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Optimization of Harmonics for Cascaded Multilevel Inverter with Variable DC Source Voltages Using Mutative Methods

Ananya Pal[1], P.K.Saha[2], G.K.Panda[3]

PG Scholar [Power Electronics and Drives], Dept. of EE, Jalpaiguri Govt. Engineering College, Jalpaiguri, West Bengal, India[1]

Professor, Dept. of EE, Jalpaiguri Govt. Engineering College, Jalpaiguri, West Bengal, India[2]

Professor, Dept. of EE, Jalpaiguri Govt. Engineering College, Jalpaiguri, West Bengal, India[3]

ABSTRACT: A new approach of Harmonic Optimization of a single phase 5-level Cascaded Inverter using Selective Harmonic Elimination (SHE) is proposed in this paper. Here the DC Source voltages are considered as time varying and hence a term DC link voltage ratio is taken into account in this regard. The switching angles and DC link voltage ratio are computed using Genetic Algorithm and Particle Swarm Optimization through solving the non-linear transcendental equations describing the SHE problem that would result in minimized Total Harmonic Distortion (THD) of the output voltage waveform. Two distinct approaches: firstly, elimination of lower order Harmonic (3rd) with maintaining a desired fundamental output voltage and secondly, reducing a number of lower order harmonics (3rd, 5th, 7th, 9th, & 11th) with maintaining the fundamental output voltage are considered in this paper to minimize the Total Harmonic Distortion (THD) with giving consideration to the switching angles and the DC link voltage ratio as the optimization variables. The %THD (considering all harmonics up to 49th) of the output voltage waveform is calculated using the switching angles and DC link voltage ratio for different modulation indices. The whole procedure is repeated for equal DC source voltages and the corresponding results are compared. The switching angles, DC link Voltage ratios, and %THD obtained from the offline computation are stored in a direct look up table which can be easily applied to the online control for real time application. Simulation is being done to demonstrate the analytical results.

KEYWORDS: Total Harmonic Distortion, Particle Swarm Optimization, Cascaded Multilevel Inverter, DC link voltage ratio, Selective Harmonic Elimination, Genetic Algorithm.

I.INTRODUCTION

The multilevel inverters have drawn tremendous interest in high-power and high-voltage application in the power industry for its unique structure and features. Hence, the maintenance of the quality of power generated by them has become the foremost concern of many of the researchers. The principle of operation of multilevel inverter is to synthesize desired staircase output voltage waveform from the separate input dc sources. A multilevel inverter can generate (2n+1) level output voltage; where n is the number of single phase full-bridge inverter. For the practical cases, fuel cells, or solar cells are used as the input dc sources, hence it is necessary to consider the variation of the dc sources [1], [2]. There are generally three topologies of a multilevel inverter are available; they are; diode-clamped, flying-capacitor, and cascaded multilevel inverter. Now, the cascaded multilevel inverter is most suitable in real power conversion than the other topologies, as it uses least number of circuit elements to achieve the same voltage levels, hence the circuit complexity is also less [3]. A number of technical papers have presented different control methods for cascaded multilevel inverters. The mostly preferred methods are fundamental frequency switching method, space vector control method, traditional PWM control method and space vector PWM method [4]. Selective Harmonic Elimination and Space Vector control method has the benefit of low switching frequency although they can not efficiently eliminate lower order harmonics for low modulation indices as compared to other techniques. Whereas, the PWM method needs high switching frequency and it can eliminate lower order harmonics efficiently but the main disadvantage is it can not eliminate the higher order harmonics. To overcome this it requires additional switching [5]-[7]. An optimal pulse width modulation is utilized for selective harmonic elimination with reduced switching frequency, which can be applicable for less number of input voltages and low modulation indices [8]. To overcome the higher-order harmonics, an active harmonic elimination technique [9] has been introduced preferring fundamental frequency switching where resultant theory is applied for computing the switching angles [10]. Moreover, some specific higher order non-triplen harmonics are eliminated by cancelling them with theire negative counterpart generated by additional switching angles A mapped phase shifted space vector modulation for multilevel voltage source inverter is used in [11], [12]. A Genetic algorithm trained neural network based SHE technique for 7-level and 11-level cascaded inverters with variable dc voltage sources are presented in [13], [14]. An 11-level cascaded inverter with equal [15], [16] and non-equal [17] dc sources with PSO and a species-based PSO (SPSO) method is presented to minimize the THD of the output voltage waveform. A single phase cascaded inverter with different level presented a comparative study of %THD obtained from different levels [18]. It also introduced a Weighted Total Harmonic Distortion (WTHD) and compared it with THD for different cases.

