Mitigation Of Harmonics In Cascade Multilevel Inverter Using Genetic Algorithm

Amrita Tuteja [1] & Dr. Amita Mahor[2]
[1]*P.G. Scholar, NIIST, Bhopal (M.P.), India*
[2] *H.O.D. Electrical & Electronics Department, NIIST, Bhopal (M.P.)*

ABSTRACT

One of the major problems in electric power quality is the Harmonic contents. This paper focuses on the elimination of harmonics . In this paper , a Genetic Algorithm (GA) optimization technique is applied to multilevel inverter to determine optimum switching angles for cascaded multilevel inverter for eliminating some higher order harmonics while maintaining the required fundamental voltage. Switching angles are generated for different values of modulation index by proposed algorithm, considering minimum voltage total harmonic distortion (THD) whereas selected harmonics are controlled within the allowable limits.

Keywords: Cascaded multilevel inverter, Genetic Algorithm (GA), Multilevel Inverter, Total Harmonic Distortion (THD).

INTRODUCTION

In recent years , Multilevel voltage source inverters have received more and more importance and attention in industrial applications such as static power converter for high power application , FACTS devices , HVDC & as electric drives for all ac motors when dc supply is used. In multilevel inverters, the desired output voltage is achieved by suitable combination of multiple low dc voltage sources used at the input side. As the number of dc sources is increased, the output voltage becomes closer to a pure sinusoidal waveform. The required dc voltage can be chosen from different sources such as photovoltaic, batteries, fuel cells, capacitors, the rectified output voltage of wind turbines, and other similar dc voltage sources [1-3]. Some of the fundamental multilevel topologies include the cascaded H-bridge structures [4], flying capacitor [5], and diode-clamped converter [6]. . Among these three topologies, cascaded multilevel converter has got more attention in literatures [9-10]. This paper particularly focuses on Cascaded multilevel converters. This topology is divided into two symmetrical and asymmetrical structures. If all dc voltage sources are equal, the inverter is then known as symmetrical multilevel inverter, otherwise it is known as asymmetrical multilevel inverter. The output waveforms of multilevel inverters are in a stepped form therefore they have reduced harmonics compared to a square wave inverter. To reduce the harmonics further, different multilevel sinusoidal PWM and space-vector PWM schemes are suggested in the literature [11-12] however, PWM techniques increase the control complexity and the switching frequency. Another approach to reduce the harmonics is to calculate the switching angles in order to eliminate certain order harmonics. In this paper GA is used to solve this problem. The optimal switching angles are generated, selective harmonic are eliminated and consequently THD of output voltage is minimized.

MULTILEVEL INVERTER CONFIGURATION

A cascaded multilevel inverter consists of several single-phase full bridge inverters connected in series. The function of this multilevel inverter is to synthesise desired ac output voltage from several dc sources connected to the individual inverter units. Fig. 1 shows a single-phase structure of a cascaded multilevel inverter. Each individual inverter is capable of generating three different voltage output +Vdc, 0 and -Vdc by connecting the dc source to the ac output side by different combinations of the four switches, S1, S2, S3 and S4. The synthesised ac output voltage waveform is the sum of all the individual inverter outputs. The number of output-phase voltage levels of the cascaded multilevel inverter is 2S + 1, where S is the number of dc sources. A typical output voltage waveform of an 11-level cascade multilevel inverter with five dc sources is shown in Fig. 2.

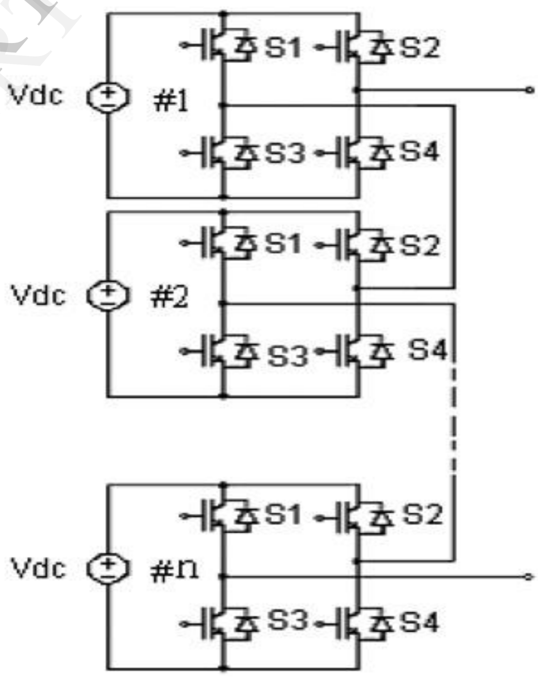

Figure 1 Single-phase configuration of a multilevel inverter

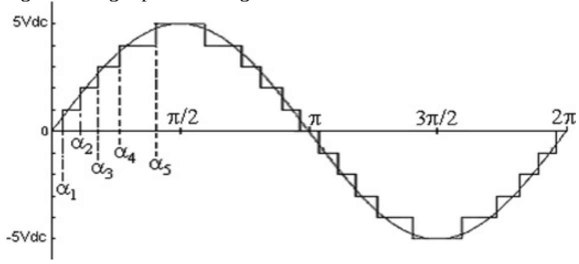

Figure 2 Output voltage waveform of an 11-level multilevel inverter

PROBLEM FORMULATION

The output voltage waveform V(t) of the multilevel inverter as shown in Fig. 2 can be expressed in Fourier series as

