International Journal of Engineering Research and General Science Volume 3, Issue 3, May-June, 2015
ISSN 2091-2730

Particle Swarm Optimization Approach for Mitigation of Harmonics in Multilevel Inverters: A Review

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Abstract— Multilevel inverter technology has emerged recently as a very important alternative in the area of high-power medium-voltage energy control. Using multilevel inverters application in fuel cell, solar cell & wind turbines is increasing now a day's rapidly. Therefore, Harmonic reduction techniques in multilevel inverters are considered very important task

Over the past decades, depending upon the topologies and control strategies, numerous optimization techniques have been proposed for desired output waveform. This paper presents a review of optimization techniques used for multilevel inverters. The pros and cons of optimization techniques are discussed. The objective of these optimization techniques is to find out the optimum firing angles of multilevel inverters, which results in minimum harmonics.This paper presents a review application of PSO for harmonic reduction in multilevel inverters.

As a preferred option for proposed work, reduction of total harmonic distortion with the aid of particle swarm optimization technique to multilevel inverters is suggested.

Keywords— *Harmonic suppression, Multilevel Inverter, PSO, Total Harmonic Distortion*.

1.INTRODUCTION

Power converters have taken a very important place in the industrial world. Initially the scope was limited up to two level converters but nowadays multilevel converters such as three levels; five levels and higher levels converters have been designed depending upon the various topologies. The main concern of system designers and application engineers has been the task of appropriate designing of multilevel converters which produce desired staircase wave with fewer harmonics. This has been mainly due to the reason that on increasing the number of levels, more harmonics are introduced in the output of the inverters. The multilevel inverter having harmonics free output attracted importance in all industrial, commercial, domestic and defense applications [4]. Hence, there has arisen the need for suitable control strategies and optimization techniques to achieve harmonics free output in multilevel inverters.

Neutral point clamped (NPC), flying capacitor (FC) and cascaded hybrid bridge (CHB) are the three multilevel converter topologies and well documented in the literature [8]. A proper selection of topology using power semiconductor devices forms the most ideal inverter for a variety of industrial applications. More emphasis will be given here to the features related to the CHB, since it is the topology to be used in this paper for harmonic control. In the late 1960s, with the series connected hybrid bridge multilevel stepped waveform concept, CHB topology came into existence [9]. Compared with NPC and FC topologies, cascaded hybrid bridge converters require the minimum number of components for producing the same number of voltage levels because of elimination of clamping diodes and voltage balancing capacitors. But CHB inverter needs separate dc sources for each cell. After selection of multilevel inverter topology; there is need to decide the control or modulation strategies and optimization techniques, which result in minimum total harmonic distortion (THD) as mentioned in standards like IEEE-519, EN 50160, IEC 61000-2-2, IEEE 61000-2-4 etc. [10].

This paper is arranged into six sections. Section I deals with the introduction, gives the brief history of multilevel inverter topologies, control strategies and optimization techniques. Most widely used CHB topology is described in section II. Suitable modulation techniques for designing of multilevel inverters are mentioned in section III. Section IV enlists the optimization techniques for finding the optimum firing angles. Comparison of all the existing optimization techniques has done in this section. Challenges and future scope are mentioned in section V. Finally conclusion has drawn in section VI.

2. CASCADED H-BRIDGE MULTILEVEL INVERTER:

A single-phase structure of an m-level cascaded inverter is illustrated in Fig. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S_{a1}, S_{a2}, S_{a11}, and S_{a21}. To obtain $+V_{dc}$, switches S_{a1} and S_{a21} are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_{a2} and S_{a11}. By turning on S_{a1} and S_{a2} or S_{a11} and S_{a21}, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defi ned by m = 2s+1, where s is the number of separate dc sources. An example phase voltage waveform for a 5-level cascaded H-bridge inverter with 2 SDCSs and 2 full bridges is shown in Fig. 2.

