_S i(t) + [R_S i^{\beta}(t)]i(t)$$

The proposed low switch count 17 level MLI integrates level shift PWM technique in switching patterns of the MLI to draw the output voltage with reduced harmonics. The output voltage and current patterns of 17 level MLI fare shown in below plots fig. 2. the harmonic profile of voltage and current waves of the 17 level MLI are depicted in fig.3 with modulation index of 1 with LS-PWM technique.

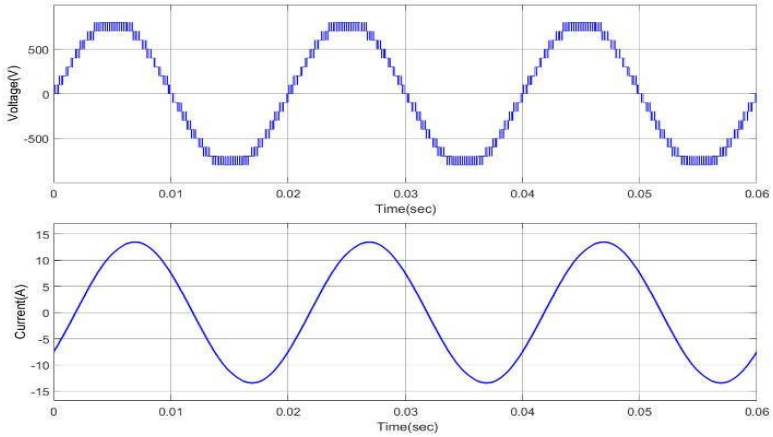


Fig 2. 17 level output voltage and load current with LS-PWM when modulation index is 1 and load is 50Ω and 50mH

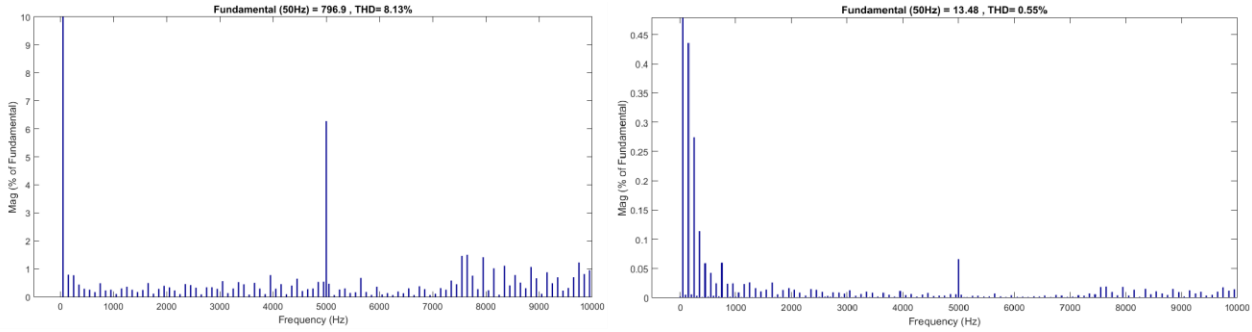


Fig 3. Voltage and current THD with LS-PWM of 17 level inverter with modulation index is 1

The output voltage and current patterns of 17 level MLI are shown in below plots fig. 4. the harmonic profile of voltage and current waves of the 17 level MLI are depicted in fig.5 with modulation index of 1 with PS-PWM technique.

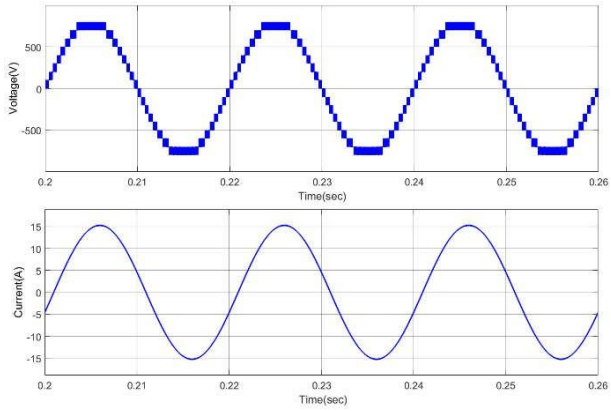


Fig 4. Output voltage and current of 17 level inverter with PS-PWM and modulation index is 1

