

# Harmonic Elimination of Multilevel Inverters Using Particle Swarm Optimization

Pooja S. Ambade<sup>1</sup>, Gaurav S. Karlekar<sup>2</sup>

<sup>1</sup>*P.G Student of Electrical Engineering Department, Ballarpur Institute of Technology, Ballarpur, India*

<sup>2</sup>*Assistant Professor of Electrical Engineering Department, Ballarpur Institute of Technology, Ballarpur, India*

**Abstract**—The Selective Harmonic Elimination (SHE) technique is the most significant harmonic elimination method employed in multilevel inverters to reduce harmonics. For any odd harmonics, the desired value equated to zero for the harmonics to be eliminated. After forming nonlinear transcendental equations and solving those equations, the values 1 to k are computed. These nonlinear equations show multiple solutions and the main difficulty is its discontinuity at certain points where no set of solution is available. This limitation is addressed by using Particle Swarm Optimization (PSO). The function of switching angles is used to formulate the objective function and the constraints. The PSO algorithm is used to compute the switching angles. By implementing these angles as additional switching angles per quarter cycle of the output voltage waveform, the harmonics are reduced or eliminated. This study takes into account two multilevel inverters—Seven level and eleven level. The performance is measured by the output voltage's THD. It is found that, PSO based switching angles greatly reduces the THD when compared with the normal switching

**Index Terms**—Multilevel Inverter, Selected Harmonic Elimination (SHE), Particle Swarm Optimization (PSO), Total Harmonic Distortion (THD)

## 1. INTRODUCTION

For high-voltage and high-power applications, multilevel power conversion has received more attention in recent years [1-3]. Among the various structures for multilevel converters, topologies based on series connected H-bridge converters due to their simplicity of control and modularity of structure is particularly attractive.

To control the output voltage and reducing undesired harmonics, various modulation methods such as sinusoidal PWM and space-vector PWM techniques

are suggested for multilevel inverters [3], [4]; another approach is to choose the switching times so that specific higher order harmonics such as fifth, seventh, 11th and 13th are suppressed in the output voltage of inverter. Technical literature refers to this approach as either Programmed PWM techniques or Selective Harmonic Elimination (SHE) [4]– [7]. Solving the nonlinear transcendental equations that describe the harmonic contents is the primary issue with these methods, they can't be done with current computer algebra software like Mathematica and Maple. Simpler stochastic optimization approaches based on genetic algorithms (GA) have recently been used to solve the same issue [9]. This method is successfully applied to seven and eleven level inverters to find all possible set of solutions for switching angles. However, the method has a low chance of dealing with high-level inverters due to the poor quality of the solutions for the eleven-level case. In addition, the GA algorithm has a slow convergence rate and takes a long time to complete each step of the algorithm to find the switching angles. because the entire procedure takes a long time to find solutions for every modulation index. In this paper the novel and popular particle swarm optimization (PSO) method is applied to solve the SHE problem for multilevel inverters. The PSO method is known to produce high-quality solutions with quick convergence and simple implementation [10, 11]. naturally offer multiple choices. This set of nonlinear equations can be solved by iterative techniques such as Newton-Raphson method [1], [2]. However, these methods necessitate a precise initial guess that is very close to the exact solution patterns. Also, this method finds only one set of solutions depending on the initial guess.

Another approach is based on mathematical theory of resultant [8], which involves converting

transcendental equations that describe the SHE problem into an equivalent set of polynomial equations and then applying mathematical theory of to find all possible sets of solutions for this, resultant is used.

### 2. CASCADED MULTILEVEL INVERTERS

Figure 1 depicts the basic structure of a single-phase H-bridge inverter, which consists of single-phase H-bridge cells connected in series. Each H-bridge inverter generates squared voltage waveforms with various duty cycles in itself ac terminal. Depending on the state of four power switches—Q1, Q2, Q3, and Q4—each bridge could produce voltages of 0, +Vdc, or -Vdc. Additionally, the staircase of 2m+1 levels of the inverter's output voltage is depicted in Fig. 1, where m represents the number of independent dc sources in one leg of the H-bridge inverter. By connecting three of these inverters in a star or delta configuration, a three-phase configuration can be created. Figure 1's switching angles must be calculated in order to get rid of unwanted higher order harmonics.