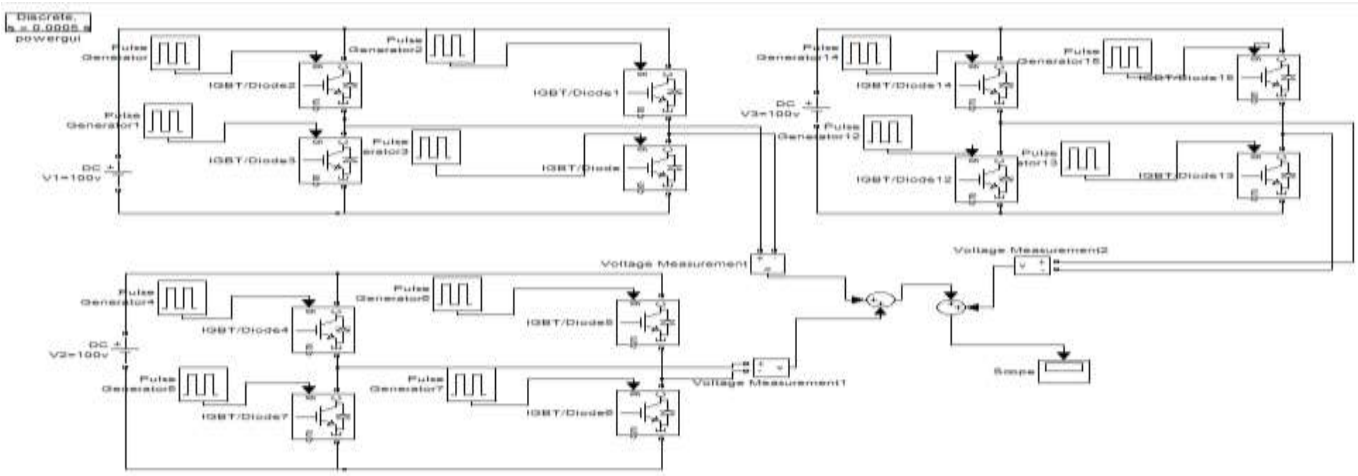

Fig 1: Single Phase Structure of a 7- level Cascaded Multilevel inverter.

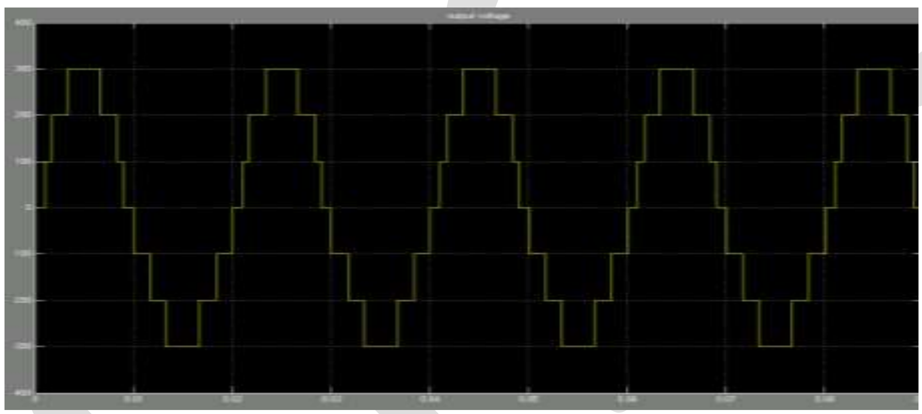

Fig. 2: output phase voltage of 7-level cascaded multilevel inverter.

3. MODULATION METHODS

In this section, two commonly used modulation method for the CHB multilevel inverter will be presented

Selective Harmonic Elimination

The basic idea of the selective harmonic elimination is to pre-determine the switching angle for each module to get the expected waveform of the output [8]. To explain its implementation in the cascaded H-bridge multilevel inverter, one example of five modules, eleven levels CHB multilevel inverter is shown in Figure.3.

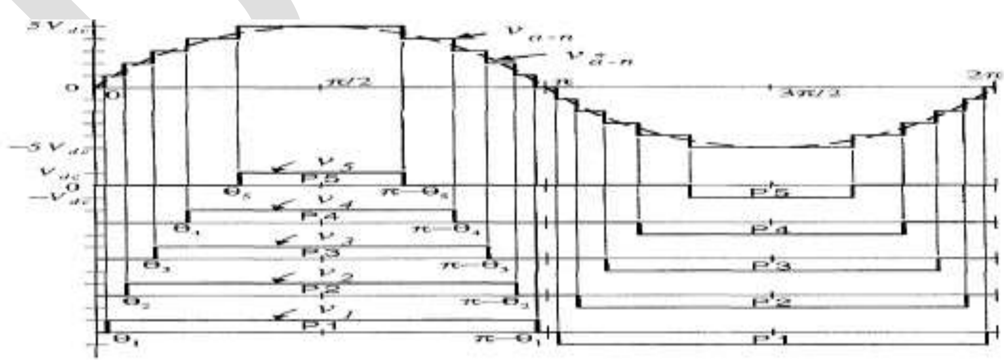

Fig.3: Output waveform of an 11-level cascade inverter.