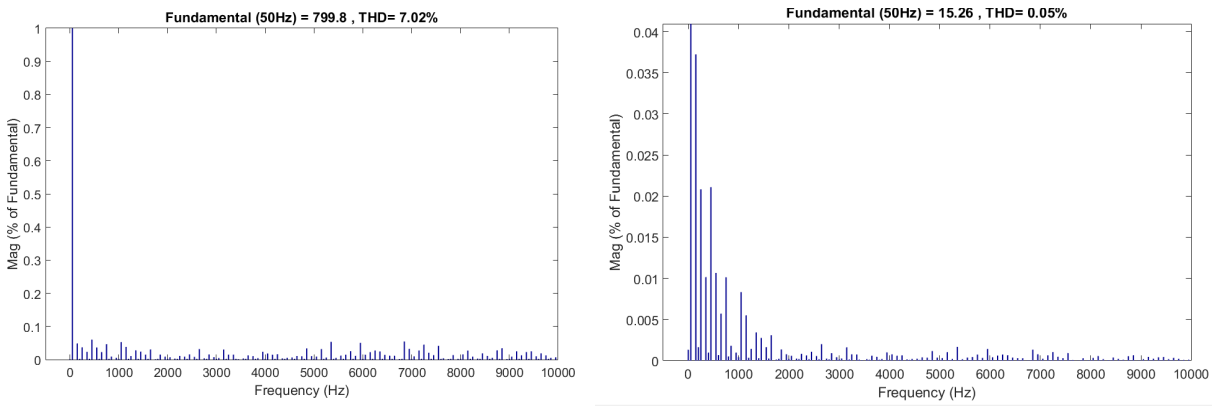


Fig 5. Output voltage and current THD of 17 level inverter with PS-PWM and modulation index is 1

The harmonic profile of voltage and current waves of the 17 level MLI are depicted in fig.6 with modulation index of 1 with POD-PWM technique.

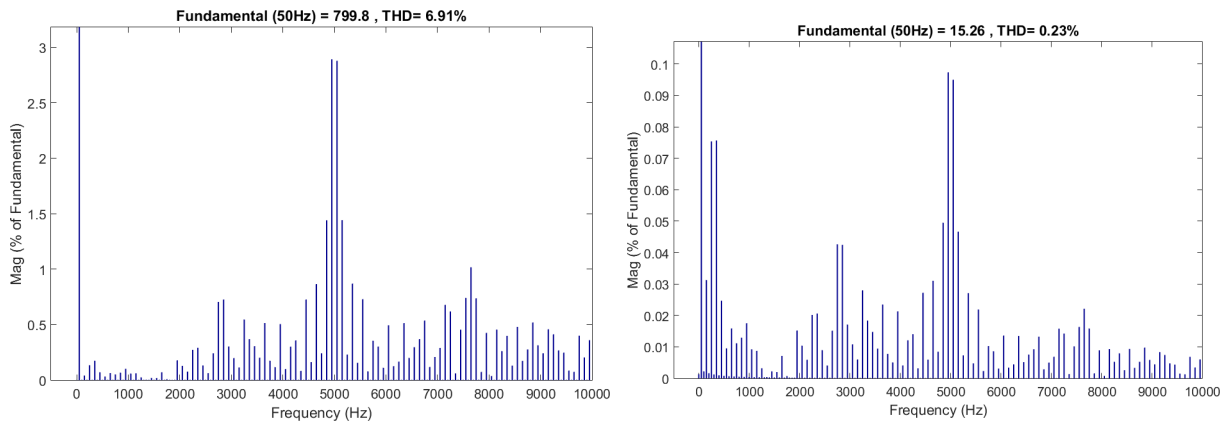


Fig 6. Output voltage and current THD of 17 level inverter with POD-PWM and modulation index is 1

The harmonic profile of voltage and current waves of the 17 level MLI are depicted in fig.7with modulation index of 1 with APOD-PWM technique.

