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Harmonic Mitigation in Three Phase Cascaded Multilevel Inverter with DC Sources Using GA And DE Algorithm

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ABSTRACT
The mitigation of harmonics in a cascaded multilevel inverter is separated dc sources by using GA and DE Algorithm and they are compared. Solving a nonlinear transcendental equation set describing the harmonic-elimination problem with dc sources reaches the limitation of contemporary computer algebra software tools using the resultant method. The proposed approach in this paper can be applied to solve the problem in a simpler manner, even when the number of switching angles is increased and the determination of these angles using the resultant theory approach is not possible. Theoretical results are verified by simulations results for a 9-level H-bridge inverter. Results show that the proposed method does effectively eliminate a great number of specific harmonics, and the output voltage is resulted in low total harmonic distortion. Determination of these angles using the resultant theory approach is not possible. Theoretical results are verified by simulations results for a 9-level H-bridge inverter.

Keywords: Differential Algorithm (DEA), Genetic Algorithm (GA), Selective harmonic elimination, DC sources.

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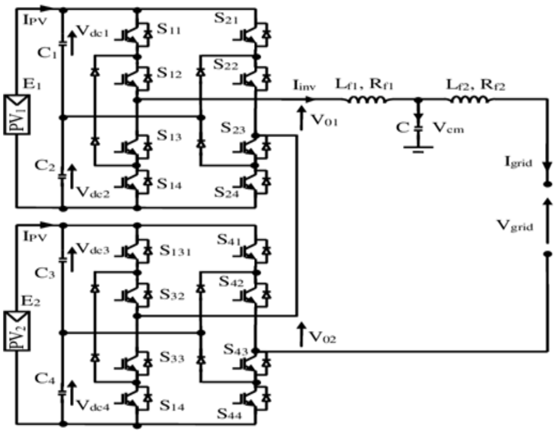
I. INTRODUCTION

A multilevel inverter is a power electronic system that synthesis a desired voltage output from several levels of dc voltage as input. The cascaded multilevel inverter consists of a series of H-bridge inverter units. Multilevel voltage source inverters are a suitable configuration to reach high power ratings. The different topologies for the cascaded multilevel inverter have received special attention due to its modularity and simplicity of control. There are different power circuit topologies for multilevel inverters. The most familiar power circuit topology for multilevel inverters is based on the cascade connection of an 's' number of single-phase full-bridge inverters to generate a (2s + 1) number of levels. However, from the practical point of view, it is somehow difficult to keep equal the magnitude of separated dc sources of different levels. This can be caused by the different charging and discharging time intervals of dc-side voltage sources. 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 and space-vector PWM techniques are suggested. However, PWM techniques are not able to eliminate lower order harmonics completely. 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 or programmed PWM techniques in technical literature. A fundamental issue associated with such method is to obtain the arithmetic solution of non-linear transcendental equations which contain trigonometric terms and naturally present multiple solutions. This set of nonlinear equations can be solved by related techniques such as the Newton–Raphson method. However, such techniques need a good initial guess which should be very close to the exact solution patterns. Furthermore, this method finds only one set of solutions depending on the 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. A systematic approach to solve the SHE problem based on the mathematical theory of resultant, where transcendental equations that describe the SHE problem are converted into an equivalent set of polynomial equations and then the mathematical theory of resultant is utilized to find all possible sets of solutions for this equivalent problem. This method is also applied to multilevel inverters with unequal dc sources. However, applying the inequality of dc sources results to the asymmetry of the transcendental equation set to be solved and requires the solution of a set of high-degree equations, which is beyond the capability of contemporary computer algebra software tools. In fact, the resultant theory is limited to find up to six switching angles for equal dc voltages and up to three switching angles for non-equal dc voltage. More recently, the real-time calculation of switching angle switch analytical proof is presented to minimize the total harmonic distortion (THD) of the output voltage of multilevel converters. However, the presented analytical proof is only valid to minimize all harmonics including triples and cannot be extended to minimize only non50 IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 10 Issue 01, January 2023 ISSN (Online) 2348 – 7968 | Impact Factor – 6.72 www.ijiset.com triple harmonics that are suitable for three-phase applications. The modern stochastic search techniques based on particle swarm optimization (PSO) to deal with the problem for equal dc sources. The DEA and PSO algorithm is developed to deal with the SHE problem with unequal dc sources while the number of switching angles is increased and the determination of these angles using conventional relating methods as well as the resultant theory is not possible. In addition, for a low number of switching angles, the proposed DEA algorithm reduces the computational burden to find the optimal solution compared with relative 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.