By using Fourier Transform, the output voltage V (ωt) can be expressed as

$$V(wt) = \frac{4Vdc}{n\pi} \sum_{n=1,3,5}^{\infty} [(\cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3) + \cdots \cos(n\theta_{ks})] \frac{\sin(nwt)}{n} \quad (1)$$

where *n* is the harmonic order. Since the waveform is both half wave symmetry and odd symmetry, *n* = 1, 3, 5, 7, . . .
Usually, the normalized Fourier coefficients of the magnitude are used for further analysis. The normalized magnitude can be obtained by dividing V_{dc} on both sides of equation. Hence, the normalized Fourier coefficients for each harmonic order components are

$$H(n) = \frac{4}{n\pi} [(\cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3) + \cdots + \cos(n\theta_5)] \quad (2)$$

Cascaded H- Bridge Multi Level Inverter

Then by choosing the conducting angle $\theta_1 - \theta_5$ appropriately, it is possible to eliminate some target harmonic components [8]. Another point need to be mentioned is that the number of harmonic components which can be eliminated by this modulation method is one less than the number of the conducting angles since one degree of freedom should be given to the fundamental components of the waveform. In this case, the number of harmonics that can be eliminated is 4. Since the triple harmonic would not exist in the line to line voltage, the 5th, 7th, 11th and 13th order harmonics are chosen as the target harmonics that need to be eliminated in this case. The following equation can be obtained:

$$\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) + \cos(5\theta_4) + \cos(5\theta_5)] = 0 \quad (3)$$

$$\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3) + \cos(7\theta_4) + \cos(7\theta_5)] = 0 \quad (4)$$

$$\cos(11\theta_1) + \cos(11\theta_2) + \cos(11\theta_3) + \cos(11\theta_4) + \cos(11\theta_5)] = 0 \quad (5)$$

$$\cos(13\theta_1) + \cos(13\theta_2) + \cos(13\theta_3) + \cos(13\theta_4) + \cos(13\theta_5)] = 0 \quad (6)$$

$$\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) + \cos(\theta_4) + \cos(\theta_5)] = 5m_i \quad (7)$$

Where *mi* is reference modulation index which is defined as $m_i = \frac{v_1}{sv_{dc}}$ and v_1 is the fundamental of the required voltage.

One advantage of this modulation method is that the inverter is switching at the fundamental frequency which decreases the switching losses. However, the pre-calculation of the conducting angle requires the solution of non-linear equation. When the level of inverter increases, the number of the non-linear equations would also be very high. Then the solution for these equations would be inaccurate which may increase the distortion in the output voltage waveform [9].

Phase Shifted Pulse Width Modulation

Phase shifted PWM is one of the most commonly used modulation method in CHB multilevel inverter since it is very suitable for the modularity of the topology. For each module, the reference signal is the same. However, the carrier waveform (usually triangular waveform) for each module would have a phase shift to ensure the step characteristic of the output voltage. How many degrees are the phase shifts between each module depends on the modulation method for the individual H-bridge inverter. If the unipolar modulation method is selected, the phase shift between each module should be $180^0/k$ to achieve the lowest output voltage distortion; if the bipolar modulation method is chosen, the phase shift between each module should be $360^0/k$ [10], where *k* is the number of modules. Three modules, seven levels CHB multilevel inverter with unipolar modulation method is shown in Figure 4.

