Selective Harmonic Minimization method For Cascaded Multilevel Inverters using ANNs

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ABSTRACT-The dc sources that feed the multilevel inverter are varying in time, and the switching angles should adapt to the dc source variations. Any variations in the input will result in harmonics at the output. To mitigate the harmonics in the inverter output, GA is used. A genetic algorithm optimization technique is applied to determine the switching angles for a cascaded multilevel inverter. Then, artificial neural networks are used to determine the switching angles for real time application. This eliminates specified order harmonics while maintaining the required fundamental output constant

Keywords - ANN, cascaded multilevel inverter, GA, neural network, real time, selective harmonic minimization, THD.

I. INTRODUCTION

MULTILEVEL inverters have drawn attention in recent years, especially in the distributed energy generation, because fuel cells, solar cells, wind turbines or micro turbines, batteries can be connected to feed the load or interconnect to the AC grid through multilevel inverters without any voltage fluctuations [1]. Multilevel inverters have a lower switching frequency and thus have reduced switching losses.

The output of multilevel inverter is in stepped form resulting in presence of harmonics. To reduce the harmonics different PWM schemes are suggested in the literature [2], [3]. But, PWM techniques increase the control complexity and the switching frequency. Another method to reduce the harmonics is by calculating the switching angles in order to eliminate certain order harmonics in the waveform [4]. Chiasson et al. [8] used the mathematical theory of resultants to calculate the optimum switching angles. But these expressions were high order polynomials that could not be solved when the number of levels is more.

In [10], analytical solutions for unequal dc sources have been obtained, and in [11], algorithms to solve for the angles have been derived. Particle swarm optimization is applied in [7] to reduce selective harmonics. All of these papers use intensive time-consuming equations to solve for the angles. Thus, the switching angle needs to be calculated offline.

Liu et al. [13] have developed methods to calculate the switching angles in real time but, their approach was not extended for unequal dc sources.

An alternate approach to find the optimum switching angles in real time for varying dc sources is to calculate the switching angle offline using GA particle swarm optimization and storing the results in a lookup table. As the number of levels increases, the dimensionality and computational requirements increases. The solutions in the look up table can be used to train the ANN [14]. The target harmonics can also have an impact on the training of ANN.

In this paper, the target harmonics for minimization are the 5th, 7th, 11th, and 13th.

This paper is organized as follows. In Section II, the multilevel inverters are explained. In Section III the problem is being described. In Section IV the set of equation for harmonic elimination is used to form the look up table using GAs. In Section V, the ANN-based control is explained, and in Section VI, experimental results are presented. Conclusions and final remarks are made in Section VII.

II. CASCADED MULTILEVEL INVERTERS

1 (a)

The cascaded inverter shown Fig. 1 (a) has many advantages such as circuit layout flexibility, additional stages can be easily added [5]. Here, five stages of H Bridge is used. The AC output comprises of stepped waveform with different switching angles as shown in Fig. 1 (b). The switching angles are considered to variables and should be determined by using GA.

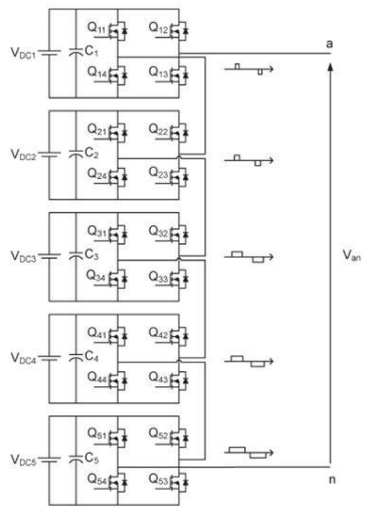


Fig. 1. Cascaded inverter: (a) topology and (b) output waveform

III. PROBLEM DEFINTION

The demand for energy is increasing as a result there is increase in demand for Renewable Energy Sources (RES) such as solar cells, fuel cells and wind mills. Interfacing of RES in distributed generation and grid suffers voltage variations. This problem can be handled by adding converters [6]. Another approach to reduce voltage variations is by the use of switching frequency devices in inverters.

For example, the wind mill output will vary in accordance with the wind speed. Due to voltage fluctuations in wind speed, the fundamental output will not remain constant. The varying output results in harmonics. If the power converters alter the switching angles in accordance with wind speed, the output will be constant and harmonics are reduced.

