Review on Selective Harmonic Palliation in Multilevel Inverter by Using Particle Swarm Optimization (PSO)

[1] Kajal Saraf, [2] Aishwarya Mhaisekar, [3] Shubham Bokilwar, [4] Anuj Borkute,
[5] Anup Pachghare
[1][2][3][4] Students, [5] Professor
Department of Electronics & Telecommunication Engineering, J.D.I.E.T.
Yavatmal- 445001
[1] kajusaraf@gmail.com, [2] mhaisekaraishwarya15@gmail.com,
[3] shubhambokilwar@gmail.com, [4] anujb996@gmail.com [5] anuppachghare8@gmail.com

Abstract- **Recent advances in power electronics have made the multilevel concept practical. It is evident that the multilevel concept will be prominent choice for power electronic in upcoming years especially for medium voltage operation. Using multilevel inverter applications in solar cells, fuel cell and wind turbines is increasing now a day's rapidly. Therefore, harmonic palliation techniques in multilevel inverter are considered very important task, which is solved by applying Particle Swarm Optimization technique.**
This paper presents a review of Particle Swarm Optimization technique used for multilevel inverter. The objective of this optimization technique is used to find an optimum solution of multilevel inverter, which results in minimum harmonics. In comparison with other methods, the technique has many advantages such as; it can produce all possible solutions for any number of multilevel inverter without much computational burden.

***Keywords*: Multilevel inverter, selective harmonic palliation (SHP), optimization technique, Particle Swarm Optimization (PSO).**

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. Today, it is hard to connect a single power semiconductor switch directly to medium voltage grids (2.3, 3.3, 4.16, or 6.9kV). For these reasons, a new family of multilevel inverters has emerged as the solution for working with higher voltage levels. The multilevel inverters have received attention in the area of high power rating and medium voltage applications. The well-known topologies are diode-clamped inverter (Neutral-point clamped), Capacitor-Clamped (Flying Capacitor), and cascaded multi cell. The Diode-clamped inverter provides multiple voltage levels through connection of the phases to a series bank of diodes [12]. But if we increase the diodes then the phase voltage also increases and it makes the system impractical to implement. Among these topologies the cascade H-Bridge inverter is best. Several patents have been obtained for this topology. Since this topology consist of series power conversion cells, the voltage and power level may be easily scaled. The main advantage of this Technique is that it provides separate D.C. source and it is having very less switching components [13].

The key issue in designing an effective multilevel inverter is to ensure that the total harmonic distortion (THD) of the output voltage waveform is within acceptable limits. The pulse width modulation and space vector pulse width modulation can be use to overcome this problem but unfortunately both the methods do not eliminate lower order harmonics. But the commonly available switching technique is selective harmonic palliation (SHP) method at fundamental frequency, for which transcendental equations characterizing harmonics are solved to compute switching angles. It is difficult to solve the SHP equations as these are highly nonlinear in nature [13]. A big task is how to get all possible solution sets where they exist using simple and less computationally complex method, iterative numerical techniques have been implemented to solve the SHP equations producing only one solution set, and even for this a proper initial guess and starting value of modulation index for which solutions exist are required. Theory of resultants of polynomials and the theory of symmetric polynomials has been suggested to solve the polynomial equations obtained from the transcendental equations. A difficulty with these approaches is that for several H-bridges connected in series, the order of the polynomials become very high thereby making the computations of the solutions of these polynomials very complex.

This paper presents a review of optimization techniques used for multilevel inverters. In this paper the different optimization techniques such as Genetic Algorithm (GA),Newton-Raphson Method etc. can be used to palliate the harmonics in multilevel inverter but among all these techniques PSO gives better resultant solution to optimize the harmonic. The objective of this 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.

II. CASCADE H-BRIDGE MULTILEVEL INVERTER

The traditional two or three level inverter does not completely palliate the unwanted harmonics in the output waveform. Three among the different topologies for multilevel converters the cascaded H-Bridge multilevel inverter has received special attention due to its modularity & simplicity. A single phase structure of a multilevel inverter cascaded inverter is illustrated in fig.1. The Cascaded H-Bridge Multilevel Inverter is to use capacitor, switches and the combination of these capacitors and switches pair is called H-Bridge. It requires a few components, the absence of diode clamped and flying capacitor in each cell and provides separate input DC voltage. Since each H-bridge has the same structure, modularized circuit layout and packaging are possible.[13] For each H-Bridge it consists of a series H-Bridge and it can generate three different output voltages, i.e. +Vdc, 0 and -Vdc by connecting the DC source to the AC output by different combinations of the four switches S1, S2, S3 and S4. The AC output of each of the different H-Bridge inverter level are connected in series such that the voltage waveform is the sum of all H-Bridge cell voltages is symmetric with respect to neutral point. So the number of voltage levels is odd. The number of levels in the output phase voltage is 2N+1, where N is the number of D.C. sources. Consider an example phase voltage waveform for all level cascaded multilevel inverter with five isolated D.C. source