The present study is mainly focused on the optimization of Total Harmonic Distortion (THD) of the output voltage of a single phase cascaded multilevel inverter with maintaining the desired fundamental output voltage. Hence different problems are formulated to find out the best approach of minimizing the THD which are to be solved using optimization techniques. For practical analysis, the non-equality among the dc source voltages is considered and the concept of non-integer dc link voltage ratio is taken into account. Moreover in the previous works considering non-equal dc source voltages the dc link voltage ratio is taken as one of the inputs of the system. Then, for different values of dc link voltage ratios the results are compared to find out the best combination. Hence it increases physical burden. In the proposed scheme, these dc link voltage ratios are considered as one of the optimization variables along with the switching angles. Hence, the proposed scheme can give the best combination of switching angles and dc link voltage ratios for the minimum %THD corresponding to a particular modulation index. Hence, it decreases the computational burden for online application. As the proposed work concentrates mainly on optimization technique of the Total Harmonic Distortion of the output voltage waveform, a comparative study of switching angles obtained from genetic algorithm and particle swarm optimization with respect to the different modulation indices. Simulation is being done to demonstrate the analytical results.

II.ANALYSIS OF CASCADED MULTILEVEL INVERTER

This topology has two cells and they can have two DC inputs varying in a practical scenario. Fig. 1 shows the schematic model of a single phase 5-level cascaded inverter and the output voltage waveform for unequal and equal DC source voltages are depicted in fig. 2.

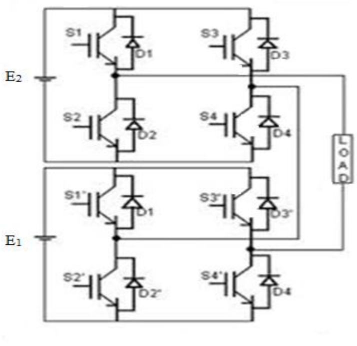

Fig. 1 Five-level Cascaded inverter

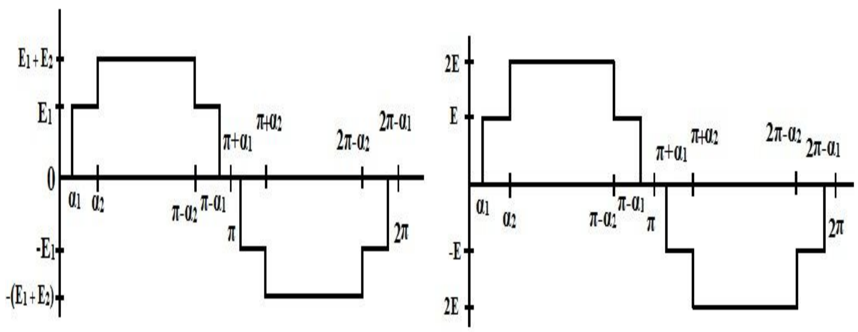

Fig. 2 (a) Output waveform for unequal DC sources and (b) Output waveform for equal input DC sources

The output voltage waveform considering quarter wave symmetry for a single phase 5-level inverter can be expressed in the Fourier form as;

Case-a (unequal DC Sources):

$$V_n(\omega t) = \sum_{1,3,5,\ldots}^{\infty} [(\frac{4}{n\pi})[E_1\cos(n\alpha_1) + E_2\cos(n\alpha_2)]\sin(n\omega t)] \quad (1)$$

Now, let us introduce a ratio denoted by ρ_i, which is may be further defined as, $\rho_i = \frac{E_i}{E_s}$;

where, E_i = the output voltage of the i^{th} cell,

E_s = the output voltage of the s^{th} cell, where (2s+1) is the number of levels in the output voltage waveform.

For a 5 level cascaded inverter $\rho_1 = \frac{E_1}{E_2}$ and $\rho_2 = 1$.

Therefore, eqn. (8) can be expressed in terms of ρ_i as;

$$V_n = \left(\frac{4E_2}{n\pi}\right)[\rho_1\cos(n\alpha_1) + \cos(n\alpha_2)] \quad (2)$$

Case –b (Equal DC sources):

$$V_n(\omega t) = \sum_{1,3,5,\ldots}^{\infty} [(\frac{4E}{n\pi})[\cos(n\alpha_1) + \cos(n\alpha_2)]\sin(n\omega t)]$$

i.e. $V_n = \left(\frac{4E}{n\pi}\right)[\cos(n\alpha_1) + \cos(n\alpha_2)]$ (3)

