

## Advancements in Harmonics Reduction: A Review of Three-Phase PSO-Based Techniques

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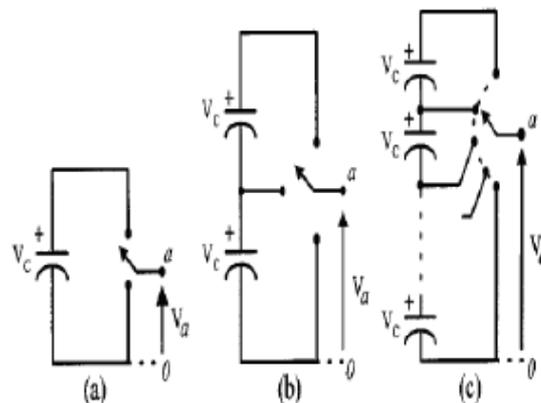
### ABSTRACT

This paper reports particle swarm optimization (PSO) technique for selective harmonic elimination (SHE) in pulse width modulated inverter. A PSO based optimization technique is proposed to minimize the overall THD of the output voltage of PWM inverter and corresponding switching angles are computed. This method is applied for the bipolar switching in three phase inverter for three switching angles and five switching angles. The switching angles are computed to completely eliminate the lower order harmonics. The result of the bipolar case using three switching angles are compared with that of a recently reported work, based on PSO technique, and is observed that the proposed method is effective in eliminating the lower order harmonics completely and overall THD is reducing to a greater extent than the previously reported work.

**Keywords:** Selective harmonic elimination (SHE), particle swarm optimization (PSO), pulse width modulation (PWM), Particle Swarm Optimization (PSO) Accelerated Particle Swarm Optimization (APSO), Selective Harmonic Elimination (SHE), Total Harmonic Distortion (THD), Inverter, Evolutionary Computing Techniques..

### I. INTRODUCTION

In recent years, industry has begun to demand higher power equipment, which now reaches the Megawatt level. Controlled ac drives in the megawatt range are usually connected to the medium-voltage network [1]. Today, it is hard to connect a single power semiconductor switch directly to medium voltage grids (2.3, 3.3, 4.16, or 6.9 kV). For these reasons, a new family of multilevel inverters has emerged as the solution for working with higher voltage levels. The commutation of the switches permits the addition of the capacitor voltages, which reach high voltage at the output, while the power semiconductors must withstand only reduced voltages. Fig.1.1 shows a schematic diagram of a single phase leg of inverters with different numbers of levels, for which the action of the power semiconductors is represented by an ideal switch with several positions. A two-level inverter generates an output voltage with two values (levels) with respect to the negative terminal of the capacitor [see Fig. 1.1 (a)], while the three-level inverter generates three voltages, and so on.



**Fig.1.1 Single Phase Leg of an Inverter with (a) Two levels (b) Three levels (c)n-levels**

Harmonics must always be limited below threshold level prescribed by standards [2], both in their total harmonics distortion (THD) and in their individual magnitudes. Several techniques have been proposed to cancel out high amplitude harmonics to eliminate or reduce the need for filtering while meeting the standard requirements. The most interesting one includes programmed harmonic elimination and multilevel converters, which do not require high frequency switching as the PWM techniques provided in [3]. Therefore multilevel converters have attracted much attention in high power application. Among the different topologies for multilevel converters, the cascaded multilevel inverter has received special attention due to its modularity and simplicity of control [4]. There are different power circuit topologies for multilevel converters. The most familiar power circuit topology for multilevel converters is based on the cascade connection of an  $s$  number of single-phase full-bridge inverters to generate a  $(2s + 1)$  number of levels. There are several literature to control the output voltage and to eliminate the undesired harmonics in multilevel converters with equal dc voltages,

various modulation methods such as sinusoidal pulse width modulation (PWM), space vector PWM techniques as suggested by [5]-[7]. Another approach is to choose the switching angles so that specific higher order harmonics such as the 5th, 7th, 11th, and 13th are suppressed in the output voltage of the inverter. This method is known as Selective Harmonic Elimination (SHE) or programmed PWM techniques in technical literature [8]-[9]. Such method solves a set of nonlinear equations by Newton-Raphson method whereas this technique needs a good initial guess. Therefore, the Newton-Raphson method is not feasible to solve the SHE problem for a large number of switching angles if good initial guesses are not available. In this paper, Particle Swarm Optimization (PSO) technique is developed to deal with the SHE problem with equal dc sources. For a large number of switching angles, the proposed PSO approach reduces the computational burden to find the optimal solution compared with iterative methods. The proposed method solves the asymmetry of the transcendental equation set, which has to be solved in cascade multilevel inverters. Simulation results are provided for an 11-level cascaded multilevel inverter to show the validity of the proposed method.