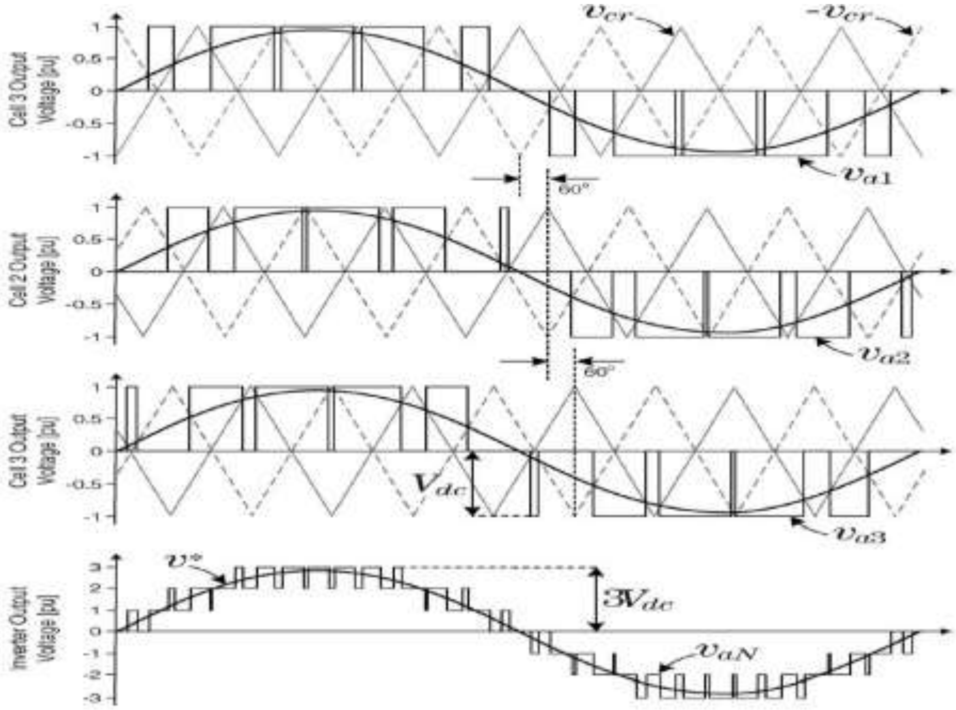

Fig.4: Three cell PS-PWM waveform generation

4. OPTIMIZATION TECHNIQUES

In MLIs, output voltage is represented using fourier series as:

$$V(wt) = \frac{4Vdc}{n\pi} \sum_{n=1,3,5}^{\infty} [(\cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3) + \cdots \cos(n\theta_{ks})] \frac{\sin(nwt)}{n} \quad (8)$$

Where V $_{dc}$= dc voltage and $0 \le \theta_1 \le \theta_2 \le \cdots \le \theta_{ks} \le \frac{\pi}{2}$

The harmonic factor (percentage) of the nth harmonic is calculated as:

$$HF_n = \frac{V_n}{V_1} \times 100; n > 1 \quad (9)$$

Here V_n represents the nth harmonic voltage and V_1 is fundamental output voltage equation (8) can be divided into three parts as:

$$V_{an}(wt) = V_{l1}(t) + V_{l2}(t) + V_{l3}(t)$$
(10)

Where $V_{l1}(t)$ is the fundamental frequency voltage, represented as

$$V_{l1}(t) = \frac{4Vdc}{\pi} (\cos\theta_1 + \cos\alpha_2 + \cos\alpha_3) \sin wt \text{ [For 7 level cascaded MLI]}$$
(11)

$V_{l2}(t)$ is the triplen harmonic voltages as

$$V_{l1}(t) = \sum_{n=3,9,15}^{\infty} \frac{4Vdc}{n\pi} [(\cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3) + \cdots \cos(n\theta_{ks})] \sin(nwt)$$
(12)

$V_{l3}(t)$ is the triplen harmonic voltages as

$$V_{l1}(t) = \sum_{n=3,9,15}^{\infty} \frac{4Vdc}{n\pi} [(\cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3) + \cdots \cos(n\theta_{ks})] \sin(nwt) \quad (13)$$

In three phase applications, triplen harmonic voltages in each phase cancel out automatically, hence no need to cancel these voltages. Another important parameter is modulation index (m_i), which represents the relationship between the fundamental voltage (V1) and

the maximum obtainable voltage (V_{1max}). It is defined as the ratio of the fundamental output voltage to the maximum obtainable fundamental voltage. Switching angles, $\theta_1, \theta_2, \theta_3$ and (in case of 7 level cascaded MLI) can be found using optimization techniques.
Equation (8) is known as non linear transcendental equations. For solving these transcendental equations, different optimization techniques have been suggested in the literature. In [16], a method was suggested so as to produce the required output voltage and simultaneously to suppress the higher order harmonics. The transcendental equations involving the harmonic content are converted into polynomial equations. These equations are further solved by the method of resultants. But in this technique, the degree of polynomials become quite large when there are numerous dc sources, which further results in high computational burden of resultant polynomials. Also, due to the computational complexity associated with these techniques, theory of resultant and symmetrical polynomials has been applied up to 11 level multilevel converters only. Limitation of resultant theory appears when applied to MLIs with unequal dc sources, where transcendental equations are no longer symmetrical and requires the solution of a set of higher degree equations.