$$V(t) = \sum_{n=1}^{\infty} (a_n \sin n\alpha_n + b_n \cos n\alpha_n) \qquad (1)$$

Owing to quarter wave symmetry of the output voltage, the even harmonics are absent (bn =0) and only odd harmonics are present [13]. The amplitude of the nth harmonic an is expressed only with the first quadrant switching angles α1, α2, . . . , αm

$$a_n = (4V_{dc}/n\pi) \sum_{k=1}^{m} \cos(n\,\alpha_k) \qquad (2)$$

and

$$0<\alpha_1<\alpha_2<\ldots<\alpha_m<(\pi/2) \qquad (3)$$

For any odd harmonics, (2) can be expanded up to the k_{th} term, where m is the number of variables corresponding to switching angles α1 through α_m of the first quadrant.
In SHE, an is assigned the desired value for fundamental component and equated to zero for the harmonics to be eliminated [14]

$$a_1 = (4V_{dc}/\pi) \sum_{k=1}^{m} \cos\alpha_k = M$$

$$a_5 = (4V_{dc}/5\pi) \sum_{k=1}^{m} \cos 5\alpha_k = 0 \qquad (4)$$

$$a_n = (4V_{dc}/n\pi) \sum_{k=1}^{m} \cos n\alpha_k = 0$$

where M is the amplitude of the fundamental component.

Non-linear transcendental equations are thus formed and after solving these equations, α1 through α_k are computed. In this work the complexity of solving the non-linear equations is prevented by converting the selective harmonic elimination problem to an optimization problem as follow:
The %THD of the output voltage can be expressed by:

$$\%\,THD = \left[\frac{1}{(\alpha 1)2} \sum_{n=5}^{\infty} (a_n)^2\right]^{1/2} \times 100$$

Where n=6i+1 (i=1,2,3…).

Voltage THD is considered as the fitness function F(α), that must be minimized with the constraints of selective harmonic elimination to reduce the overall THD in the output voltage waveform.

GENETIC ALGORITHM

The GA is a stochastic global search method that mimics the metaphor of natural biological evolution. GAs operates on a population of potential solutions applying the principle of survival of the fittest to produce (hopefully) better and better approximations to a solution. At each generation, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from, just as in natural adaptation.

It imitates biological evolution by using genetic operators like reproduction, Crossover, mutation etc. To minimize a function, *f (x l , x 2 .....x k)* using GA**,** first, each *xi* is coded as a binary or floating-point string of length m**.** In this paper, a binary string is preferred, e.g.

X_1 = [10001…01001]
X_2 = [01010 ... 01110] (1)
. . . .
X_k= [01110 ... 01000]

The set of *{x1*. x2, ... *xk}* is called a *chromosome* and x, are called *genes.* The algorithm works as follows:

B. Initialize population:

Set a population size, N, i.e. the number of chromosomes in a population. Then initialize the chromosome values randomly. If known, the range of the genes should be considered for initialization. The narrower the range, the faster GA converges.

C. Evaluate each chromosome:

Use a cost function specific to the problem at hand to evaluate the fitness value (FV) of each chromosome

$$FV = \frac{1}{f(x1,x2,....xk)} \text{ or}$$

$$FV = -f(x1,x2....xk) \qquad (2)$$

Add all the FVs to get the total fitness. Divide each FV by the total FV and find the Weigh/probability of selection, p_i, for each chromosome. The integer part of the product, p_i N gives the number of descendents (offspring) from each chromosome. At the end, there should be N descendent chromosomes. If the number of descendents calculated is less then N, the rest of the descendents are found randomly considering the reproduction probabilities, p_i, of each chromosome.

D.Crossover Operation:

A floating number (between 0 and 1) for each Chromosome is assigned randomly. If this number is smaller than a pre-selected crossover probability**,** this chromosome goes into crossover**.** The chromosomes undergoing crossover are paired randomly. In this case assume x_1 and x_2 are paired. The crossing point is randomly selected, assume 3 in this case.
Then, before crossover
X_1= [11001….10111]
X_2= [01010….10100] (3)

And after crossover,

X_1= [11001….10100]
X_2= [01010….10111] (4)
As seen above, the bits after the 3rd one are exchanged.