## II. LITERATURE REVIWE AND OLD ARTICLES

**A.Sadhukhan , S.Ganguly:** This paper presents the particle swarm optimization based harmonic elimination pulse width modulation (HEPWM) technique for three-phase voltage source inverter (VSI) to reduce predominant lower order harmonics at its output. The switching strategy of power semiconductor devices of VSI decides the nature of its output voltage. In this regard, the switching strategy can be broadly classified as lower and higher switching frequency pulse width modulation (PWM) methodology. In this paper, lower switching frequency HEPWM is adopted to reduce switching losses in VSI as well as significant lower order harmonics are almost eliminated. For obtaining the required HEPWM waveform, the switching angles are computed using PSO technique so that the THD up to 43rd order harmonics are considered to be minimized at different values of fundamental component. The PIC microcontroller is used to generate HEPWM signals which are applied to the VSI in hardware platform.

**Bhupender Sharma:** This paper present some pointed out factors or parameters related to optimal power flow solutions by using the Particle swarm optimization and Genetic algorithm to observe some refined status and supervise the practicality for a particular electrical network. The work presented in this paper utilizes an optimal power flow problem. The OPF utilizes all control variables to help to minimize the cost of the power system operation. It also yields valuable economic information and insight into the power system. In this way, the optimal power flow problem very adeptly addresses the control and economic problems. After formulating the OPF problems, results are obtained by using genetic algorithm and particle swarm optimization, programming work is carried out in Mat lab. A case study on an IEEE-30 bus system expresses some sound idea in a very positive result oriented manner directed towards the applicability of the proposed approaches in the practical electrical network system. A comparison in both the proposed approaches is made and some important features are extracted out as: for the same electrical network configurations both the methods are proved almost better but not so much comparatively competitive for the optimal power flow. Results show that the algorithm is well competent for optimal power flow under practical constraints and price based conditions.

**Ahmed A. A. Esmim:** This paper presents the particle swarm optimization (PSO) algorithm for solving the optimal distribution system problem for power loss minimization. The proposed methodology determines control variable settings, such as the number of shunts to be switched, for real power loss minimization in the transmission system. The problem is formulated as a nonlinear optimization problem. The PSO is a relatively new and powerful intelligent evolution algorithm for solving optimization problems. It is a population-based approach. The proposed approach employs the PSO algorithm for the optimal setting of optimal power (OPF) based on loss minimization (LM) function. The proposed approach has been examined and tested on standard IEEE 14, IEEE 30 and IEEE 118 bus test systems. The obtained results are compared with those using other techniques in a previous work to evaluate the performance.

**MadichettySreedhar:** The problem of eliminating harmonics in Inverters has been the focus of research for last three decades. For maximizing efficiency of conversion, it is desirable to choose an optimum switching frequency, which will minimize switching losses. The most common method of eliminating lower order harmonics and voltage control is Sinusoidal Pulse Width Modulation (SPWM) technique [4]. Selective Harmonic Elimination (SHE) produces a fundamental wave form of magnitude higher than SPWM [1],[2]. The number of pulses per half cycle in SHE is likely to be less than SPWM, so that switching losses are lower. This feature is very important for high power applications in which power devices cannot be switched at higher frequencies due to high switching losses. The major problem faced by switch mode DC to AC conversion is that non sinusoidal output voltages are produced. The non sinusoidal waveforms of an inverter can be passed through filters to remove harmonics, but this may be costly at higher power levels. Selective Harmonic Elimination for inverters involves the solution of a number of transcendental equations with large number of

possible solutions. These solutions will eliminate some specific harmonics. The aim of the current work is to pin point the best solution that will result in the minimum Total Harmonic Distortion (THD).

### III. DIFFERENT TYPES OF MULTILEVEL INVERTERS

Numerous multilevel converter topologies have been developed in the recent literature [1]-[7]. Three different basic multilevel converter topologies are the neutral point clamped (NPC) or diode clamped [6], the flying capacitor (FC) or capacitor clamped, the cascaded H-bridge (CHB) [8] and hybrid MLI [7]. Figure 2.2 shows the Family tree of multilevel inverters.