Modulation Index of multilevel inverter may be expressed as,

$$M = \frac{V_1}{\frac{4E_2}{\pi}} \quad (4)$$

III.SELECTIVE HARMONIC ELIMINATION PROBLEM

The set of nonlinear equations for SHE technique for single phase five-level cascaded inverter can be formulated as;

- Case-a (For unequal DC link voltages):

$$\begin{aligned}
V_1 &= \rho_1\cos(\alpha_1) + \cos(\alpha_2) = \frac{\pi V_{b1}}{4E_2} = M \\
V_3 &= \rho_1\cos(3\alpha_1) + \cos(3\alpha_2) \leq \varepsilon_1 \\
V_5 &= \rho_1\cos(5\alpha_1) + \cos(5\alpha_2) \leq \varepsilon_2 \\
V_7 &= \rho_1\cos(7\alpha_1) + \cos(7\alpha_2) \leq \varepsilon_3 \\
V_9 &= \rho_1\cos(9\alpha_1) + \cos(9\alpha_2) \leq \varepsilon_4 \\
V_{11} &= \rho_1\cos(11\alpha_1) + \cos(11\alpha_2) \leq \varepsilon_5 \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
V_{49} &= \rho_1\cos(49\alpha_1) + \cos(49\alpha_2) \leq \varepsilon_{24}
\end{aligned} \quad (5)$$

- Case-b (For equal DC link voltages):

$$\begin{aligned}
V_1 &= \cos(\alpha_1) + \cos(\alpha_2) = \frac{\pi V_{b1}}{4E} = M \\
V_3 &= \cos(3\alpha_1) + \cos(3\alpha_2) \leq \varepsilon_1 \\
V_5 &= \cos(5\alpha_1) + \cos(5\alpha_2) \leq \varepsilon_2 \\
V_7 &= \cos(7\alpha_1) + \cos(7\alpha_2) \leq \varepsilon_3 \\
V_9 &= \cos(9\alpha_1) + \cos(9\alpha_2) \leq \varepsilon_4 \\
V_{11} &= \cos(11\alpha_1) + \cos(11\alpha_2) \leq \varepsilon_5 \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
V_{49} &= \cos(49\alpha_1) + \cos(49\alpha_2) \leq \varepsilon_{24}
\end{aligned} \quad (6)$$

Where, Ɛ is tolerance and M is modulation index which is described at equation (4).

The equation (5) & (6) are solved using Particle Swarm Optimization to calculate α_1, α_2 & ρ_1. A set of switching angles are computed off-line with varying modulation indices. These optimum switching angles are used to trigger semiconductor switches for a particular modulation index.

The THD of the output voltage may be defined as

$$\text{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^{\,2}}}{V_1} \quad (7)$$

IV.PARTICLE SWARM OPTIMIZATION

The voltage THD is analogous to the objective function F(α) in the developed PSO algorithm. To reduce the overall THD of the output voltage waveform, this objective function F(α) has to be minimized with the following the SHE equations. Mathematically, the problem can be formulated as follows:

Minimize F(α)= F($\alpha_1, \alpha_2, \alpha_3, \dots \alpha_m$)
Subject to $0<\alpha_1, \alpha_2, \alpha_3, \dots \alpha_m<\frac{\pi}{2}$;

$$\begin{aligned} &V_1 = M;\\ &V_3 \le \varepsilon_1;\\ &V_5 \le \varepsilon_3;\\ &.\\ &.\\ &.\\ &V_{49} \le \varepsilon_{24}; \end{aligned} \quad (8)$$

Where $\varepsilon_1, \varepsilon_2, \dots\dots, \varepsilon_m$ are the allowable limits of individual harmonics. The PSO is a population-based search technique. In the present problem, each particle (search point) of the population is composed of the switching angles per quarter cycle α_1 through α_m. To start the search procedure, the switching angles are randomly generated satisfying the conditions of (9) for the chosen number of population. Using these random values, individual harmonics are computed, which represents the fitness of a search point. The best combination of angles among the population of search points at a certain iteration is called pbest or present best solution, whereas the best solution up to present iteration is called the gbest or global best solution for the variables α_1 through α_m. At each iteration, new search points are generated from the current search points and the information regarding the pbest and gbest solutions using the following equations [19], [20]

$$V_i^{k+1} = \omega.V_i^k + c_1 rand(\quad)(pbest_i^k - x_i^k) + c_2 rand(\quad)(gbest_i^k - x_i^k) \quad (9)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (10)$$

Where, c_1 and c_2 are the learning factors, rand () is the random numbers between 0 and 1, w is the inertia weight, v_i is the particle velocity and k is the iteration number.
The pbest and gbest values are updated after each iteration. The process is repeated until the convergence is obtained.