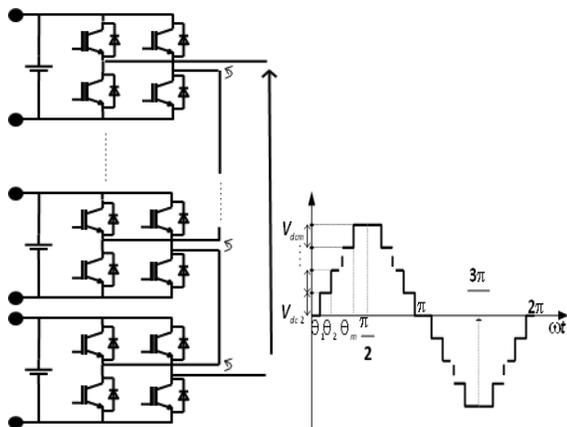


Fig. 1 A 2m+1 levels H-bridge inverter structure with m separated dc sources and the staircase output phase voltage.

### 3. WORKING PRINCIPLE

A cascaded multilevel inverter consists of a series of H- bridge (single-phase full-bridge) inverter units [11] [12] [7] [14] [15]. The general function of this multilevel inverter is to synthesize a desired voltage from several separate dc sources (SDCS's), which may be obtained

from batteries, fuel cells, or solar cells. Fig.3.1 shows a single-phase structure of a cascade inverter with SDCS's. Each SDCS is connected to a single- phase full bridge inverter. Each inverter level can generate three different Voltage outputs, +Vdc, 0, and -Vdc, by connecting the dc source to the ac output side by different combinations of the four switches, S1, S2, S3, and S4. To obtain +Vdc, switches S1 and S4 are turned on. Turning on switches S2 and S3 yields -Vdc. By turning on S1 and S2 or S3 and S4, the output voltage is zero. The ac outputs of each of the different level full-bridge inverters are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels in a cascade inverter is defined by 'm = 2s+1', where 's' is the number of dc sources. An example phase voltage waveform for an 11-level cascaded inverter with five SDSC's and five full bridges is shown in Fig.2

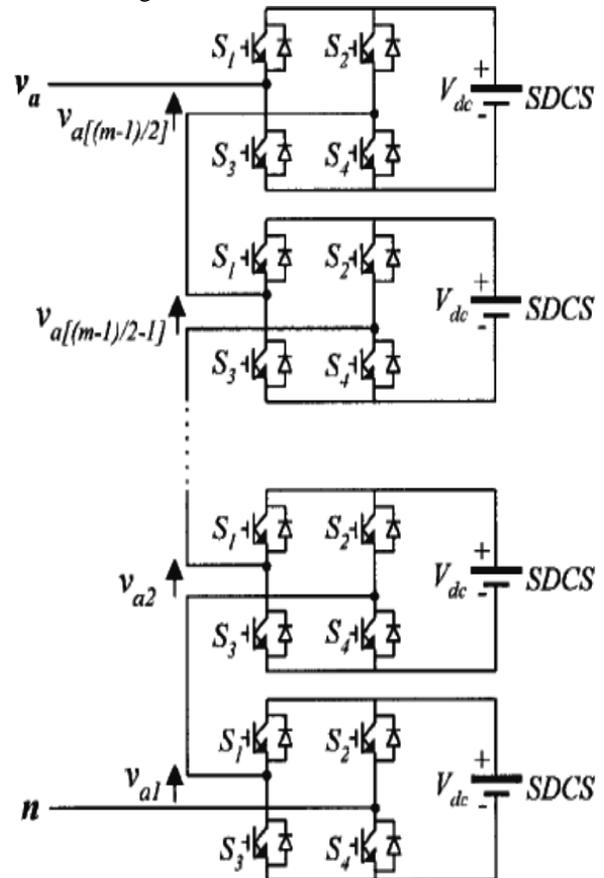


Fig 2 Single Phase Structure of a Multilevel Cascaded Inverter

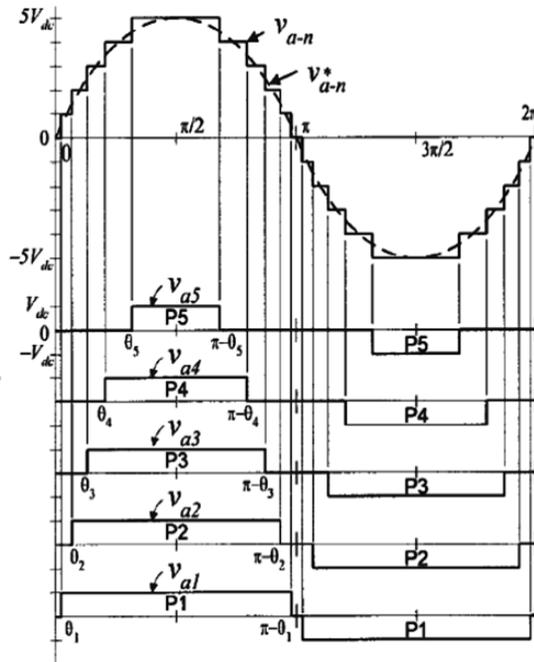


Fig 3. Output Voltage Waveform of the 11 Level Cascade Inverter.