Cascaded H-Bridge Multilevel Inverter

A single-phase structure of an m-level cascaded inverter is illustrated in Figure 1. 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, +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. To obtain +Vdc, switches S1 and S4 are turned on, whereas –Vdc can be obtained by turning on switches S2 and S3. By turning on S1 and S2 or S3 and S4, 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 defined by m = 2s+1, where s is the number of separate dc sources. An example phase voltage waveform for a 9-level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Figure 2. The phase voltage van = va1 + va2 + va3 + va4 + va5. +va4 + va5. .



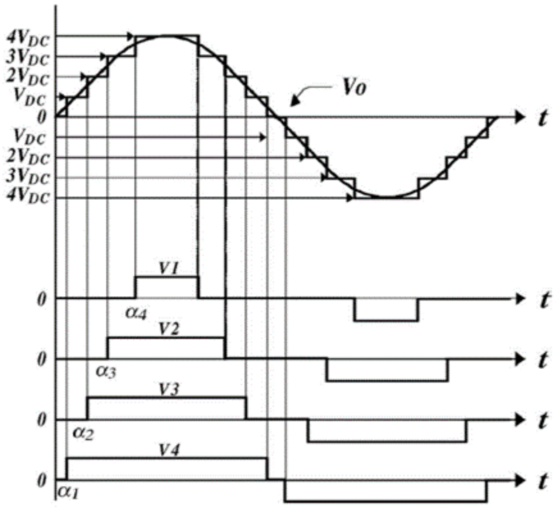


Fig.1 Multilevel cascaded H-bridges. Fig.2 Output phase voltage waveform

For a stepped waveform such as the one depicted in Fig. 2 with s steps, the Fourier Transform for this waveform follows

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

Where n = 1, 3, 5, 7, …

Comparisons of DCI, CCI, CMI

Diode Clamped Inverter (DCI)	Capacitor Clamped Inverter (CCI)	Cascade Multilevel Inverter (CMI)
Switching is easier. At fundamental frequency Efficiency is high.	Control is complicated to track the voltage Levels for Capacitors	Communication between full bridge is requires reference and carrier waveform.
All the phases share a common dc bus, Which minimizes the Capacitance requirements of the converter	Capacitors have large Fraction of dc bus Voltage across them so rating of these is Design challenge.	Needs separate dc Sources for real power Conversions and applications are limited.
It is efficient for Motor drives, traction motors and easy to design it.	Switching utilization and efficiency is poor for real power transmission	DC source is well suited for various Renewable energy Sources.

Harmonic Elimination Control Technique Using Algorithms using GA & DEA

Harmonic Elimination pulse width modulation (HEPWM) method has been widely applied to remove harmonics due to its superior frequency spectra. It requires the solution of a set of transcendental nonlinear equations. Soft computing (SC) methods are extensively employed to solve this problem because of their effective global search ability. Genetic Algorithm (GA) and Differential evolution

(DE) has surpassed most of the SC methods in diverse fields but it has never been utilized to solve this problem. In this work. GA and DE are utilized to solve the HEPWM problem for eleven level cascaded multilevel voltage source inverter (MVSI). Simulation results have shown that the discontinuities of the HEPWM angle trajectories are nullified and a wider over-modulation range has been covered, enhancing the utilization of DC link voltages and extending the application of HEPWM for high power applications.

Harmonic-Elimination Problem with Un-Equal Dc Sources

By applying Fourier series analysis, the staircase output voltage as shown in Figure 1. of multilevel inverters with unequal sources can be described as follows:

$$V(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4Vdc}{n\pi} X \left(k_1 \cos(n\theta_1) + k_2 \cos(n\theta_2) + k_3 \cos(n\theta_3) + \cdots + k_s \cos(n\theta_s)\right) \sin(n\omega t)$$

Where,

Ki Vdc is the i^{th} dc voltage,

Vdc is the nominal dc voltage,

θ1– θm is the switching angles

θ1– θm must satisfy the following condition:

The number of harmonics which can be eliminated from the output voltage of the inverter is s-1. For example, to eliminate the fifth-order harmonic for a five-level inverter, equation set (3.1) must be satisfied. Note that the elimination of triplet harmonics for the three-phase power system applications is not necessary, because these harmonics are automatically eliminated from the line–line voltage

$$\begin{cases} k_1 cos(\theta_1) + k_2 cos(\theta_2) = (\pi/2)M \\ k_1 cos(5\theta_1) + k_2 cos(5\theta_2) = 0. \end{cases} \quad (1)$$