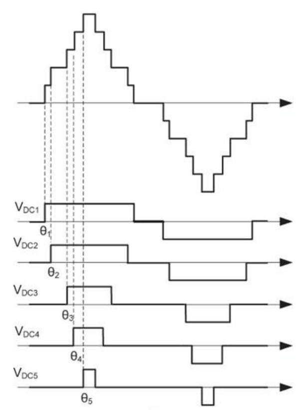
The proposed methodology has two steps. First, the switching angles are calculated offline for predetermined input values through GA. Then, the GA is used to train the ANN for real time calculation of switching angles.

IV. GENETIC ALGORITHMS

The genetic algorithm (GA) is based on natural evolution and populations. GA is a population-based search method. The evaluation function represents a heuristic estimation of solution quality and the search process is driven by the variation and the selection operator. GA provides a general approach for searching for global minima or maxima within a bounded, quantized search space. Since GA only requires a way to evaluate the performance of its solution guesses without any a prior information, they can be applied generally to nearly any optimization problem [9]. The GA is composed of a fitness function, a selection technique, and crossover and mutation operators which are governed by fixed probabilities.

The optimum result is the end product containing the best elements of previous generations where the attributes of a stronger individual tend to be carried forward into the following generation. The GA iteration algorithm explores the search space using information from the points it has to bias the search towards the optimal point.

In a practical cases, in a multilevel inverter, all the dc sources vary to some degree. This variation can be due to the state of charge in a battery or fuel cell system, or it can be a function of solar irradiation in PV cells. In this way, it is necessary to monitor and control the switching angles to keep the desired output voltage characteristics. Under variations in the dc input sources, it is desired to maintain the fundamental output voltage. In applications for three phase machines, there is no need to cancel the harmonics that are a multiple of three because it is canceled in the line voltage. The set of equations for the GA is



1 (b)

$$V_{fund}=\frac{4}{\Pi}(V_{dc1}\cos(\theta_1)+V_{dc2}\cos(\theta_2)+\ldots+V_{dc5}\cos(\theta_5)) \quad (1)$$

$$V_{5th}=\frac{4}{\Pi.5}(V_{dc1}\cos(5\theta_1)+V_{dc2}\cos(5\theta_2)+\ldots+V_{dc5}\cos(5\theta_5)) \quad (2)$$

$$V_{7th}=\frac{4}{\Pi.7}(V_{dc1}\cos(7\theta_1)+V_{dc2}\cos(7\theta_2)+\ldots+V_{dc5}\cos(7\theta_5)) \quad (3)$$

$$V_{11th}=\frac{4}{\Pi.11}(V_{dc1}\cos(11\theta_1)+V_{dc2}\cos(11\theta_2)+\ldots+V_{dc5}\cos(11\theta_5)) \quad (4)$$

$$V_{13th}=\frac{4}{\Pi.13}(V_{dc1}\cos(13\theta_1)+V_{dc2}\cos(13\theta_2)+\ldots+V_{dc5}\cos(13\theta_5)) \quad (5)$$

The data set of angles to control the multilevel inverter for each different value of the dc sources using (1)-(5) was programmed with GA.

The equations (2)–(5) are set to be zero (no low-order harmonics). To solve (2)–(5) using GA, it is necessary to provide the real dc source values and the desired output voltage. The output voltage is set to 110 Vac, the data set is solved based on the different source value provided. After measuring the real values of the dc sources, a set of angles is found so that the output voltage is kept constant and the 5th, the 7th, the 11th, and the 13th harmonics are eliminated. A fitness function for the GA that evaluates each individual in the population was defined as follows:

$$f(V_{fund},V_{5th},V_{7th},V_{11th})=k_1|V_{fund}-110|+k_2|V_{5th}|+k_3|V_{7th}|+k_4|V_{11th}|+k_3|V_{13th}| \quad (6)$$

In (6), the coefficients k2 to k5 need to have higher value than k1, usually ten times greater for unbiased optimization. That procedure requires trial and error until a good balance is found. For this paper, k1 = 10 and k2 = k3 = k4 = k5 = 100.

The solution of the fitness function by GA requires 5input voltages to be varied for all its range. This is a trial and error problem since there is no previous information about the input voltages. For analysis the input dc voltage is varied between 24 to 40V.

V. ANN

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information [16]. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements working in unison to solve specific problems. ANNs are generally time consuming to train but fast to run and can be easily parallelized once it is accordingly trained. Comparatively, lookup tables increase exponentially as the number of dc sources increases and it needs to deal with extrapolation leading to time-consuming algorithms and analytical approaches have to deal with the computational time required for the task.