3.2.1 Diode-clamped (neutral-clamped) multilevel inverters (DCMLI)

3.2.2 Capacitors-clamped (flying capacitors) multilevel inverters (FCMLI)

3.2.3 Cascaded multilevel inverters (CMLI)

3.2.4 Hybrid multilevel inverters (H-MLI)

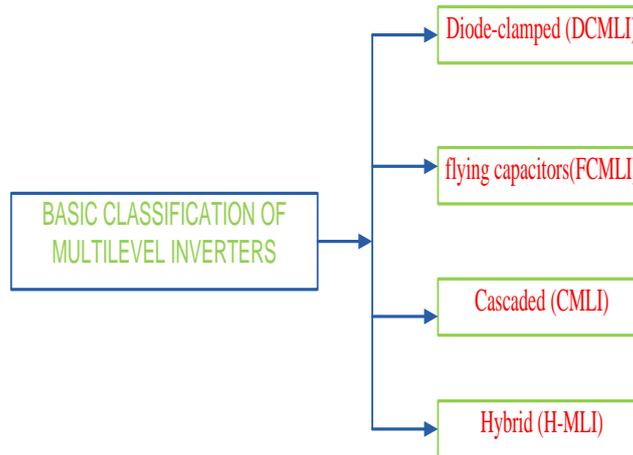


Fig.3.2: classification of multilevel inverter structures

#### 3.2.1 Diode-clamped multilevel inverters

This inverter uses diodes and provides multiple voltage levels through the different phases to the capacitor banks which are in series [16]. A diode transfers a limited amount of voltage, thereby reducing stress on the electrical devices.

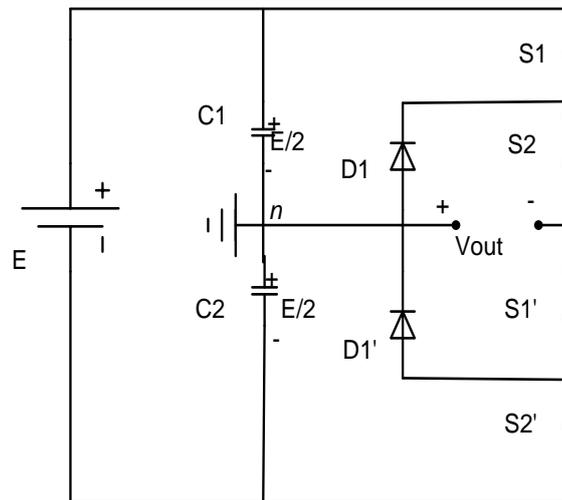


Fig.3.3: single phase diode clamped multilevel inverter for three levels [6]

#### 3.2.2 Capacitor-clamped mli (flying capacitor inverters)

The structure of this inverter is similar to that of the diode-clamped inverter except that instead of using clamping diodes, capacitors are used. Figure 2.4 illustrates the fundamental building block of a phase-leg capacitor-clamped inverter [9].

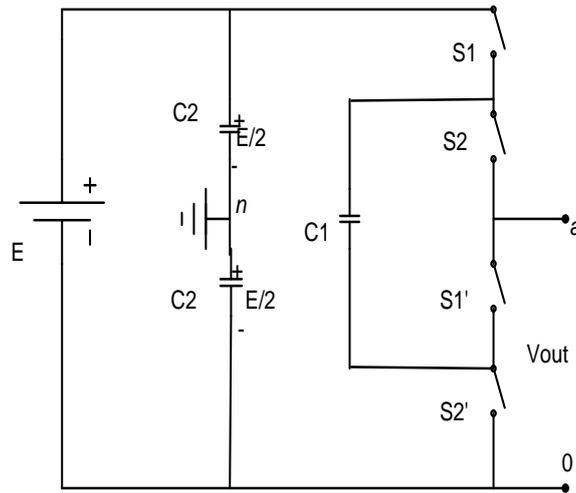


Fig.3.4: single phase flying capacitor inverter structure for three levels [9]

**3.2.3 Cascaded h -bridge multilevel inverter**

A single-phase full-bridge inverter is made up of four transistors and four diodes. The transistor can be replaced by other solid-state switches like Thyristors, MOSFET, GTOs, and IGBTs etc. Solid-state switches are unidirectional switches i.e. they conduct in only one direction [9]. A diode is connected anti-parallel to each transistor to realize a bidirectional switch. Due to the circuit’s close resemblance to the letter ‘H’, the full bridge inverter is also known as an H-bridge inverter