(N=5) is shown in fig.2

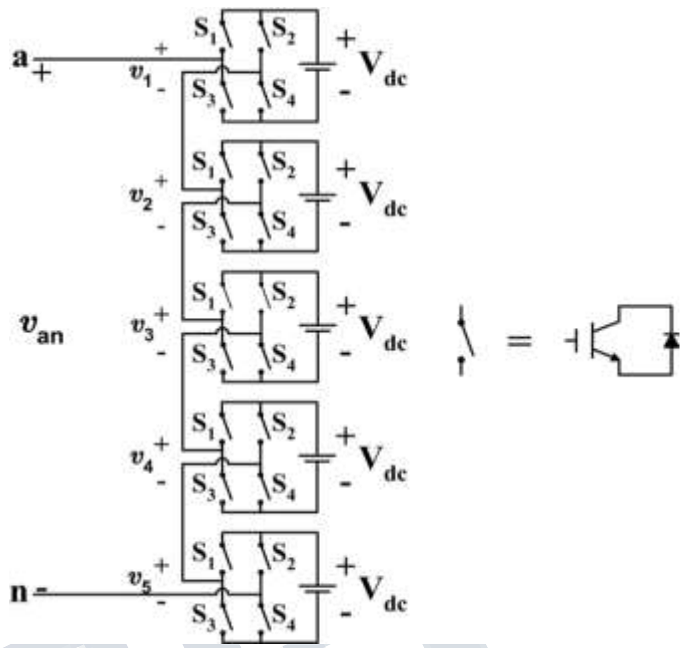

Fig.1 Cascaded H-bridges 11 level Inverter [4]

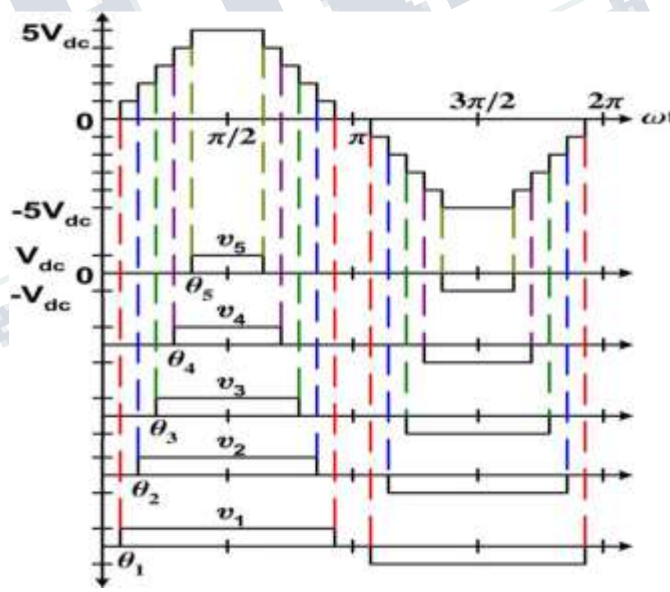

Fig.2 Staircase output voltage waveform of cascaded H-bridges multilevel inverter.[4]

III. SELECTIVE HARMONIC PALLIATION (SHP) TECHNIQUE

The SHP technique has to be useful in palliating some of the undesired harmonics without increasing the switching frequency. To explain its implementation in the CHBMI, consider one example of five module, eleven levels CHBMI is shown in fig. 2

In general, the Fourier series expansion of the staircase output voltage waveform from fig 2 is
Given by: [9]

$$Van(\omega t)=\sum_{k=1,2,3}^{\infty} \frac{4Vdc}{k\Pi}[\cos(k\theta_1)+\cos(k\theta_2)+\ldots \mathrm{Cos}(k\theta s)] \sin(k\omega t) \ldots\ldots(1)$$

In equation (1), *s* is the number of H-bridges connected in series/cascade per phase, *k* is order of harmonic components, *Vdc1*, *Vdc2* … *Vdcs* are dc voltage sources for H bridges. It can be seen from above eq. a fundamental peak voltage *V1*, it is required to determine the *s* switching angles such that the selection of one angle is used to determine *V*1 and remaining (*s*-1) angles are used to palliate the same number of harmonics (generally lower order harmonics), and also all switching angles limited between $0 < \theta_i\ \pi/2$.[5]

Thus, the components of the output voltage can be divided into three parts, namely i) fundamental component (*k*=1), ii) triplen odd harmonic components (*k* =3, 9, 15 …) and iii) non triplen odd harmonic components (*k* = 5, 7, 11, 13, 17 …).

In three-phase power system, triple harmonics are canceled out automatically in line-to-line voltages asa result only non-triplen odd harmonics are present in line-to-line voltages [3].