The phase voltage ‘Van’ of the waveform which is shown in Fig.3.2 is expressed as

$$V_{an} = V_{a1} + V_{a2} + V_{a3} + V_{a4} + V_{a5}$$

(3.1)

The output voltage of the inverter is almost sinusoidal, and it has less than 5% THD with each of the bridges switching only at fundamental frequency. Each bridge unit generates a quasi – square waveform by phase shifting its positive and negative phase legs switching timings. The Fig.3.3 shows the switching timings to generate a quasi-sine waveform. Note that each switching device always conducts for 180o (or ½ cycles), regardless of the pulse width of the quasi-square wave. This switching method makes all of the active devices current stress equal. For a stepped waveform such as the one depicted in Fig.3.2 with ‘s’ steps, the Fourier Trans- form for this waveform is as follows:

$$\text{Where, } n = 1, 2, 3, 7, \tag{3.2}$$

$$\text{Where, } n = 1, 2, 3, 5, 7, \tag{3.3}$$

The conduction angles  $\theta_1, \theta_2, \dots, \theta_s$  can be chosen such that the voltage total harmonic distortion is a minimum. Normally these angles are chosen so as to cancel the predominant lower frequency harmonics.

#### 4. SELECTIVE HARMONIC ELIMINATION

A generalized quarter-wave symmetric stepped voltage waveform synthesized by a  $(2m+1)$  – level inverter is shown in the Fig.2, Where ‘m’ is the number of switching angles. By applying Fourier series analysis, the amplitude of any odd harmonic of the stepped waveform can be expressed as Eq.(4.1), whereas the amplitudes of all even harmonics are zero.

$$h_{n} = (4V) / (k n \pi) * \sum [\text{from } k = 1 \text{ to } m] \text{ of } \cos(n \alpha_k) \tag{4.1}$$

where  $V_k$  is the kth level of dc voltage, n is an odd harmonic order, m is the number of switching angles, and  $\alpha_k$  switching angle. According to the Fig 2.12,  $\alpha_1$  to  $\alpha_m$  must satisfy.

$$\alpha_1 < \alpha_2 < \dots < \alpha_m < n/2$$

To minimize harmonic distortion and to achieve adjustable amplitude of the fundamental component, up to m-1 harmonic contents can be removed from the voltage waveform. In general, the most significant low-frequency harmonics are chosen for elimination by properly selecting angles among different level inverters [9] [10], and high-frequency harmonic components can be readily removed by using additional filter circuits. According to equation (2.12), to keep the number of eliminated harmonics at a constant level, all switching angles must be less than  $\pi$

$$V(\omega t) = \frac{4V_{dc}}{\pi} \sum_n [\cos(n\theta_1) + \cos(n\theta_2) + \dots + \cos(n\theta_s)] \times \frac{\sin(n\omega t)}{n}$$

/ 2. However,

if the switching angles do not satisfy the condition, this scheme no longer exists. As a result, this modulation strategy basically provides a narrow range of modulation index, which is its main disadvantage. For example, in a seven-level equally stepped waveform, its modulation index is only available from 0.5 to 1.05. At modulation indexes lower than 0.5, if this scheme is still applied, the allowable harmonic components to be eliminated will reduce from 2 to 1. The total harmonic distortion (THD) increases correspondingly.

#### 5. PARTICLE SWARM OPTIMIZATION

$$H(n) = \frac{4}{n\pi} [\cos(n\theta_1) + \cos(n\theta_2) + \dots + \cos(n\theta_s)]$$

Particle Swarm Optimization is similar to genetic algorithm in that system is initialized with a

population of random solutions. It is unlike a GA, however, in that each potential solution is also assigned a randomized velocity, and then “flown” through the hyperspace.

- 1) Each particle keeps track of its coordinates in hyperspace which are associated with the best solution (fitness). This value is called pbest.
- 2) The “global” version of the particle swarm optimizer keeps track of the overall best value, and its location, obtained thus far by any particle in the population, this is called gbest.
- 3) The PSO concept consists, at each time step, changing the velocity (accelerating) each particle toward its pbest and gbest.
- 4) Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward pbest and gbest