In [17, 18] switching angles are calculated using Newton Raphson (N-R) numerical technique, where certain number of harmonic components have eliminated. But N-R methods have some drawbacks like divergence problems, need to define initial value and also provide no optimum solution.

Genetic algorithm (GA) technique is used in [19] for eliminating some higher order harmonics while maintaining the required fundamental voltage. GA is a computational approach by which optimization problems can be solved using genetic methods and the theory of evolution. But for implementation of this method, proper selection of certain parameters such as initial population size, crossover operation, mutation operation etc. are required; thereby implementation of this algorithm becomes tedious for higher MLIS.
In [20, 21], a new approach has discussed for real time calculation of firing angles using artificial neural networks (ANN). The approach is accomplished by first transforming the nonlinear transcendental harmonic elimination equations for all possible switching schemes into a one input (modulation index) and multi output (switching angles) three layers ANN. Then, the complete set of solutions of the equations is found using the back propagation of the errors between the desired harmonic elimination and the non linear equation systems output using the switching angle given by the ANN. Simulations in the [21] indicates that the switching angles issued by look up table and through trained neural network are almost equal. Therefore, a conclusion has drawn that a look up table can be replaced by a trained neural network, hence reducing the computational effort and storing capacity. Further a trained neural network produces switching angles by interpolation/extrapolation even for those values of modulation index, where switching angles are not calculated.
In [22], generalized pattern search (GPS), simulated annealing (SA) and genetic algorithm (GA) are used for calculating the firing angles to eliminate harmonics in 13 level inverter. The proposed algorithms can be applied to higher MLIs. The simulation results showed that GPS and SA methods are more efficient than GA.

Real time calculation of switching angles for minimum THD has done using step modulation [23]. However, the limitation of stepped modulation technique lies in its narrow modulation index. Bee optimization technique is used in [24] for harmonic elimination in cascaded MLI. In this paper, 7 level cascaded MLI is used. The algorithm is based on food foraging behaviour of a swarm of a honeybees. Simulation results showed that bee algorithm (BA) has higher precision and probability of convergence than GA.
Harmony search algorithm (HSA) and particle swarm optimization (PSO) are other optimization techniques for finding out the firing angles of cascaded MLIs [25]. HSA searches those certain values which optimize the fitness function and also simultaneously satisfy the problem's constraints. HSA imposes fewer mathematical requirements and does not require initial value settings for decision variable. For optimization of non linear transcendental equations, PSO methodology is a very powerful approach. In [26], a novel PSO technique to determine the optimum firing angles of MLIs is presented. This optimization technique is applied to non linear transcendental equations characterizing the harmonic content to minimize the low order harmonics. Fig. Shows the flowchart of PSO technique. Simulation results showed that PSO can simply find the optimum switching angles and has faster convergence with better quality solutions than GA approach. PSO completely outperforms both GA and HSA. [27] Presents PSO based optimal switching technique for harmonic elimination in cascaded MLIs.
A species based PSO (SPSO) method, which includes the suitable adjustment of niche radius for calculation of the optimum firing angles of MLIs, has been proposed in [28]. Simulation and hardware results are mentioned for cascaded hybrid 11 level inverter. Results indicate that all the lower as well as higher order harmonics are effectively minimized in the output sinusoidal voltage waveform of MLI. Also the switching frequency of multilevel inverter and the THD have decreased dramatically.

5. PARTICLE SWARM OPTIMIZATION:

Particle Swarm Optimization (PSO) was invented by Kennedy and Eberhart1 in the mid 1990s while attempting to simulate the choreographed, graceful motion of swarms of birds as part of a socio cognitive study investigating the notion of "collective intelligence" in biological populations. In PSO, a set of randomly generated solutions (initial swarm) propagates in the design space towards the optimal solution over a number of iterations (moves) based on large amount of information about the design space that is assimilated and shared by all members of the swarm. PSO is inspired by the ability of flocks of birds, schools of fish, and herds of animals to adapt to their environment, find rich sources of food, and avoid predators by implementing an "information sharing" approaches, hence, developing an evolutionary advantage. A complete chronicle of the development of the PSO algorithm forms merely a motion simulator to a heuristic optimization approach.

Inspired initially by flocking birds, Particle Swarm Optimization (PSO) is another form of Evolutionary Computation and is stochastic in nature much like Genetic Algorithms. Instead of a constantly dying and mutating **GA** population we have a set number of particles that fly through the hyperspace of. the problem. A minimization (or maximization) of the problem topology is found both by a panicle remembering its own past best position and the entire group‘s (or flock's, or swarm's) best overall position. This algorithm has been shown to have CA like advantages without the big computational hit.The PSO algorithm is based on the concept that complex behaviour follows from a few simple rules.