For example, In case of 11 level cascaded multilevel inverter, 5 switching angles (i.e. $\theta_1,\theta_2 \ldots\theta_5$) need to be calculated for the 5 H-bridges i.e. 5 degrees of freedom available. one degree of freedom is used to control the magnitude of the fundamental output voltage and the remaining four degrees of freedom are generally used to palliate 5th, 7th, 11th, and 13th order harmonic components as they dominate the total harmonic distortion [3].

The expression for the fundamental voltage in terms of switching angles is given by,

$$V1 = \frac{4Vdc}{k\Pi}[(\cos\theta_1)+\cos(\theta_2)+\cos(\theta_3)+\cos(\theta_4)+\cos(\theta_5)] \ldots(2)$$

The switching angles are used to set the amplitude of the fundamental harmonic and cancel a set of specific harmonics.

The maximum fundamental voltage is obtained when all the switching angles are zero and the V1max is given as

$$V1max=5\times(\frac{4Vdc}{k\Pi})\ldots\ldots\ (3)$$

The modulation index, *m* is defined as the ratio of the fundamental output voltage to the maximum obtainable.

voltage $(M=\frac{V1}{5\times\frac{4Vdc}{\Pi}} \ldots\ldots\ldots.(4)$

The above stated conditions can be written in following way by combining (1) and (4)

$\mathrm{Cos}(\theta_1) + \mathrm{Cos}(\theta_2) + \mathrm{Cos}(\theta_3) + \mathrm{Cos}(\theta_4) + \mathrm{Cos}(\theta_5) = 5M$…….. (5)

$\mathrm{Cos}(5\theta_1) + \mathrm{Cos}(5\theta_2) + \mathrm{Cos}(5\theta_3)+ \mathrm{Cos}(5\theta_4) + \mathrm{Cos}(5\theta_5) = 0$…… (6)

$\mathrm{Cos}(7\theta_1) + \mathrm{Cos}(7\theta_2) + \mathrm{Cos}(7\theta_3)+ \mathrm{Cos}(7\theta_4) + \mathrm{Cos}(7\theta_5) = 0$…… (7)

In this θ_1, θ_2, θ_3, $\theta_4$and $\theta_5$equations are unknown vales and these angles can be calculated [2].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 [6].

IV. OPTIMIZATION TECHNIQUE

In this paper Switching angle in case of 11 level CHBMI can be found by using optimization technique. And the different optimization technique has been suggested for solving the transcendental equation. But the transcendental equations involving the harmonic content and they are converted into polynomial equations. These equations can be solved by resultant method. But in this technique have one drawback, when there are number of dc sources that time the degree of polynomials become quite large, which foster results in high computational burden of resultant polynomials. Also, due to this problem the theory of resultant and symmetrical polynomials has been applied up to 11 level multilevel converters only. So whenever we applied to multilevel inverter with unequal dc sources then limitation of resultant theory appears, where transcendental equations are no longer symmetrical and requires the solution of a set of higher degree equations[7].

The switching angles are also calculated using Newton Rap son (N-R) numerical technique, where certain number of harmonic components have palliated. But N-R methods have some drawbacks like divergence problems, need to define initial value and also provide no optimum solution[7,8]. The another optimization technique i.e. genetic algorithm used for palliating some higher order harmonics in MI and also can be solve optimization problem and therefore it becomes more tedious for higher MI. Many optimization technique such as generalized pattern search

(GPS), simulated annealing (SA), genetic algorithm (GA), and bee algorithm (BA) are used for harmonic palliation in cascaded MI [7].

In this paper particle swarm optimization technique is used for palliating harmonics in MI.PSO is a very powerful approach for optimization of nonlinear transcendental equations. This optimization technique is applied to nonlinear transcendental equations characterizing the harmonic content to palliate the low order harmonics.

V. PARTICLE SWARM OPTIMIZATION

PSO is a heuristic global optimization method that optimizes a problem by iteratively trying to improve candidate solution with regard to a given measure of quality. It was first introduced by Dr. Kennedy and Dr. Eberhart in 1995. Basically, the PSO was inspired by the sociological behavior associated with swarms such as flocks of birds and schools of fish[11]. PSO uses a number of particles that constitute a swarm moving round in the search space looking for the best solution. This implies that each particle has memory, which allows it to remember the best position on the feasible search space that has ever visited. Each particle is determined by two vectors in D-dimensional search space: the position vector $Xi = [xi_1, xi_2. . . xi_D]$ and the velocity vector $Vi = [vi_1, vi_2, . . . , vi_D]$ [12]. Each particle in the swarm refines its search through its present velocity, previous experience, and the experience of the neighboring particles. The best position of particle i found so far is called personal best and is denoted by $Pi = [pi_1, pi_2, . . . , pi_D]$, and the best position in the entire swarm is called global best and is denoted by $Pg = [pg_1, pg_2, . . . , pg_D]$ [12].

