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Harmonic Elimination in Cascade Multilevel Inverter with Non Equal DC Sources using Genetic Algorithm

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Abstract: The elimination of harmonics in a cascaded multilevel inverter by considering the un-equality of separated dc sources by using Genetic and Differential Evolutionary Algorithm and compared. Solving a nonlinear transcendental equation set describing the harmonic-elimination problem with non-equal 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 an 11-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.

Keywords: Genetic Algorithm (GA), multilevel inverter, selective harmonic elimination, unequal dc sources.

I. INTRODUCTION

Multilevel voltage-source inverters are a suitable configuration to reach high power ratings and high quality output waveforms besides reasonable dynamic responses. Among the different topologies for multilevel inverters, the cascaded multilevel inverter has received special attention due to its modularity and simplicity of control. The principle of operation of this inverter is usually based on synthesizing the desired output voltage waveform from several steps of voltage, which is typically obtained from dc voltage sources. 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 (2*s* + 1) number of levels. However, from the practical point of view, it is somehow difficult to keep equal the magnitude of separated dc sources (SDCSs) 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 (PWM) and space-vector PWM techniques are suggested.

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 non-triple harmonics that are suitable for three-phase applications.

The GA 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 iterative methods as well as the resultant theory is not possible.

In addition, for a low number of switching angles, the proposed GA algorithm 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.

II. CASCADED MULTILEVEL INVERTER WITH UNEQUAL DC SOURCES

A single-phase structure of an m-level cascaded inverter is illustrated in Figure 2.2. 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_1, S_2, S_3, and S_4. To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_2 and S_3. By turning on S_1 and S_2 or S_3 and S_4, 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 an 11-level cascaded

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H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Fig. 1.

The phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4} + v_{a5}$.$+v_{a4} + v_{a5}$.

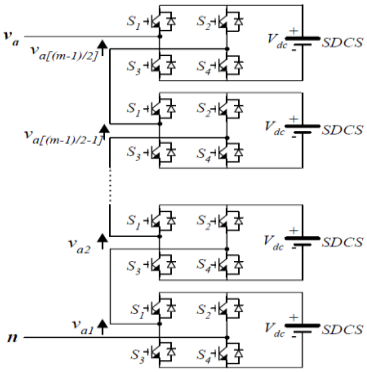

Fig.1 Single-phase structure of a multilevel cascaded H-bridges

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

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

Where n = 1, 3, 5, 7,...

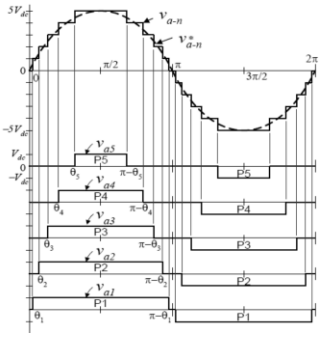

Fig.2 Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources

A. *Comparison of topologies*

Table 1.1 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 are poor for real power transmission	DC source is well suited for various Renewable energy Sources.

III. HARMONIC ELIMINATION PROBLEM WITH UNEQUAL 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:

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

Where,

$k_i V_{dc}$ is the i^{th} dc voltage,
V_{dc} is the nominal dc voltage,
θ_1–θ_m is the switching angles
θ_1–θ_m must satisfy the following condition:

$$0 \le \theta 1 \le \theta 2 \le \cdots \le \theta s \le \frac{\pi}{2}$$

(2.1)

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 (2.1) must be satisfied. Note that the elimination of triplen harmonics for the three-phase power system applications is not necessary, because these harmonics are automatically eliminated from the line–line voltage

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

(2.2)

In Eqn. (2.2), modulation index M is defined as $M = V_1/sV_{dc}$ and V_1 is the fundamental of the required voltage.

The fitness function is given by

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

A. *Methodology*

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Recommended font sizes are shown in Table 1

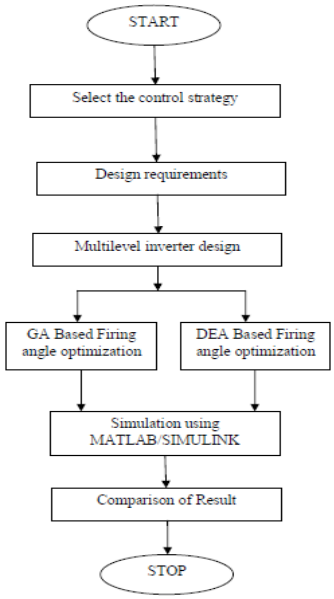

Fig. 3 Flowchart of Methodology

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B. 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).