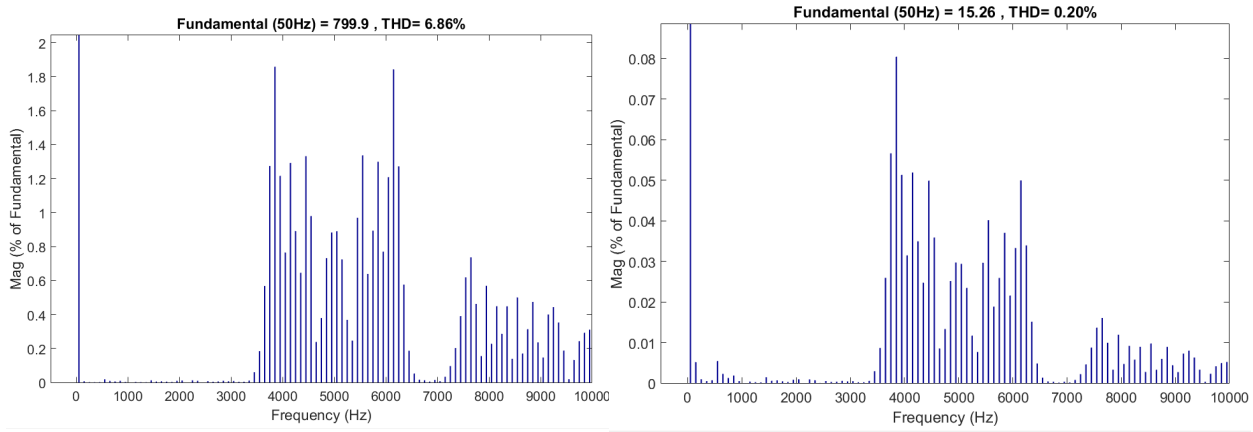


Fig 7. Output voltage and current THD of 17 level inverter with APOD-PWM and modulation index is 1

The output voltage and current patterns of 17 level MLI are shown in below plots fig. 8. the harmonic profile of voltage and current waves of the 17 level MLI are depicted in fig.9 with modulation index of 1 with NLC-PWM technique.

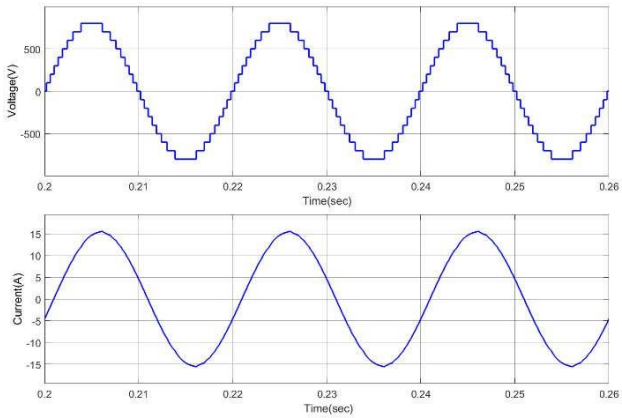


Fig 8. Output voltage and current of 17 level inverter with NLC-PWM and modulation index is 1

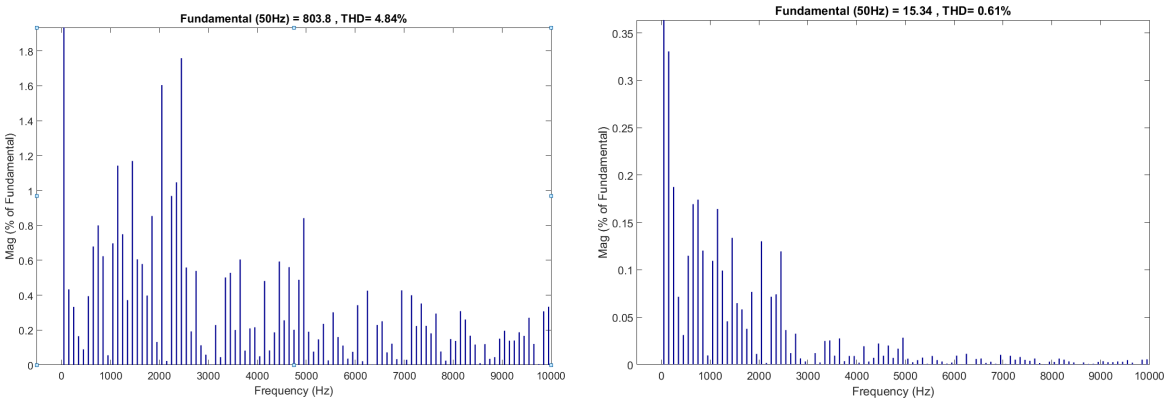


Fig 9. Output voltage and current THD of 17 level inverter with NLC-PWM and modulation index is 1