In Eqn. (1), modulation index M is defined as M = V1/sVdc andV1 is the fundamental of the required voltage. The fitness function is given by

$$f(\theta_1, \theta_2, \ldots \theta_5) = 100 \text{ x } \left[\left|M - \frac{|V1|}{sV_{dc}}\right| + \left(\frac{|V_5| + |V_7| + \cdots + |V_{3s-2 \text{ or } 3s-1}|}{sV_{dc}}\right)\right] \quad (2)$$

$0 \le \theta 1 \le \theta 2 \le \cdot\cdot\cdot \le \theta s \le \pi/2$

Formulating the problem

The step- by- step procedure to solve the SHE problem with unequal dc sources using GA is as follows.

Get the data for the system. At the first step, the required parameters of the algorithm such as population size, modulation index (M), Nominal Voltage, Number of Inverter level, max iteration number are determined.

Random population generation.

Fitness function

Parent Selection

Crossover

Mutation

Survival Selection

The step- by- step procedure to solve the SHE problem with unequal dc sources using DEA is as follows.

Get the data for the system similar to GA.

Initialization – to create an initial population of candidate solutions by assigning random values to each decision parameter of each individual of the population.

Mutation – the mutant vector is generated according to equation 3

$$v_{i,G+1} = x_{r1,G} + F \cdot (x_{r2,G} - x_{r3,G}) \qquad (3)$$

Crossover – The crossover operator creates the trial vectors, which are used in the selection process. The trial vector is a combination of a mutant vector and a parent (target) vector based on different distributions.

Fitness Evaluation –The fitness evaluation evaluates the parent and trial vectors using the fitness function

$$f(\theta_1, \theta_2, \ldots . \theta_5) = 100\text{x}\left[\left|\mathbf{M} - \frac{|\mathrm{V1}|}{sV_{dc}}\right| + \left(\frac{|V_5| + |V_7| + \cdots + |V_{3s-2 \text{ or } 3s-1}|}{sV_{dc}}\right)\right] \qquad (4)$$

Selection – The selection operator chooses the vectors that are going to compose the population in the next generation. This operator compares the fitness of the trial vector and fitness of the parent vector, and select the one that performs better (Minimum fitness value).

Genetic Algorithm

Genetic algorithms are inspired by Darwin's theory about evolution. Solution to a problem solved by genetic algorithms is evolved. Algorithm is started with a set of solutions (represented by chromosomes) called population. Solutions from one population are taken and used to form a new population. This is motivated by a hope, that the new population will be better than the old one. Solutions which are selected to form new solutions (offspring) are selected according to their fitness - the more suitable they are the more chances they have to reproduce. This is repeated until some condition (for example number of populations or improvement of the best solution) is satisfied.

Outline of the Basic Genetic Algorithm

Start Generate random population of n chromosomes (suitable solutions for the problem).

Fitness Evaluate the fitness f(x) of each chromosome x in the population

New population Create a new population by repeating following steps until the new population is complete.

Selection Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected).

Crossover With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents.

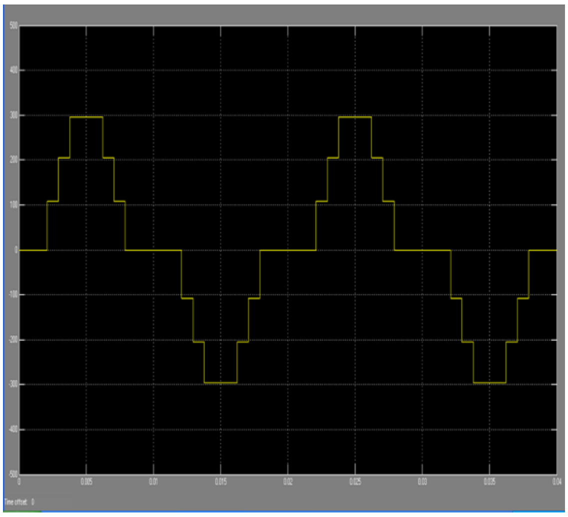
Mutation With a mutation probability mutate new offspring at each locus (position in chromosome).