It should be noted that unlike the other iterative methods PSO does not require any initial guess of the variables for convergence. With a considerable number of generations and large number of population in each generation, the algorithm searches for all probable set of solutions and finally compute the angles α_1 through α_m to contribute the minimum THD, keeping the individual harmonics within the limits as specified by (8). A flowchart of the PSO algorithm is shown in Fig. 3.

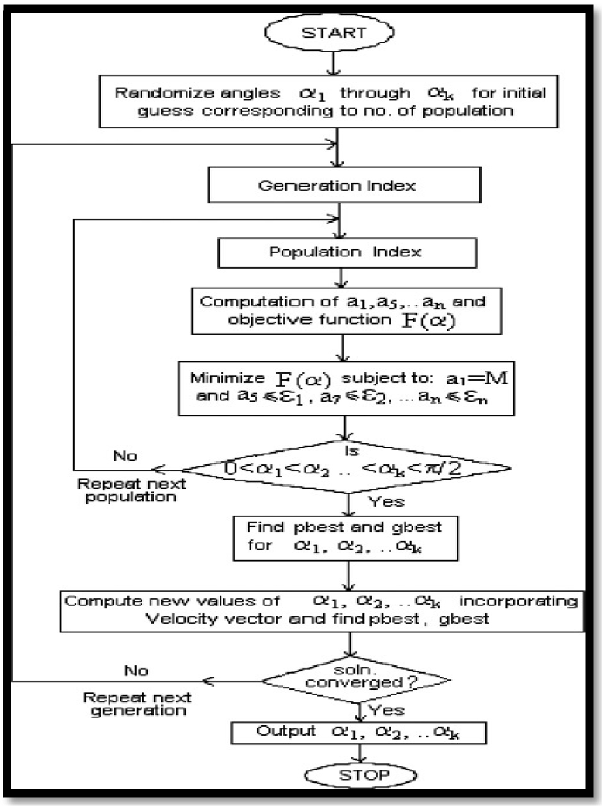

Fig. 3 Flowchart of Particle Swarm Optimization

In the proposed harmonic minimization technique, two different objective functions characterizing SHE (Equation 5 and 6) are compared to get minimum possible output voltage THD with considering modulation index from 0.9 to 1.9 with resolution 0.1. As the present research work is done with considering varying DC voltage sources, the concept of non-integer dc link voltage ratio is taken into account. Solar cells or fuel cells are generally used as voltage sources of multilevel inverters, in accordance with that the range of DC link voltage ratio is considered in between 1.02 to 3. The different harmonic optimization approaches are discussed below.

A. Harmonic Elimination (HE)

In this method, for both the cases of unequal and equal dc source voltages, fundamental component of the output voltage is assigned to modulation index i.e. V_1=M and third harmonic component is eliminated i.e. V_3=0. The objective function for this method is formulated as:

$$f(\alpha)= k_1|V_1-M|^2 + k_2|V_3-\varepsilon_1|^2 \qquad (11)$$

B. Harmonic Reduction (HR)

In this method, fundamental component of the output voltage is assigned to modulation index i.e.V_1=M, while other lower order harmonics i.e. V_3, V_5, V_7, V_9 and V_{11} are minimized. The fitness function for this case can be derived as:

$$f(\alpha)= k_1|V_1- M|^2 + k_2*|V_3^2+V_5^2+V_7^2+V_9^2+V_{11}^2| \qquad (12)$$

For quarter wave symmetry the range of switching angles is

$$0 < \alpha_1 < \alpha_2 < \frac{\pi}{2}, \text{ and, } 1.06 < \rho 1 < 3 \quad (13)$$

where, α is, for unequal dc source multilevel inverter, the set of switching angles and dc voltage ratio i.e. $[\alpha_1\ \alpha_2\ \rho_1]$, and for equal dc source multilevel inverter, only the set of switching angles i.e. $[\alpha_1\ \alpha_2]$; V_1 is fundamental component, V_3, V_5, V_7, V_9 and V_{11} are the 3rd, 5th, 7th, 9th, and 11th order voltage harmonics respectively and M is the modulation index. $\mathcal{E}_1$ is the tolerance of V_3 whose magnitude is taken as 0.005. k_1 and k_2 are the weight-age factor. Using the equations (9) and (10) the fitness values of objective functions (11) and (12) are calculated for each iteration.

V. ANALYTICAL AND SIMULATION RESULTS

1. Analytical Results:
   A. Unequal voltage sources: The SHE equation 5 is used here to compute the switching angles and DC link voltage ratio using which the %THD is calculated for the two optimization approaches. Table 1 shows %THD obtained for each modulation indices.