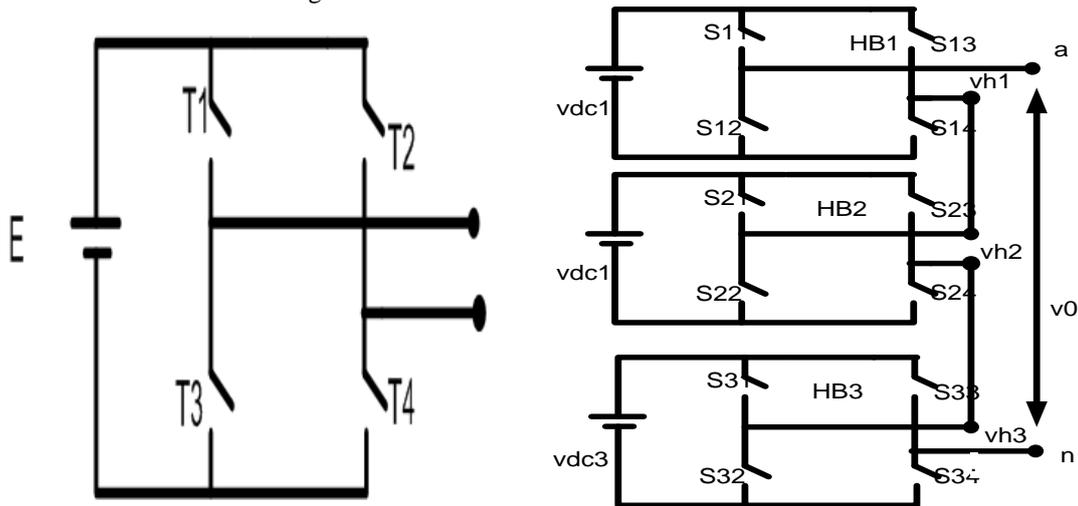


Fig.3.5: Basic H-bridge configuration and cascaded connection of HB’s

**3.2.4 Hybrid h-bridge inverter**

A hybrid H-bridge inverter consists of a series of H-bridge inverter units. The general function of this Multi-level inverter is to synthesize a desired voltage from several DC source. The AC terminal voltages of different level inverters are connected in series such as the hybrid topologies, the dc voltage sources magnitudes are unequal or changed dynamically.

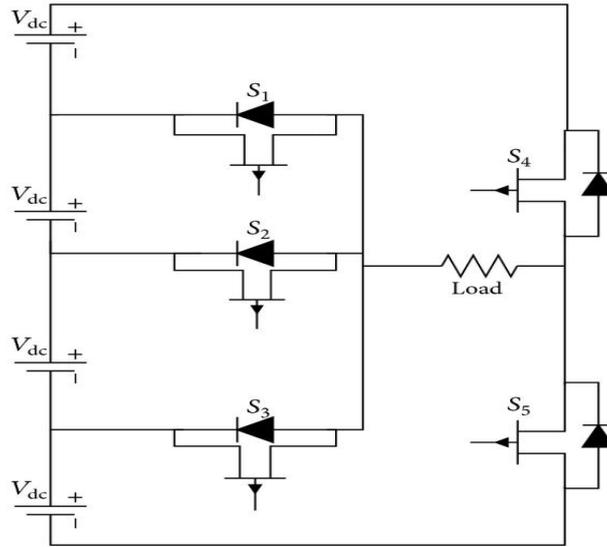


Fig.3.6: A typical hybrid topology

Problem formulation: Assuming the equal DC source is applied to each of the inverter and taking into consideration the characteristics of the inverter waveform Fourier series expansion of stepped output voltage waveform of the multilevel inverter with equal dc sources can be expressed as:

$$V_o(\omega t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{n} \{ \cos(n\theta_1) + \cos(n\theta_2) +$$

$$\cos(n\theta_3) + \cos(n\theta_4) + \cos(n\theta_5) \} \times \sin(\omega t)$$

Equation (3)

Where  $V_{dc}$  is the nominal dc voltage and the variables  $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5$  (firing angles) are given as  $0 < \theta_1 < \theta_2 < \theta_3 < \theta_4 < \theta_5 < \pi/2$ . Subject to the firing angles  $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5$  are within the limit given as  $0 < \theta_1 < \theta_2 < \theta_3 < \theta_4 < \theta_5 < \pi/2$  Where  $V_1$  is the fundamental voltage and  $V_n$  is the  $n$ th order harmonics voltage. In this paper the minimum value of THD can be achieved by the Particle Swarm Optimization (PSO) technique [8].