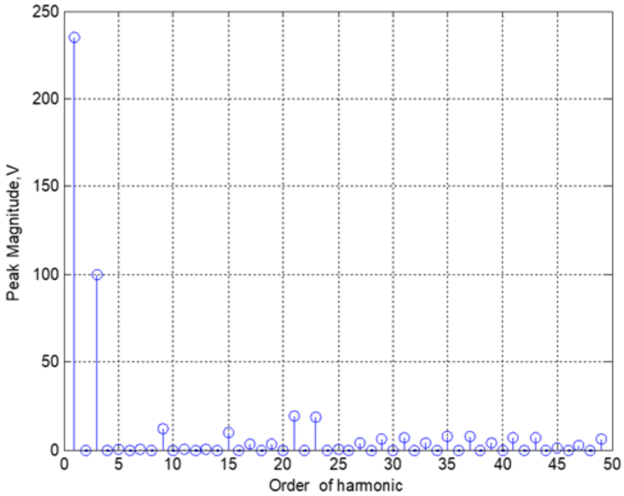
Differential Evolution Algorithm

The DE algorithm is a population-based algorithm like genetic algorithms using the similar operators; crossover, mutation and selection. The main difference in constructing better solutions is that genetic algorithms rely on crossover while DE relies on mutation operation. This main operation is based on the differences of randomly sampled pairs of solutions in the population. The algorithm uses mutation operation as a search mechanism and selection operation to direct the search toward the prospective regions in the search space. The DE algorithm also uses a non-uniform crossover that can take child vector parameters from one parent more often than it does from others. The recombination (crossover) operator efficiently shuffles information about successful combinations, enabling the search for a better solution space. An optimization task consisting of D parameters can be represented by a D-dimensional vector. In DE, a population of NP solution vectors is randomly created at the start. This population is successfully improved by applying mutation, crossover and selection operators.

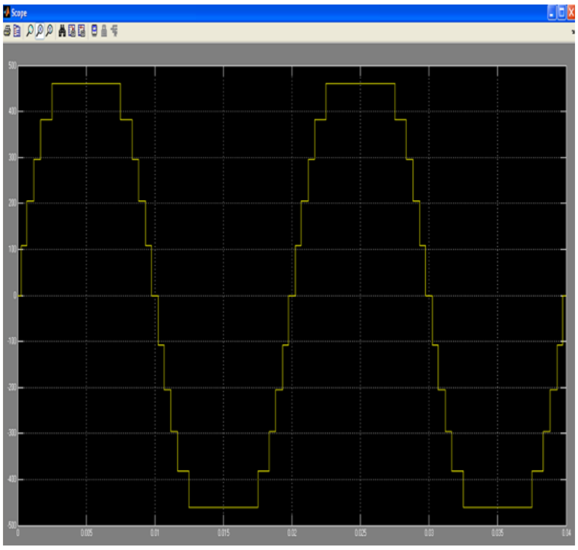
II. RESULT AND DISCUSSION

GA
Modulation index:0.7





Modulation index: 1.075



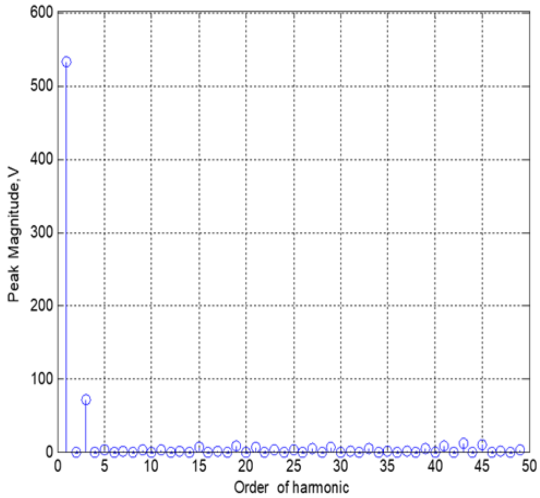
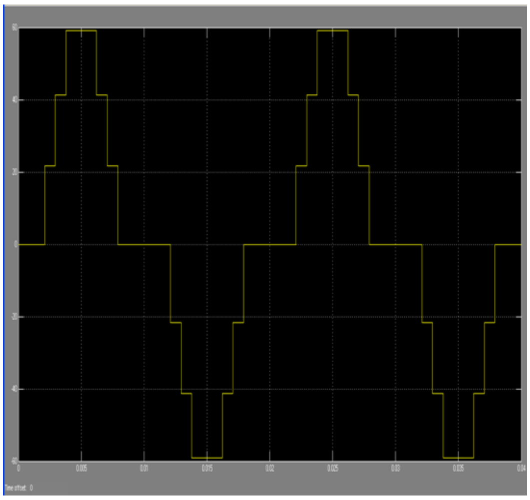
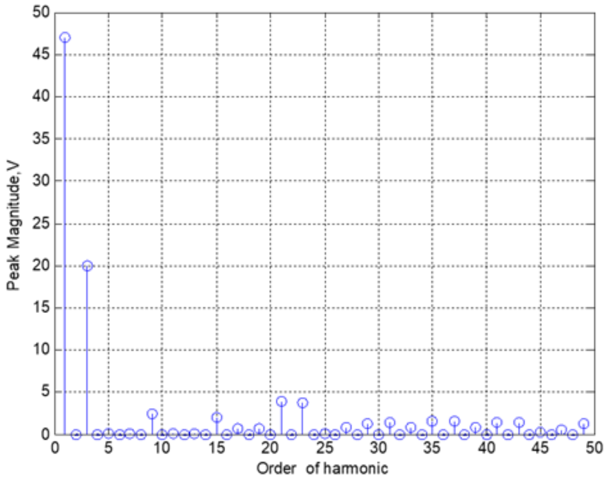