Table 1 Minimum %THD obtained with unequal DC sources for HE & HR

M		k_1	k_2	α_1	α_2	ρ_1	ρ_2	% THD
0.9	Harmonic Elimination	175	75	0.524	1.569	1.06	1	29.98
	Harmonic Reduction	1025	2.5	0.521	1.569	1.06	1	29.82
1	Harmonic Elimination	90	51	0.514	1.561	1.138	1	29.49
	Harmonic Reduction	875	1	0.459	1.542	1.081	1	29.07
1.1	Harmonic Elimination	90	51	0.498	1.541	1.218	1	29.87
	Harmonic Reduction	875	1.8	0.459	1.539	1.186	1	28.97
1.2	Harmonic Elimination	90	51	0.452	1.483	1.236	1	30.1
	Harmonic Reduction	875	1.2	0.459	1.536	1.296	1	28.85
1.3	Harmonic Elimination	90	51	0.278	1.303	1.077	1	28.74
	Harmonic Reduction	3625	2.2	0.352	1.218	1.06	1	27.13
1.4	Harmonic Elimination	90	51	0.191	1.206	1.063	1	27.54
	Harmonic Reduction	1875	2.8	0.208	1.167	1.06	1	25.82
1.5	Harmonic Elimination	90	51	0.262	1.232	1.209	1	25.74
	Harmonic Reduction	1075	1.25	0.189	1.057	1.06	1	22.46
1.6	Harmonic Elimination	90	51	0.154	1.058	1.122	1	23.25
	Harmonic Reduction	3675	8.8	0.163	0.988	1.06	1	20.91
1.7	Harmonic Elimination	90	51	0.221	0.855	1.07	1	16.38
	Harmonic Reduction	3275	8.8	0.265	0.738	1.02	1	15.55
1.8	Harmonic Elimination	90	51	0.271	0.832	1.169	1	15.84
	Harmonic Reduction	3275	8.8	0.242	0.682	1.06	1	15.70
1.9	Harmonic Elimination	90	51	0.29	0.838	1.286	1	15.99
	Harmonic Reduction	3275	8.8	0.273	0.697	1.177	1	15.93.

It can be observed that the minimum %THD for unequal DC sources is obtained from the Harmonic Reduction technique for modulation index 1.7 at α_1= 0.265 radian, α_2= 0.738 radian, ρ_1=1.02 with %THD as 15.55%.

   B. Equal DC sources: The SHE equation 6 is used here to compute the switching angles using which the %THD is calculated for the two optimization approaches. Table 2 shows %THD obtained for each modulation indices.

Table 2 Minimum %THD obtained with equal DC sources for HE & HR

M		k_1	k_2	α_1	α_2	% THD
0.9	Harmonic Elimination	90	51	0.5	1.548	29.97
	Harmonic Reduction	2025	3.8	0.471	1.557	28.41
1	Harmonic Elimination	90	51	0.43	1.479	31.77
	Harmonic Reduction	2225	6	0.443	1.504	31.24
1.1	Harmonic Elimination	90	51	0.358	1.407	31.43
	Harmonic Reduction	750	2.8	0.344	1.376	31.06
1.2	Harmonic Elimination	90	51	0.28	1.329	30.33
	Harmonic Reduction	425	2.4	0.389	1.248	29.54
1.3	Harmonic Elimination	90	51	0.196	1.246	29.33
	Harmonic Reduction	1525	8.8	0.21	1.228	28.45
1.4	Harmonic Elimination	90	51	0.101	1.154	29.21
	Harmonic Reduction	1475	3.8	0.205	1.145	25.72
1.5	Harmonic Elimination	90	51	0.0	1.047	30.01
	Harmonic Reduction	5075	2	0.179	1.028	22.08
1.6	Harmonic Elimination	90	51	0.125	0.917	20.25
	Harmonic Reduction	1825	3.8	0.148	0.923	19.67
1.7	Harmonic Elimination	90	51	0.327	0.718	17.3
	Harmonic Reduction	3050	3.8	0.26	0.719	15.57

For the equal DC sources again it can be noticed that the minimum %THD is achieved from the Harmonic Reduction technique for modulation index 1.7 at α_1= 0.26 radian, α_2= 0.719 with %THD as 15.57%.

k_1 and k_2 need to be adjusted properly through trial and error method for unbiased optimization. The variation of %THD with respect to different modulation indices is plotted for Harmonic Elimination and Harmonic Reduction technique with unequal and equal DC sources are shown in fig. 4 and fig. 5.