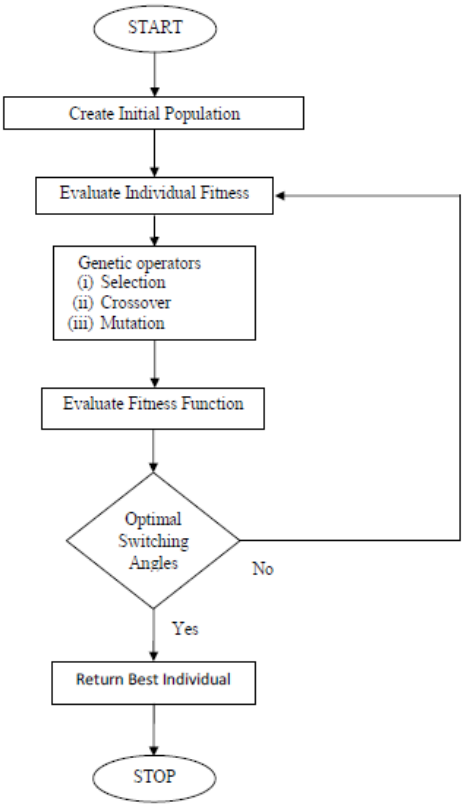


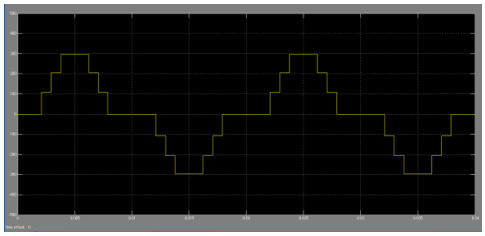
Fig. 4 Flowchart of GA

IV. RESULT

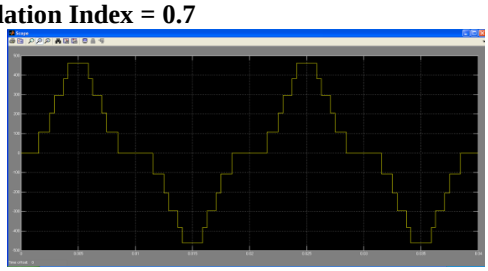
Table 4.1 Results of GA

MI	Angle					Fitness value	THD
0.47	37.677	52.94	67.99	87.23	88.4	2.6361	3.63
0.7	27.736	45.14	52.75	67.03	73.9	1.8798	2.97
0.9	7.3371	24.14	36.39	51.12	67.8	1.7717	2.62
1.075	4.5004	12.04	21.36	29.84	44.9	1.3775	2.41

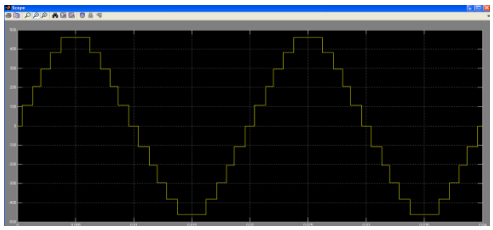
Modulation Index = 0.47



Modulation Index = 0.7



Modulation Index = 0.9



Modulation Index = 1.075

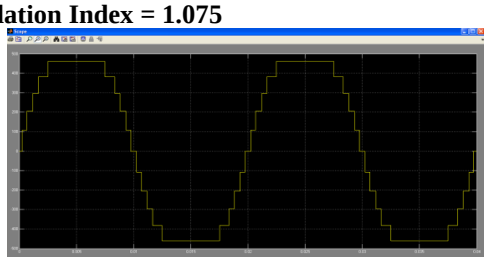
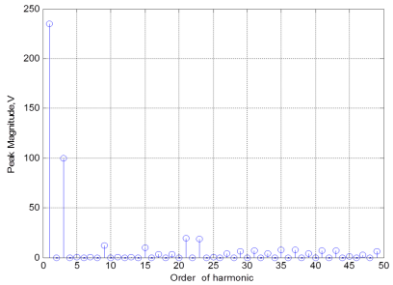


Fig. 5 Output Voltage Waveforms of various MI.

Modulation Index = 0.47



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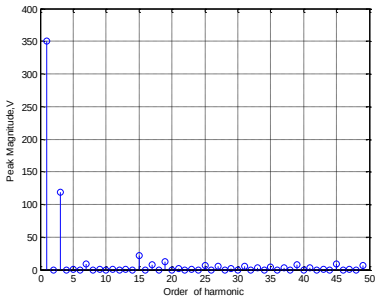
Modulation Index = 0.7



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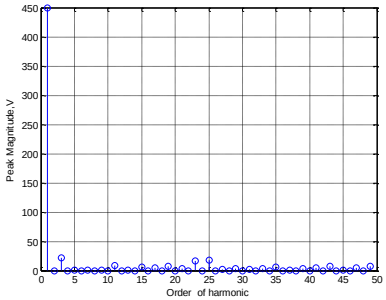

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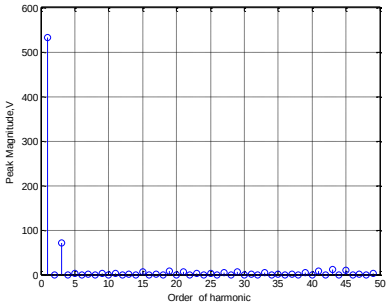

Fig. 6 FFT of Output Voltage Waveform of Various MI.

V. CONCLUSION

The proposed algorithm is very effective, efficient and reliable in finding solutions to high order non linear equations. This algorithm solve the non linear transcendent equations with a much simpler formulations. Also it can be used for any number of voltage levels without complex analytical calculations.

Computer simulations based on 11-level cascade H-bridge inverter can gives us the verification of validity of the proposed algorithm.

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