Each particle is determined by two vectors in Dimensional search space: the position vector $X_i = [X_{i1}, X_{i2......}. X_{iD}]$ and the velocity vector $V_i = [V_{i1}, V_{i2}. . . Vi_D]$. Each particle in the swarm refines its search through its present velocity, previous experience, and the experience of the neighbouring particles. The best position of particle i found so far is called personal best and is denoted by $P_i = [P_{i1}, P_{i2}, . . . , P_{iD}]$, and the best position in the entire swarm is called global best and is denoted by $P_g = [P_{g1}, P_{g2}, . . . , P_{gD}]$. At first, the velocity of the i^{th} particle on the d^{th} dimension is updated by using (6), and then, (7) is used to modify the position of that particle

$$V_{id}(t+1)=\chi[V_{id}(t)+\varphi_1 r_1(P_{id}-X_{id}(t))+\varphi_2 r_2(P_{gd}-X_{id}(t))] \quad (6)$$

$$Xid(t+1)=Xid(t)+Vid(t+1) \quad (7)$$

where φ_1 and φ_2 are the cogitative and social parameters, respectively. In these equations, r_1 and r_2 are random values uniformly distributed within [0, 1]. $V_i^{(t)}$ which is the velocity of i^{th} particle at iteration‘t' must lie in the range $V_d^{min} < v_{id}^{(t)} < V_d^{max}$. The parameter V_d^{max} determines the resolution, or fitness, with which regions are to be searched between the present position and the target position. If V_d^{max} is too high, particles may fly past good solutions. If V_d^{max} is too small, particles may not explore sufficiently beyond local solutions. The constants $C_1$and C_2 pull each particle towards *pbest* and *gbest* positions. Low values allow particles to roam far from the target regions before being tugged back. On the other hand, high values result in abrupt movement towards, or past, target regions. Hence, the acceleration constants C_1 and C_2 are often set to be 2.0 according to past experiences. Suitable selection of inertia weight *'ω'* provides a balance between global and local explorations, thus requiring less iteration on average to find a sufficiently optimal solution. As originally developed, ω often decreases linearly from about 0.9 to 0.4 during a run. In general, the inertia weight ω is set according to the following equation.

$$\omega=\omega_{max}-[(\omega_{max}-\omega_{min})\div iter_{max}]\times iter \quad (8)$$

where - ω inertia weight factor, ω_{max} maximum value of weighting factor, ω_{min} minimum value of weighting factor, $iter_{max}$ maximum number of iterations,iter current number of iteration.Each individual moves from the current position to the next one by the modified velocity using the following equation (9)

$$P_{gid}^{(t+1)} = P_{gid}^{(t)} + V_{id}^{(t+1)} \quad (9)$$

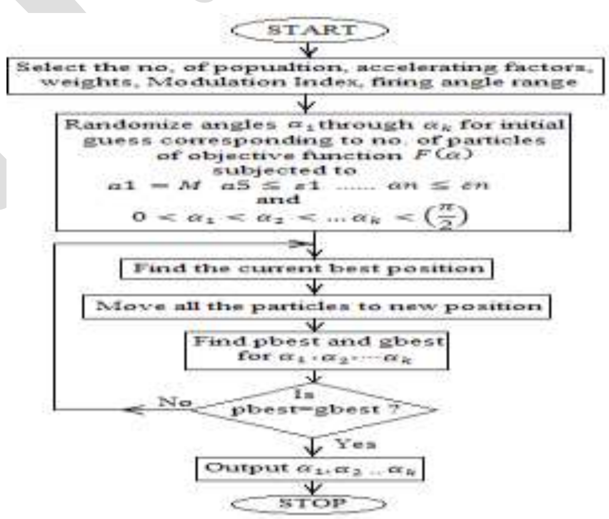

Fig.5 Flowchart of Particle Swarm optimization Algorithm

6. REVIEW ON APPLICATION OF PSO IN MULTILEVEL INVERTER:

In 2008 A.K. Al-Othman and Tamer H. Abdelhamid presents an extremely fast optimal solution of harmonic elimination of multilevel inverters with non-equal dc sources using a novel Particle Swarm Optimization (PSO) algorithm. In this paper PSO employed to compute the optimal solution set of switching angles of Multilevel Inverter. A comparison between the PSO technique and the conventional Newton-Raphson method in terms of computational times and resulted %THD is calculated; where it reveals that the PSO algorithm can be effectively used for selective harmonic elimination of multilevel inverters and results in a dramatic decrease in both the computational times and the output voltage %THD.