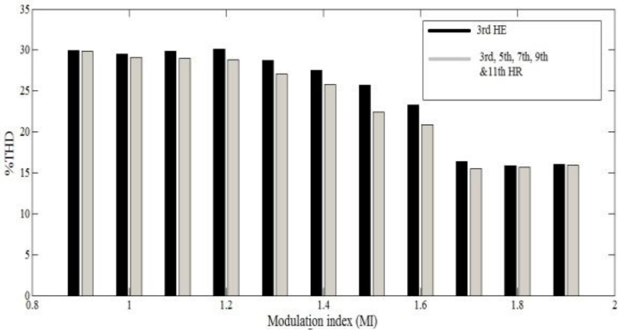

Fig. 4 Modulation indices vs %THD for unequal DC sources (Analytically obtained)

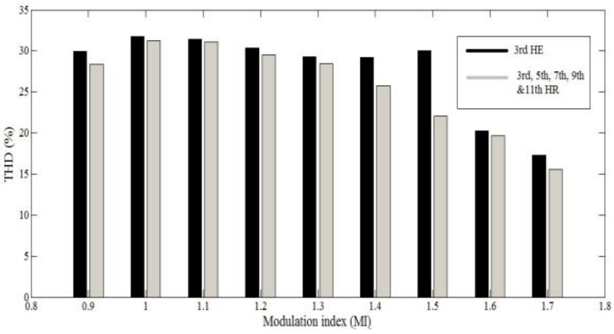

Fig. 5 Modulation indices vs %THD for equal DC sources (Analytically obtained)

2. Simulation Results:

The analytical results are validated through simulation results. The simulation results are obtained through MATLAB 7.6.0 in SIMULINK by modeling a single phase cascaded 5-level inverter with resistive load. The magnitude of the DC source is taken as 12V. Fig. 6 and fig. 7 shows %THD variation for Harmonic Elimination and Harmonic Reduction against different modulation indices for unequal and equal DC sources respectively.

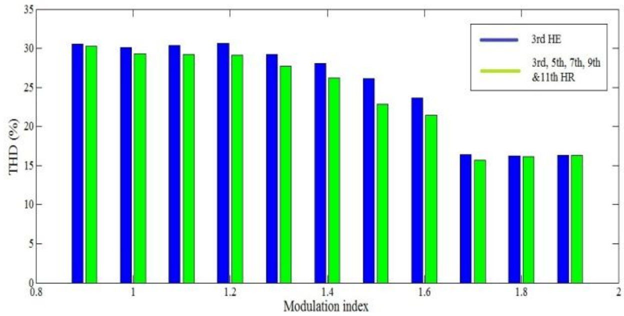

Fig. 6 Modulation indices vs %THD for unequal DC sources (Simulation result)

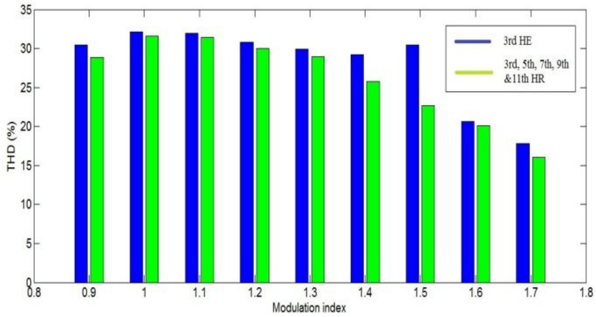

Fig. 7 Modulation indices vs %THD for equal DC sources (Simulation result)

The simulation results also depicts that between the two harmonic minimization approach the later gives better optimization of %THD than the first one. The output voltage waveform and Fourier analysis spectrum with unequal DC sources for the HR approach corresponding to a modulation index 1.6 is shown in fig. 8 and fig. 9 respectively.

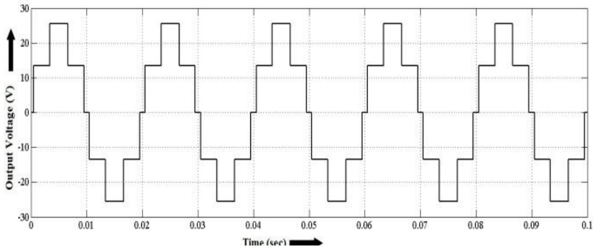

Fig. 8 Output voltage waveform of 5-level cascaded inverter for unequal DC sources with HR technique at modulation index=1.6