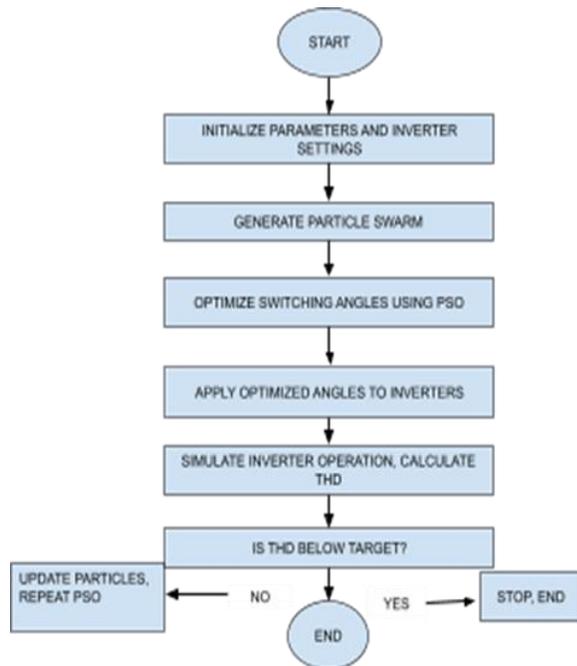


Fig 4 Flow Chart for PSO Algorithm

## 6. EXPECTED SIMULATION RESULTS AND ANALYSIS

To reduce the harmonics, the switching angles are computed by the PSO technique and the switching angles are used as additional switchings along with the fundamental switching.

The frequency spectrum of the output voltage waveform obtains with additional switching angles i.

It is clear that the magnitude of the 7th and 11th order harmonics is reduced. The 3rd order harmonic can be eliminated by suitable transformer connection.

To reduce the harmonics, the switching angles are computed by the PSO technique and the switching angles are used as additional switchings along with the fundamental switching.

The frequency spectrum of the output voltage waveform obtains with additional switching angles. It is clear that the magnitude of the 5th, 7th and 11th order harmonics are reduced. The 3rd order harmonic can be eliminated by suitable transformer connection.

## 7. CONCLUSIONS

Harmonics inherently manifest in multilevel inverters, necessitating the precise manipulation of switching angles for their elimination. This research advocates the application of Particle Swarm Optimization (PSO) to minimize the Total Harmonic Distortion (THD) in multilevel inverter output voltage. The developed algorithm enables the identification of multiple solutions, a critical factor in harmonic mitigation. By incorporating supplementary switching angles, the proposed approach effectively addresses higher and lower-order harmonics, resulting in a remarkable reduction of THD. Through this integrated methodology, the study contributes to the optimization of switching angles and consequently, to the significant improvement of harmonic characteristics in multilevel inverters.

## REFERENCES

- [1] J. S. Lai and F. Z. Peng, “Multilevel converters— A new breed of power converters,” *IEEE Trans. Ind. Applicat.*, vol. 32, no. 3, pp. 509–517, May/Jun. 1996.
- [2] L. M. Tolbert, F. Z. Peng, and T. G. Habetler, “Multilevel converter for large electric drives,” *IEEE Trans. Ind. Appl.*, vol. 35, no. 1, pp. 36–44, Jan./Feb. 1999.
- [3] J. Rodríguez, J. Lai, and F. Peng, “Multilevel inverters: a survey of topologies, controls and applications,” *IEEE Trans. Ind. Electron.*, vol. 49, pp. 724–738, Aug. 2002.
- [4] D. G. Holmes and T. A. Lipo, *Pulse Width*

Modulation for Power Converters—Principles and Practice. New York: Wiley, 2003.

- [5] H. S. Patel and R. G. Hoft, “Generalized harmonic elimination and voltage control in thyristor inverters: Part I -harmonic elimination,” *IEEE Trans. Ind. Applicat.*, vol. IA-9, no. 3, pp. 310–317, May/Jun. 1973.
- [6] , “Generalized harmonic elimination and voltage control in thyristor inverters: Part II -voltage control technique,” *IEEE Trans. Ind. Applicat.*, vol. IA-10, no. 5, pp. 666–673, Sep./Oct. 1974.
- [7] P. N. Enjeti, P. D. Ziogas, and J. F. Lindsay, “Programmed PWM techniques to eliminate harmonics: A critical evaluation,” *IEEE Trans. Ind. Applicat.*, vol. 26, no. 2, pp. 302–316, Mar./Apr. 1990.
- [8] J. N. Chiasson, L. M. Tolbert, K. J. McKenzie, and Z. Du, “Control of a multilevel converter using resultant theory,” *IEEE Trans. Contr. Syst. Technol.*, vol. 11, no. 3, pp. 345–354, May 2003.
- [9] B. Ozpineci, L. M. Tolbert, and J. N. Chiasson, “Harmonic optimization of multilevel converters using genetic algorithms,” *IEEE Power Electron. Lett.*, vol. 3, no. 3, pp. 92–95, Sep. 2005.
- [10] J. Kennedy, R.C. Eberhart, “Particle Swarm Optimization,” *Proc. IEEE Int. of. Neural Networks*, Piscataway, NJ, USA, 1942-194