In 2008 Chris M. Hutson, et al. investigated the application of an MDPSO algorithm for selection of a modulation sequence for a three level Five-phase motor drive. A modified discrete particle swarm (MDPSO) algorithm is used in an attempt to find the optimal space vector modulation switching sequence that results in the lowest voltage THD. Comparison of the MDPSO algorithm to an integer particle swarm optimization (IPSO) is presented for all three modulation indices (M=0.9, M=0.75, M=0.6) tested. The MDPSO algorithm performed better overall than the IPSO in terms of converging to the best solution with significantly lower iterations.

In 2008 H. Taghizadeh and M. Tarafdar Hagh presents the novel particle swarm optimization technique to determine the optimum switching angles of multilevel converters to produce the required fundamental voltage while at the same time not generate lower order harmonics. This optimization method is applied to transcendental equations characterizing the harmonic content to minimize low order harmonics. Comparing the results of PSO with mathematical Methods for seven and eleven level inverter. It finds that PSO can simply find the optimum switching angles and also with comparing with Genetic Algorithm and it is clear that PSO has faster convergence with better quality solutions than GA approach to solve this problem.

In 2008 R.N. Ray , et al. compute the switching angles for selected harmonic elimination (SHE) in a multilevel inverter using the particle swarm optimisation technique. The objective function derived from the SHE problem is minimised using the PSO algorithm to compute the switching angles while lower-order harmonics are eliminated. In this paper the combination of switching angles corresponding to minimum voltage THD at sufficiently close points of modulation indices with consideration of linearity between two successive points are stored in a DSP memory for online application.

In 2009 Kashefi Kaviani ,et al. applies an advanced variation of Particle Swarm Optimization method to 7 to 17-level inverters. Results are compared with Continuous Genetic Algorithm, as a well-known intelligent method, and one of the most successful numerical methods, namely Sequential Quadratic Programming. Results confirm that PSO completely outperforms both CGA and SQP for all cases.

In 2009 Mehrdad Tarafdar Hagh, , et al. developed an algorithm based on species-based PSO (SPSO) to deal with the problem where the number of switching angles is increased and their determination using conventional iterative methods in addition to GA and simple PSO techniques is not possible. So an MSPSO algorithm with adaptive adjustment of niche radius has been proposed to determine the optimum switching angles of multilevel inverters. Simulation and experimental results are provided for an 11-level cascaded H-bridge inverter to validate the accuracy of computational results. Results show that all undesired harmonics up to 50th order have been effectively minimized at the output voltage waveform of inverter. Comparison of results with active harmonic elimination technique shows that the THD and the switching frequency of output voltage decreased dramatically.

In 2010 Jin Wang, and Damoun Ahmadi, introduced concept of a four-simple-equation-based method. In this paper presents a different approach, which is based on equal area criteria and harmonic injection. With the proposed method, regardless of how many voltage levels are involved, only four simple equations are needed. The results of a case study with maximum of five switching angles show that the proposed method can be used to achieve excellent harmonic elimination performance for the modulation index range at least from 0.2 to 0.9. . To show the effectiveness of the proposed method in applications with large numbers of switching angles, experimental results on a 1-MVA 6000-V 17- level cascade multilevel inverter are taken by the author.

In 2010 H. Taghizadeh and M. Tarafdar Hagh, present the elimination of harmonics in a cascade multilevel inverter by considering the nonequality of separated dc sources by using particle swarm optimization. In addition, for a low number of switching angles, the proposed PSO approach reduces the computational burden to find the optimal solution compared with iterative methods and the resultant theory approach. The proposed method solves the asymmetry of the transcendental equation set, which has to be solved in cascade multilevel inverters. Simulation and experimental results are provided for an 11-level cascaded multilevel inverter to show the validity of the proposed method.

In 2010 M. Sarvi M. R. Salimian used two algorithms: 1-genetic algorithm and 2- PSO is used to optimize THD in Multilevel inverters. Theoretical and simulated results are used to compare these techniques. Also in this paper proposes a method for optimization of specific harmonics and improving the characteristics of switching in multilevel inverters. In this method, the switching angle of each levels and the output voltage of them is determined and is used for optimization. Then the effect of changing in the output voltage of each inverter on reduction of one or more specific harmonic is analyzed. In this paper result of GA and PSO is compared and shows that GA is better for optimizing THD in multilevel converters. The amplitude of specific harmonics can be decreased better by changing the amplitude of each level in comparison of assuming constant amplitude.