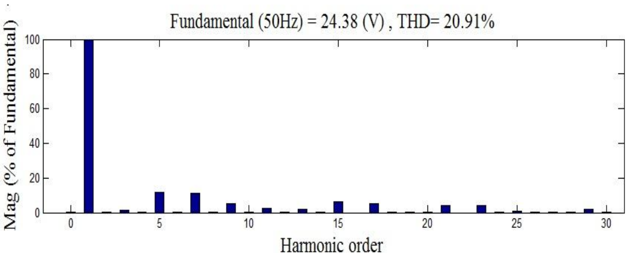

Fig. 9 FFT analysis of 5-level cascaded inverter for unequal DC sources with HR technique at modulation index=1.6

VI.GENETIC ALGORITHM

The GA is an evolutionary method to solve the optimization problems by imitating the behavior of populations during generations and based on the theory of evolution. This method is based on the idea that stronger individuals are likely the winners in a competing environment. It assumes that the solution of a problem is an individual and can be represented by a set of parameters. To minimize a function, each variable parameter coded as a binary form. The GA investigates the search space from the points it has to bias the search towards the best point. This algorithm is a stochastic search method and has been shown that the answer is appropriate for problems where there are many global minimum or search space is extensive. A positive value, generally called fitness value, is used to measure the degree of "goodness" of the chromosome for solving the problem, and this value is closely dependent to its objective value. The objective function of a problem is an important source providing the mechanism for evaluating the status of each chromosome. It takes the chromosome as input and also, produces a number or list of numbers such as objective value as a measure to the chromosome's performance. This is a main link between algorithm and the system.

The objective function used for the GA is given by

$f(\alpha)= k_1|V_1- M|^2 + k_2*|V_3^2+V_5^2+V_7^2+V_9^2+V_{11}^2|$

k_1 and k_2 are the coefficients that are chosen using trial and error to get a good balance in the problem. A comparative study of switching angles obtained from PSO and GA using the aforementioned objective function is carried out in the next section.

VII.COMPARISON OF SWITCHING ANGLES OBTAINED FROM PSO WITH GA

From the analytical and simulation results it is observed that the elimination of lower order harmonic (3^{rd}) gives a little bit inferior result than the Harmonic Reduction approach. In this section a comparative study of %THD obtained from Particle Swarm Optimization with Genetic Algorithm is presented. Table 3 gives the analytical and simulation results of %THD obtained from PSO and GA.

Table 3 Data set obtained through GA and PSO run

MI	GA						PSO					
	α_1 (rad)	α_2 (rad)	ρ_1	ρ_2	%V_{thd}		α_1 (rad)	α_2 (rad)	ρ_1	ρ_2	%V_{thd}	
					Analytical	Simulation					Analytical	Simulation
1.4	0.208	1.201	1.06	1	26.999	27.11	0.208	1.167	1.06	1	25.8203	26.04
1.5	0.19	1.059	1.06	1	22.515	22.79	0.189	1.057	1.06	1	22.463	22.6
1.6	0.167	0.994	1.067	1	20.931	21.18	0.163	0.988	1.06	1	20.913	21.12
1.7	0.263	0.718	1.02	1	15.596	15.76	0.265	0.738	1.02	1	15.551	15.68
1.8	0.231	0.673	1.06	1	15.768	15.91	0.242	0.682	1.06	1	15.704	15.85

The simulation results for GA and PSO with modulation index 1.7 is shown in fig. 10 –fig. 13.

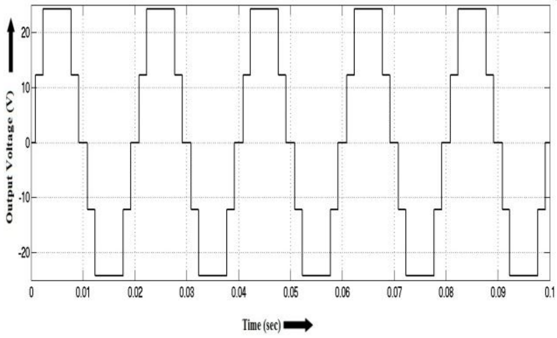

Fig. 10 Output voltage waveform obtained by executing GA for modulation index 1.7