#### IV. PARTICLE SWARM OPTIMIZATION

PSO is a simple and efficient population-based optimization method proposed by Kennedy and Eberhart(1995). PSO is motivated by social behavior of organisms such as fish-schooling and bird-flocking. In PSO, potential solutions called particles fly around in a multidimensional problem space. A population of particles is called a swarm. Each particle in a swarm flies in the search space towards the optimum or a quasi-optimum solution based on its own experience, experience of nearby particles, and global best position among particles in the swarm.

The elements of  $\theta_i$  are the solutions of the harmonic minimization problem, and the  $d$ th element of that is corresponding to the  $d$ th switching angle of the inverter. The step-by-step procedure to solve the SHE problem with equal dc sources to minimize the THD is as follows[9].

1. At the first step, the required parameters of the algorithm such as population size  $M$ , maximum iteration number  $iter_{max}$ , etc., are determined and the iteration counter is set to 1.
2. Each variable (particles) in the population is randomly initialized between 0 and  $\pi/2$ ; similarly, the velocity vector of each particle has to be generated randomly from  $-V_{max}$  to  $V_{max}$ .
3. Each particle is evaluated to fit in the objective function given .
4. In the minimization process of equation (3), if the current position of the  $i$ th particle is better than its previous personal best position, replace  $P_{best_i}$  with the current position  $X_i$ .
5. From the personal best of the particle if the best position of the personal bests of the particles is better than the previous position called global best, then replace the present global best with the previous one.
6. Update the velocity and position vector based on equation (4) and (5) and repeats the process to reach the optimal solution.
7. If the iteration counter reaches maximum set value stop the process to obtain the final result; else, increase the iteration counter and go back to step( 3) and repeat the whole process.

## V. PREVIOUS SIMULATION RESULT

The THD minimization problem is solved by PSO technique and the program was developed in MATLAB. For test case the simulations results are presented for a single phase cascaded H-bridge inverter. The THD of output line voltage upto 49<sup>th</sup> order harmonics with modulation index  $m=0.47$  was calculated and it was around 6% when 10 volt dc supply was given to the invertors. The optimal switching angle for the above THD are  $\theta_1 = 5.2338$ ,  $\theta_2 = 16.3852$ ,  $\theta_3 = 30.9033$ ,  $\theta_4 = 42.9065$  and  $\theta_5 = 62.6564$ . The %THD calculated by proposed approach is better than the result provided in reference [10]

It has been seen that the magnitude of 3rd, 5th, 7th, 9<sup>th</sup> and 13th order harmonics are negligible.

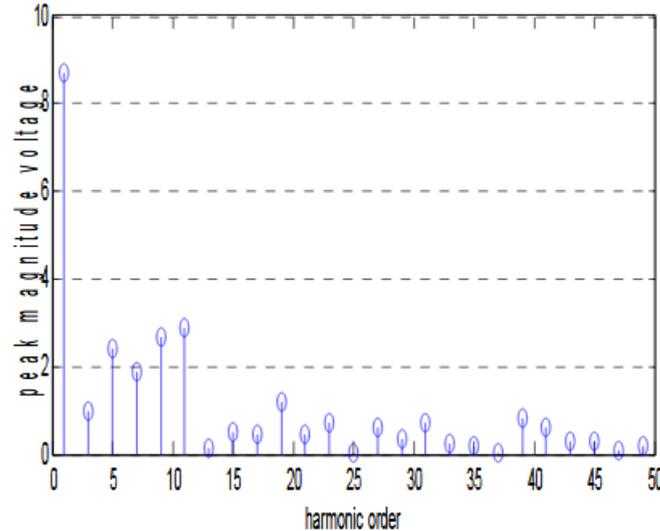


Fig. 5: FFT analysis of the multi level cascaded inverter.

## VI. CONCLUSION

The PSO technique to minimize the total harmonics distortion (THD) with the help of selected harmonics elimination (SHE) procedure with equal dc sources in H-bridge cascade multilevel inverter is implemented in this paper. The proposed method is able to find the optimum switching angles in a simple manner. The proposed PSO technique minimizes the computational burden and has smooth convergence criteria than other methods. A complete analysis for 11-level inverter has been presented and it is shown that a significant amount of THD reduction can be attained which is within the prescribed IEEE limits.

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