## 2.2 Modified SHE-PWM using PSO Algorithm to 17 level inverter

For above proposed 17 level MLI the conduction and switching losses are in calculated in a manner which cannot be suppressed in an easy way. In order to counter the losses and to yield quality output the particle swarm optimization PSO algorithm is utilized for the proposed calculation in 17 level MLI to compute the switching system. Modified SHE PSO is renowned switching procedure that is broadly used to explicitly wipe out the selected order harmonics from the output waveform of the MLI. MLI produces voltage with appropriate switching points. At first glance, harmonics are in the output voltage and moreover, odd frequencies are hard to compute albeit the even harmonics are zero at the resultant output.

Subsequently, modified SHE-PSO technique can utilize Fourier investigation work to compute the odd harmonics in the voltage. Appropriately, Fourier examination of result stage voltage is given by

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

The odd harmonics amplitude including the fundamental component of the system can be expressed as

$$a_n = \frac{4V_{cd}}{n\pi} \sum_{k=1}^{s} \cos(n\theta_k) \tag{2}$$

PSO first described by Kenney and Eberhart in 1995, was inspired by two separate concepts: the idea of swarm intelligence based on the social interaction exhibited by swarm, and the field of evolutionary computation. In PSO algorithm, two best values determine each particle's position. The first one is the best value that the particle achieved so far and has been stored. This value is named as individual best. Another one is obtained by the PSO optimizer among the population so far, which is called global best. Also each particle has a position representing the value of variables and a velocity that directs the particle towards the individual and global bests. The fitness function is a particular type of objective function to find the best solution from among all feasible solutions. In PSO, the constraints can also be included in the fitness function. The PSO algorithm consists of three main steps, as follows:

→ Evaluate the fitness of each particle
→ Update individual and global best fitness and position
→ Update velocity and position of each particle

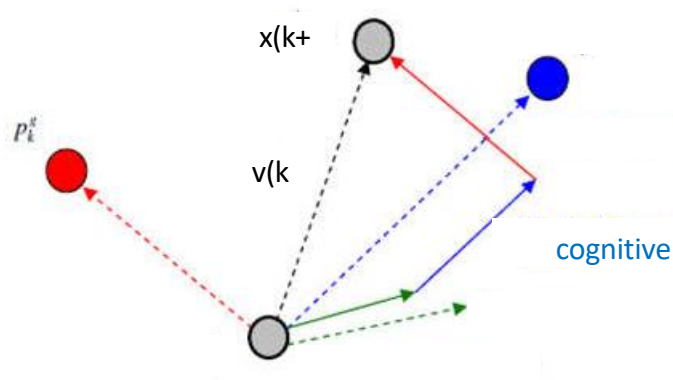


Fig 10. Concept of modification of a searching point by PSO

The position of each particle in the swarm is updated using the equation (3). Where x is particle position and v is particle velocity in the iteration k. The velocity is calculated as follows:

$$\mathbf{v}_i(k+1) = \text{Inertia} + \text{cognitive} + \text{social}$$

$$\vartheta^i_{k+1} = \omega \times \vartheta^i_k + c_1 \times rakd_1(\quad) \times (p^i_k - x^i_k) + c_2 \times rakd_2 \times (p^g_k - x^i_k) \tag{3}$$

Where, $P_i$ is the best individual particle position and $P_g$ is the best global position, $c_1$ and $c_2$ are the cognitive and social parameters, respectively; $r_1$ and $r_2$ are random numbers between 0 and 1. $c_1$ and $c_2$ are usually close to 2 and affect the size of particle's step towards the individual best and global best, respectively. In this study, both values are assumed to be 2 in order to attract the particle towards the best points equally.

$V_{ik}$, called inertia, makes the particle move in the same direction and with the same velocity.

If c1 >> c2 then each particle is more attracted to individual best positions, conversely, if c2 >> c1, then the particles are more attracted to the global best positions.