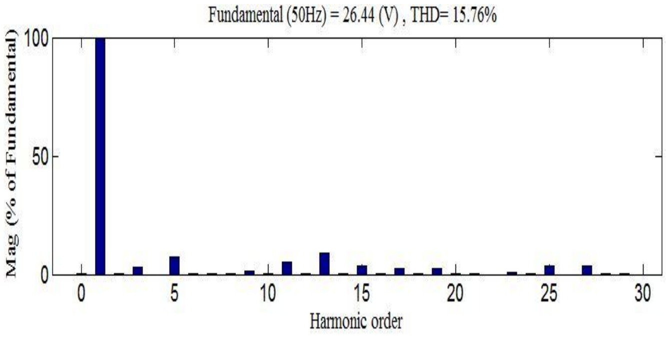

Fig. 11 FFT analysis obtained by executing PSO for modulation index 1.7

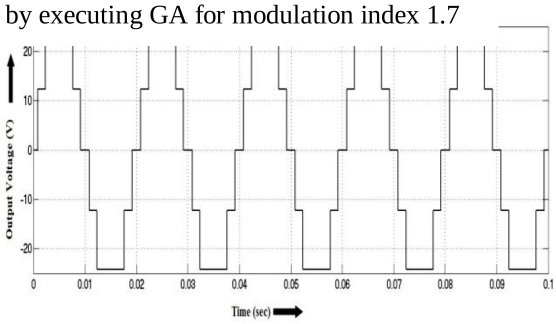

Fig. 12 Output voltage waveform obtained by executing PSO for modulation index 1.7

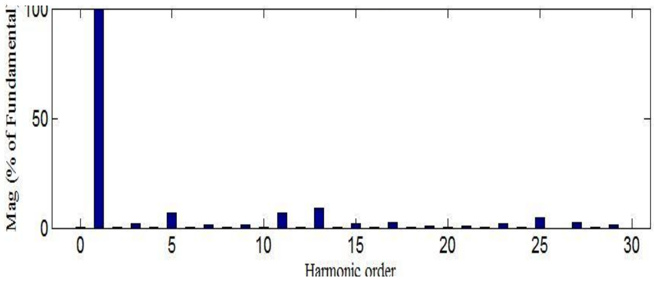

Fig. 13 FFT analysis obtained by executing PSO for modulation index 1.7

After observing the results it can be conclude that both methods can obtain proper switching angles for optimal operation of the inverter but it has been shown that PSO is more accurate than GA.

VIII.CONCLUSION

The main objective of this investigation has been to evolve the best approach to minimize the Total Harmonic Distortion of the output voltage waveform of the cascaded multilevel inverter with maintaining the desired fundamental component within a minimum possible switching. Particle Swarm Optimization is used to solve those SHE equations considering the above mentioned objective functions. The results are compared for both unequal and equal dc source voltage cases. From the results it can be conclude that eliminating the lower order harmonic gives a little bit inferior result than the Harmonic Reduction approach. The advantage of this method is that, besides eliminating the targeted order of harmonics, it also optimizes the other order of harmonics to minimize the THD. Consideration of varying DC sources also giving better result as compared to the non-varying DC source case. GA and PSO have been applied to solve the formulated SHE problem of Harmonic Reduction approach. The analytical and simulation results shows both methods can obtain proper switching angles for optimal operation of the inverter but PSO proved to be more accurate than GA. Hence, it can be conclude that the proposed scheme i.e. optimization of harmonics of the output voltage waveform of a single phase 5-level cascaded inverter with unequal DC source using Particle Swarm Optimization is giving superior results than the other optimization methods.

These offline computed switching angles and DC link voltage ratios along with %THD corresponding to each modulation index are stored in a direct look up table in the processor memory which can be easily implemented to the online control of cascaded 5-level inverter with varying DC sources.

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BIOGRAPHY

Ananya Pal was born in West Bengal, India on September 28, 1990. He has received his B.Tech degree in Electrical Engineering from Academy of Technology, Hooghly, West Bengal in 2012. Currently she is pursuing her M.Tech degree in Power Electronics and Drives from Jalpaiguri Govt. Engineering College, Jalpaiguri, West Bengal. Her recent research of interests includes Optimization of Harmonics from Multilevel Inverter, PSO and GA.

Pradip Kumar Saha, Professor, Jalpaiguri Government Engineering College, Jalpaiguri,WB- 735102. BE (Electrical) from B.E. College, Shibpore. M.Tech (Electrical) Specialization: Machine Drives & Power Electronics from IIT- Kharagpur. PhD from University of North Bengal. FIE, MISTE, Certified Energy Auditor.

Goutam Kumar Panda, Professor and Head, Department of Electrical Engineering, Department of Electrical Engineering, Jalpaiguri Government Engineering College, Jalpaiguri,WB-735102,BE (Electrical) from J.G.E. College, Jalpaiguri, M.E.E (Electrical) Specialization: Electrical Machines & Drives from Jadavpur University. PhD from University of North Bengal. FIE, MISTE, Certified Energy Auditor.