Table 1: GA (Nominal voltage 25V)

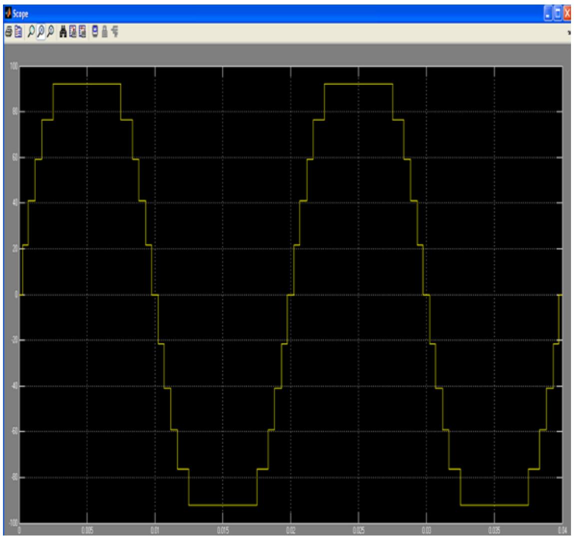
Sr. No.	Modulation index	Angle					Best fitness value	THD
1	0.7	27.7364	45.1437	52.7554	67.0311	73.9256	1.8798	2.9785
2	1.075	4.5004	12.0497	21.3627	29.8443	44.9095	1.3775	2.4137

DE
Modulation index: 0.7





Modulation index: 1.075



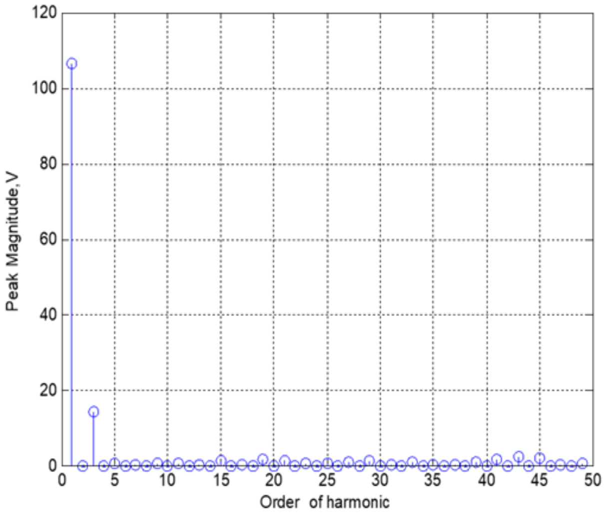


Table 2: DE (Nominal voltage: 25 V)

Sr. No.	Modulation index	Angle					Best fitness value	THD
1	0.7	29.3655	49.2390	49.2436	66.8150	72.4167	0.7940	2.9785
2	1.075	6.9998	8.3367	21.9034	27.9978	42.9525	0.9428	2.4035

III. CONCLUSION

This paper is used to determine the switching angles and THD of cascaded multilevel inverters by using Differential Evolution Algorithm. Simulations are carried out to verify the algorithm when applied to a single-phase multilevel inverter. In this paper Differential Evolution optimization technique is used to generate optimal switching angles in order to eliminate a certain order of harmonics. The algorithm was developed using MATLAB software and is run for a number of times independently to ensure the feasibility and the quality of the solution. Differential Evolution Algorithm solves the nonlinear transcendent equations with a much simpler formulation. Also, the results show that the differential evolution algorithm optimization technique effectively eliminates low order harmonics and the switching angles are used to optimize the total harmonic distortion (THD) of the output voltage.

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