The PSO calculation must be liable for tracking down the ideal switching angles ($\theta_k$) of the arrangement of conditions as depicted in Eq. 2. It limits the THD and helps to maintain the steady &sufficiency of the crucial symphonious part to the ideal output voltage. The calculations were written in MATLAB forboth the function fitness and also the PSO. The flow chart for the PSO based algorithm that is implemented for the MLI for 17 level inverter is depicted in fig.11

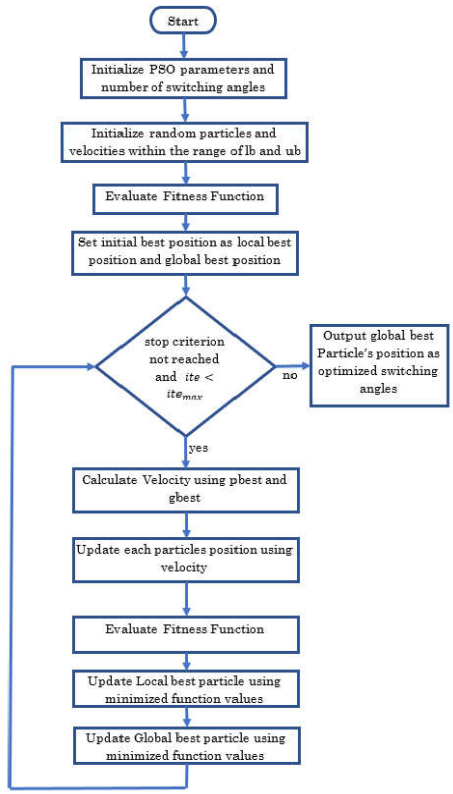


Fig.11 Flow chart of modified SHE-PWM using PSO algorithm in 17 level invertersystem.

The output voltage levels of the 17 level MLI after implementing the modified SHE-PSO algorithm into the system is plotted in fig.12. The voltage and current waves obtained after careful analysis and selection of switching angles for optimized performance of MLI are plotted in fig.13.

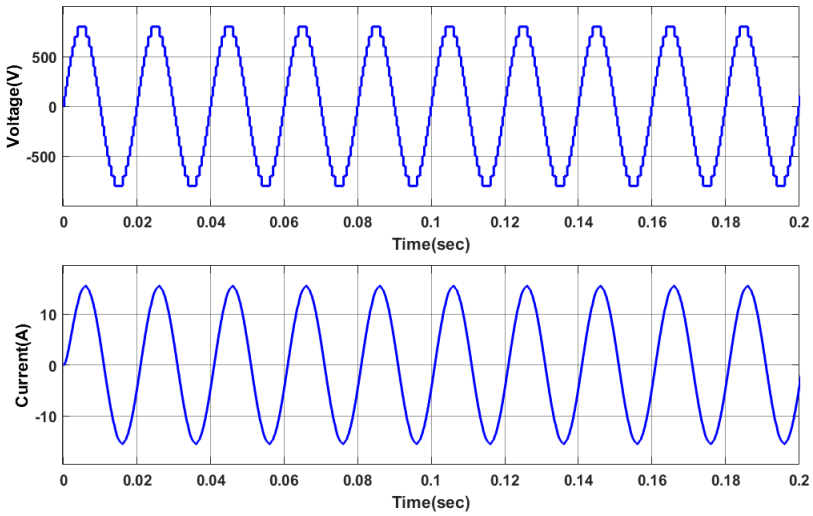


Fig.12 17 level inverter output voltage and current with Modified SHE with 50Ω and 50mH load

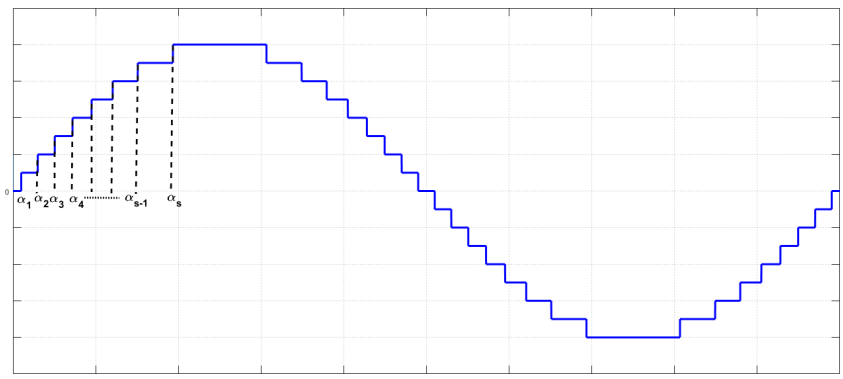


Fig.13Output voltage levels of MLI with switching angles

The optimized switching angles that are decided by the PSO algorithm after selective elimination of harmonics are tabulated below in table.1 for both the positive and negative waveforms which are:

| | |
|---|---|
| $\alpha_1$ | 3.6 |
| $\alpha_2$ | 10.8 |
| $\alpha_3$ | 18.18 |
| $\alpha_4$ | 25.938 |
| $\alpha_5$ | 34.21 |
| $\alpha_6$ | 43.4 |
| $\alpha_7$ | 54.32 |
| $\alpha_8$ | 69.65 |

Table.1 optimized angles for 17 level inverter with Modified SHE using PSO.

The hormonic analysis of output voltage and current of 17 level inverter with Modified SHE-PWM usig PSO is depicted in fig 14. The below results denote the efficiency of the PSO algorithm in terms of voltage and current harmonics, power quality.

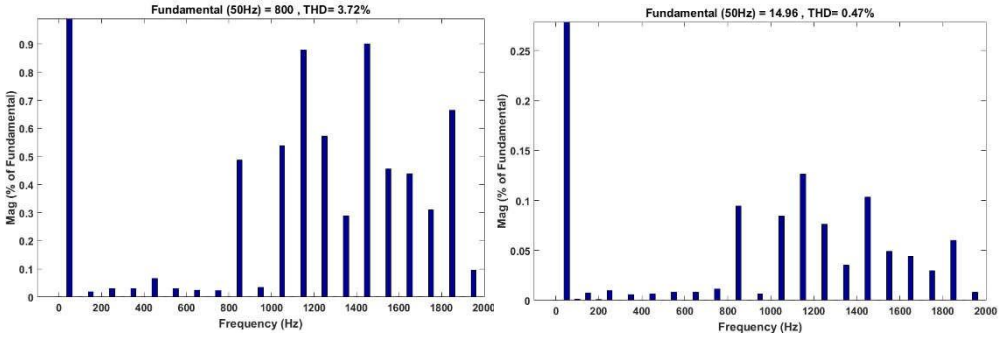


Fig.14THD of output voltage and current for 17 level inverter with Modified SHE using PSO

From the THD analysis it is clear that the harmonic content of the modified SHE-PWM using PSO algorithm is at reduced rate of 3.72% & 0.47% for voltage and current in comparison to conventional PWM techniques like LS-PWM, PS-PWM, POD-PWM, APOD-PWM and NLC-PWM. The comparison of the THD values of all the simulations are tabulatedin table.2

| **Topology** | **17 level MLI** | | | | | |
|---|---|---|---|---|---|---|
| **PWM technique** | LS-PWM | PS-PWM | POD-PWM | APOD-PWM | NLC-PWM | Modified SHE-PWM using PSO Algorithm |
| **Voltage** | 8.13% | 7.02% | 6.91% | 6.86% | 4.84% | **3.72%** |
| **Current** | 0.55% | 0.05% | 0.23% | 0.20% | 0.01% | **0.47%** |

Table.2 THD comparison of the proposed simulations

## III.CONCLUSION

In this paper the modified selective harmonic elimination based PSO algorithm to solve the problem of optimized switching angles and also suppress the higher order harmonics in solving the non-linear transcendental equation.The simulation models and results are provided for both the MLIs for modified SHE-PSO in contrast to LS-PWM, PS-PWM, POD-PWM, APOD-PWM and NLC-PWM techniques. The results from both the simulations prove that the PSO based MLI generates qualitative power with precisely determined solutions, with very lower harmonics in comparison to conventional PWM techniques for 17 level MLI. The output waves denote that the switching angles are optimized with high-speed convergence in the system.The concept of adopting PSO to modified SHE-PWM can be applied to higher levels of multilevel inverters for better improvement in the total harmonic distortion.

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