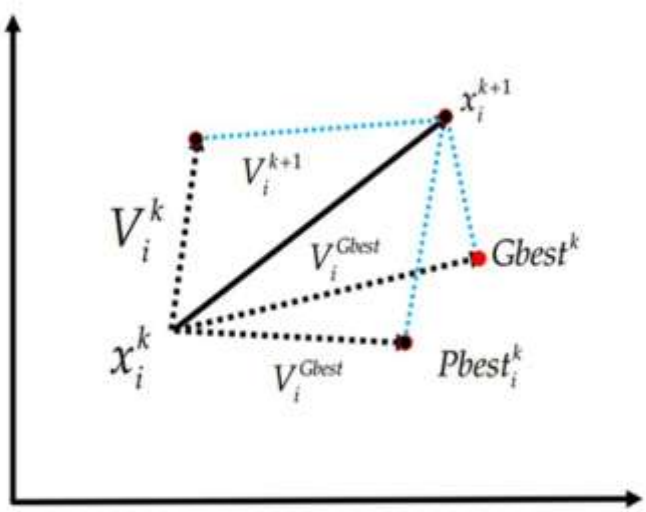

Fig.3: Concept of modification of a searching point by PSO

Each particle tries to update its position by using information of current positions, current velocities, distance between current position and pbest and distance between the current position and gbest. The mathematical model which represented in equation (8) indicates how particle updates itself in each iteration.

$$V_i^{k+1} = w\, v_i^k + c_1 r_1^k [P^k_{best,i} - x_i^k] + c_1 r_1^k [G_{best} - x_i^k] \quad \ldots\ldots\ldots(8)$$

$$x_i^{k+1} = x_i^k + V_i^{k+1} \quad \ldots\ldots\ldots(9)$$

w : the inertia weight parameter, which controls the global and local exploration capabilities of the particle.
v_i^{k+1} : velocity of ith particle at kth iteration,
c1, c2 : The cogitative and social parameters
$r_1$and r_2 : random numbers between 0 and 1
x_i^k : Current position of ith particle at kth iteration
$P^k_{best,i}$: pbest of ith particle
G^k_{best} : gbest of the group

A large inertia weight factor is used during initial exploration and its value is gradually reduced as the search proceeds. The concept of time-varying inertial weight (TVIM) is given by,[5]

$$W = Wmax - \frac{(Wmax - Wmin)}{itermax}\, iter$$

Where, $iter_{max}$is the maximum number of iterations.

A. The PSO Algorithm

The palliation of THD in multilevel inverters is achieved by using this PSO algorithm because of its simple in nature and easy to implement, computational efficient. The procedure for getting optimized results the objective function is taken as the THD equation is as follows,

$$\%\,THD = \frac{(\sqrt{V22 + V32 + \ldots\ldots\ldots\ldots..Vn2})}{V1 \times 100}$$

For every iteration the value of the THD is updated for their suitable best values by changing the velocity and position of the current particles. Similarly the values of switching angles also updated for optimum values to get lower value of THD[5].

B. Steps to solving the SHP Problem [13]

1. Enter the data for the system: Input the value of required parameters for the algorithm such as population size M, maximum iteration number itermax, acceleration constant,

start& end values of inertia weight etc., and set the iteration counter k = 1.

2. Create the initial position and velocity matrix of particle: Each particle position is randomly initialized between 0 and π / 2 and particle velocity vector within -Vmax and Vmax.

3. Compute the objective function: Every particle in the population is assessed using objective function and so is obtained using equation (8) by applying required SHP set. The switching angles [θ_1, θ_2, θ_3, θ_4 ,θ_5] thus can be calculated up to the 3s – 2th order while s is odd and up to the 3s-1th order when s is even by minimizing the cost function in order to achieve the harmonic profile.

4. Revise the personal and global best position: The fitness values obtained above is set initially as Pbest value of the particle and are compared amongst the other for the best replacement as per swarm size. In addition, if the Pbest of the particles is better than the global best, then global best Pg are replaced with Pbest.

5. Determine the inertia weights using the data available from the previous studies as presented in the paper.

6. All particles in the population are revised by the velocity and position matrix rules (4) and (6), respectively. Also the matrix so obtained is verified for its correctness within given constraints established in step (2).

7. Termination criterion: If the iteration counter k reaches intermix, stop; else, increase the iteration counter k = k + 1 and go back to step (3).

8. Plot the result to obtain the output voltage waveform along with performance characteristics Graph.

VI. CONCLUSION

The PSO technique has been applied to solve SHP problem in CHBMI. This method is able to find the optimum switching angles in simple way. It also palliates any desired number of harmonics, computational burden, running time and ensure to improve the quality of power system.

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