In this 2011 Rambir Singh, et al. presents a study of three optimization algorithms for different errors as variables of fitness function to find optimum gain values of a PI controller for shunt active power filters (SAPF). comparative study of PI controller tuning in a SAPF using three evolutionary algorithms (EAs), viz. bacteria foraging (BF), bacteria foraging with swarming (BFS) and particle swarm optimisation (PSO), for current harmonic mitigation. The minimization of integral time square error (ITSE) and integral time absolute error (ITAE) as performance indices is used as objective function for optimisation. The simulation results show that PSO tuned PI with ITSE as minimized parameter performs better.

In 2011 Harish S Krishnamoorthy developed A novel modified-PSO based shunt active power filter was designed and simulated at different load conditions using MATLAB. An empirical equation was developed for each control parameter with respect to input and the effectiveness of the entire system was tested at different load conditions. The system evinces very good performance, by reducing the THD below 5% after the initial 4 or 5 cycles and improving PF to values as high as 0.99 for most cases based on the empirical equations; which show that the control system is a robust one for varying load conditions. This method can be used in 3-phase APFs too, applying different control schemes such as d-q control, sliding mode control, etc. The main advantages of the proposed system are that the hardware need not be changed for varying loads and there is no requirement of advanced hardware for the control system. A simple DSP can be used for controlling the entire system. For all these reasons, the authors associate good commercial value for this system in terms of its effectiveness and simplicity.

In 2012 Rachid TALEB, et al. proposed method for the harmonic elimination strategy of a Uniform Step Asymmetrical Multilevel Inverter (USAMI) using Particle Swarm Optimization (PSO) which eliminates specified higher order harmonics while maintaining the required fundamental voltage. In this paper a seven-level USAMI is considered and the optimum switching angles are calculated to eliminate the fifth and seventh harmonics.

In 2012 T.JEEVABHARATHI, V.PADMATHILAGAM proposed the method for elimination of harmonics in a Cascaded Multilevel Inverter (CMLI) by considering the non-equality of separated dc sources by using Particle Swarm Optimization (PSO) is presented. The PSO has been proposed to solve the SHE problem with nonequal dc sources in H-bridge cascaded multilevel inverters. When the resultant approach reaches the limitation of contemporary algebra software tools, the proposed method is able to find the optimum switching angles in a simple manner. The simulation and experimental results are provided for an 11-level cascaded H-bridge inverter to validate the accuracy of the computational results.

In 2012 Ricardo Maldonado et al. presents the simulation and construction of a 9-level Flying Capacitor Multilevel Inverter (FCMI), with a control based on the Fundamental Frequency Switching Method (FFSM) and redundant switching states. A Particle Swarm Optimization (PSO) algorithm was developed to determine the MOSFETs firing angles to reduce the resulting Total Harmonic Distortion (THD). MATLAB/Simulink was used to simulate the FCMI and implement the PSO algorithm. A microcontroller was used to generate the sixteen different signals to control the firing angles for the hardware implementation. Simulation and experimental results confirmed the proper function of the FFSM control and capacitor balancing. To obtain a higher efficiency in the FCMI, the MOSFETs need to be replaced by Power MOSFETs with much lower Ron resistance and the capacitance need to be increased in each capacitor to achieve a FCMI with higher current rating.

7. CONCLUSION:

The different optimization techniques such as Newton Raphson method, resultant theory and symmetric polynomial, genetic algorithm, harmony search algorithm, particle swarm optimization etc. have been proposed to minimize the total harmonic distortion in cascaded multilevel inverters. Maintaining the desired level of fundamental output voltage, all the lower order harmonics are minimized or controlled within the permissible limits. Thereby, results in minimum total harmonic distortion and the corresponding firing angles are determined. The proposed methods are able to find the optimum firing angles in a simple manner. These techniques ensure the accuracy and quality of firing angles of cascaded multilevel inverters such that output voltage waveform results in minimum total harmonic distortion.

ACKNOWLEDGMENT

The author's would like to thanks to all referees for their useful remarks, which helped to improve the paper. Author's wishing to express cordial thanks to SVITS, Indore (M.P.), INDIA for their kind support.

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