E. Mutation Operation:

A floating number (between 0 and 1) for each bit is assigned randomly. If this number is smaller than a preselected mutation probability**,** this bit mutates. Assume that the 2nd and 4^{th} bits of X_1 and 2nd, 3rd and 5th bits of X_2 need to be mutated.
Then, before mutation and after crossover,
X_1= [11001….10111]
X_2= [01010….10100] (5)

and after mutation,
X_1= [10011….10111]
X_2 = [00111….10100] (6)

Finally, the new population is ready for another cycle of Genetic algorithm. The algorithm runs a certain number of times as required by the user. At the end, the chromosome with the maximum FV is the answer.

RESULTS

To validate the computational results for switching angles, a simulation is carried out in MATLAB/SIMULINK software for an 5-level cascaded H-bridge inverter and unequal dc sources. The nominal dc voltage is considered to be 100 V, and the values of K_1 and K_2 are 1.05 and 0.88 respectively. For the 5-level inverter, the optimum value of switching angles, which minimize the harmonics for different iterations are shown below:

Table 1. Minimum THD at optimal value of switching angle

No. of Iterations	Switching Angles in radians		THD(%)
	α_1	α_2	
50	0.3546	0.5573	0.3858
100	0.3800	0.6080	1.2513
150	0.5573	0.2026	1.0259

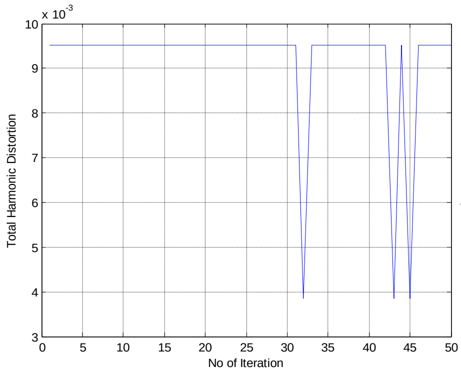

Figure 3 Convergence characteristics for switching angle α_1 =0.3546 & α_2 = 0.5573

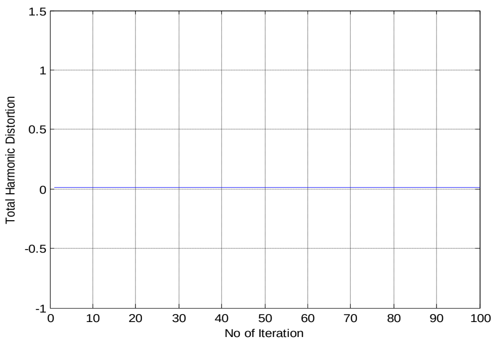

Figure 4 Convergence characteristics for switching angle α_1 =0.3800 & α_2 = 0.6587

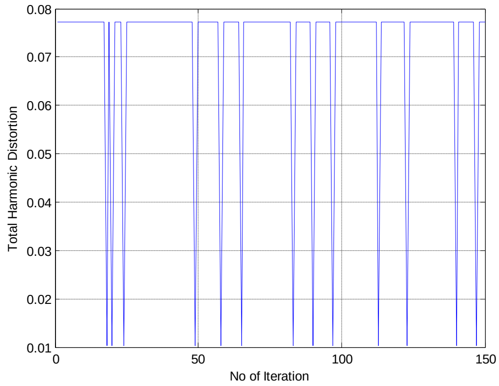

Figure 5 Convergence characteristics for switching angle α_1 =0.5573 & α_2 = 0.2026

Figure 6 shows the output waveform for 5 –level inverter for the optimal value of switching angle. The optimal value of switching angle at which the method gives minimum THD are α_1 =0.3546 & α_2 = 0.5573

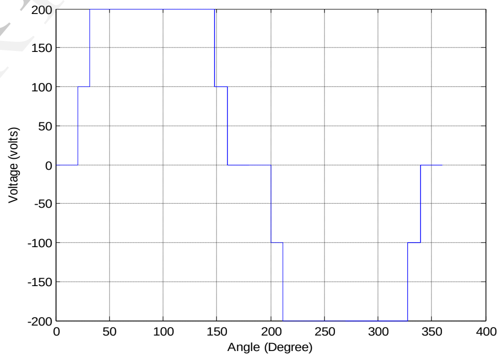

Figure 6 Output Waveform of 5- level inverter

CONCLUSION

In this paper a method based on GA was applied to eliminate selected order of harmonics and to reduce output voltage THD. Besides controlling individual selected harmonics within the allowable limits, the method also optimizes the other order of harmonics to minimize the overall voltage THD. In comparison with other suggested methods, the proposed technique has many advantages such as: it can produce all possible solution sets for any numbers of multilevel inverter without much computational burden, speed of convergence is fast, it can produce continuous solutions for the complete range of modulation index thereby giving more flexibility in control action etc. The effectiveness of applied method has been verified through simulation and the results were presented. The results show that the proposed method effectively minimizes a large number of specific harmonics, and the output voltage results in very low THD.

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