The ANN topology proposed is shown in Fig. 2. It is a feedforward ANN with a tangent-sigmoid function activation hidden layer and a linear activation function output layer. This ANN takes the real dc source values and gives the switching angles for the control system.

The main reason for using ANN is to learn from the given data. Performance is evaluated during training as shown in Fig. 6. In this figure, for each topology, a number of training sessions are done and shown in this picture as the average value.

VI. SIMULATION RESULTS

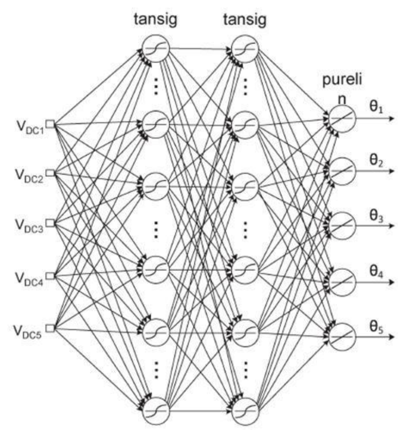


Fig. 2. Feedforward ANN topology

In Fig. 3, the experimental results for an 11-level inverter operating with unequal dc sources are shown with the voltage values indicated. In Fig. 4, the frequency with a THD of 16.27%. In this same figure, a high value of the third and ninth harmonics can be noticed; those harmonics were not minimized due to the fact that they will be canceled in line voltage for a three-phase application.

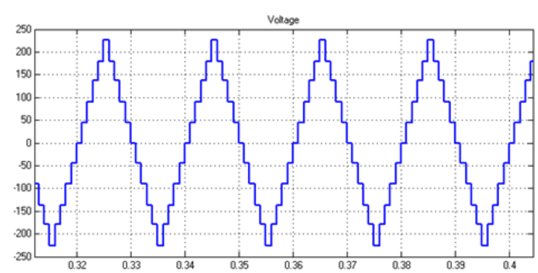


Fig.3. Multilevel inverter line output voltage waveform.

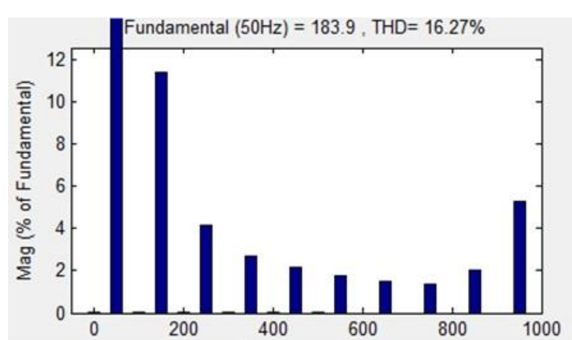


Fig.4. Output voltage frequency spectrum for Fig. 3

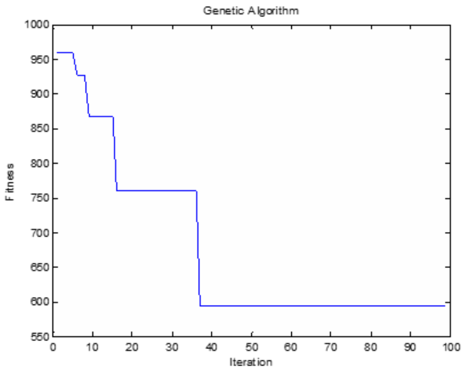


Fig.5. GA optimization

The output voltage as a function of dc source input variation and quality of solutions measured by GA‘s fitness value. The typical GA fitness curve for 100 iterations is shown in Fig. 5.The minimum value of fitness function is obtained after nearly 40 iterations. For the same values of dc sources, during real time operation the ANN takes only 4 iterations as shown in Fig. 6.

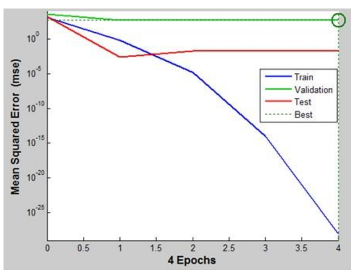


Fig.6. ANN performance results

The THD analysis of the output voltage after optimization is shown in Fig. 7. The THD obtained is less than 5%. Thereby improving the performance of the entire system.

Fig. 7. THD value after optimization

VII. CONCLUSION

A new method for real-time computation of switching angles using ANNs has been presented. The solutions were found offline using GAs to obtain the look up table for use during the training process of the neural network. The trained neural network is used then for online real-time determination of the angles. Experimental results were shown to validate this approach.

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