Artificial Neural Network Based Optimized Harmonic Stepped Waveform Technique for Cascaded H-Bridge Eleven Level Inverter

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Abstract: This research paper proposes an Optimized Harmonic Stepped Waveform (OHSW) technique based on an artificial neural network to control a single phase cascaded H-bridge eleven level inverter. By applying this OHSW technique, specific harmonics can be eliminated and the output voltage total harmonic distortion can be improved on a cascaded h-bridge eleven level inverter with separate dc sources. A procedure to achieve the appropriate switching angles of the OHSW is also proposed. This method uses artificial neural networks to determine the switching angles for different dc source values at any time and the simulation results show that it efficiently canceling the harmonics generated by the inverters and demonstrates a satisfying behavior.

Key words: Multilevel inverter, cascaded H-bridge multilevel inverter, total harmonic distortion, eleven level inverter, optimized harmonic stepped waveform technique, artificial neural network

INTRODUCTION

A multilevel inverter is a power electronic system that synthesizes a desired output voltage from several levels of dc voltages as inputs. With an increasing number of dc voltage sources, the inverter output voltage waveform approaches a nearly sinusoidal waveform while using a fundamental frequency-switching scheme. The primary advantage of multi level inverter is their small output voltage, results in higher output quality, lower harmonic component, better electromagnetic computability and lower switching losses (Chiasson *et al.*, 2004; Rodriguez *et al.*, 2002).

Multilevel inverters also have interest in the field of high-voltage high-power applications such as laminators, mills, conveyors, compressors and UPS Systems. Some of the fundamental multilevel topologies include the diode clamped (Marchesoni *et al.*, 1988), flying capacitor (Meynard and Foch, 1992) and cascaded H-bridge structures (Nabae *et al.*, 1981). The most familiar power circuit topology for multilevel converters is based on the cascade connection of an s number of single-phase full-bridge inverters to generate a (2s+1) number of levels. The key issue in designing an effective multilevel inverter is to ensure that the Total Harmonic Distortion (THD) of the output voltage waveform is within acceptable limits. To control the output voltage and to eliminate the undesired harmonics in multilevel converters various modulation methods such as sinusoidal Pulse Width Modulation (PWM), selective harmonic elimination and space-vector PWM techniques are suggested (Holmes and Lipo, 2003; Kouro *et al.*, 2007; Patel and Hoft, 1973, 1974; Fei *et al.*, 2010; Enjeti *et al.*, 1990).

Among modulation techniques being used these days, optimized harmonic stepped-waveform technique is suitable for multilevel inverter topologies. By employing this technique along with the multilevel topology, a low THD output waveform without any filter circuit is possible. Besides, switching devices switch only one time per each cycle. That can improve the switching loss problem as well as EMI problem.

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. In this study, the neural approach is developed to deal with the OHSW technique to find proper switching angles to minimize the total harmonic distortion in multilevel voltage waveform. Simulation results are provided for a 11-level cascaded H-bridge multilevel inverter to show the validity of the proposed method.

CASCADED H-BRIDGE ELEVEN LEVEL INVERTER

The cascaded multi-level inverter circuit provides high quality output when the number of levels in the output increases and also this reduces the filter components size and cost. Figure 1 shows the schematic of a single-phase cascaded eleven level inverter. Five identical inverter modules are connected in series to form a single-phase 11-level inverter. All modules are fed by DC voltage sources of the same magnitude. The output voltage has 11 voltage levels from -5 dc to +5 Vdc. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage

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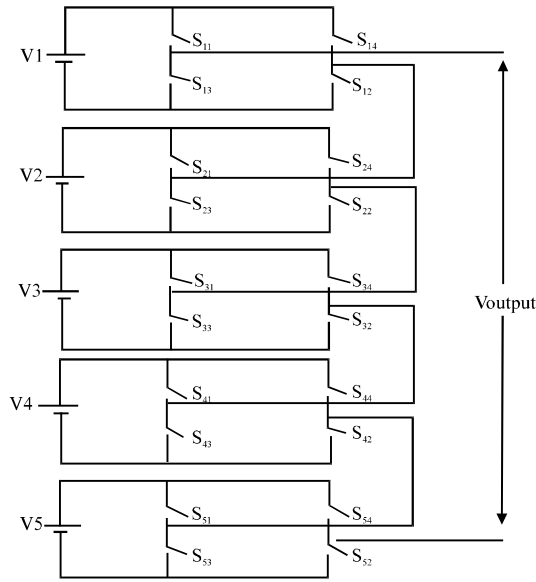
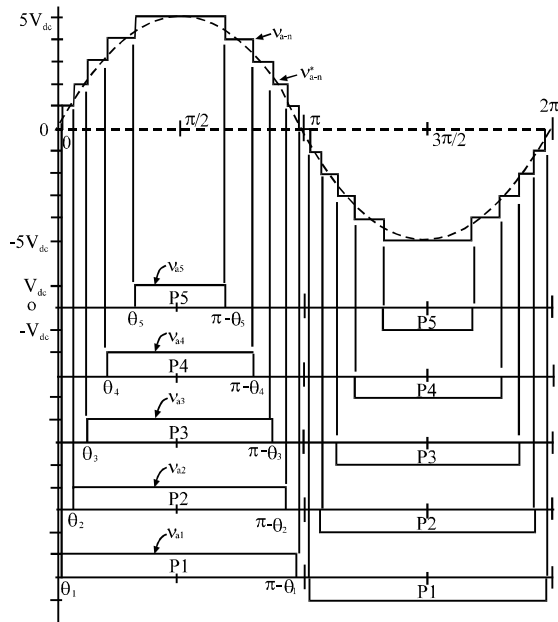Fig. 1: Schematic of a single-phase cascaded eleven level inverter

Fig. 2: Output voltage waveform of an eleven level cascaded inverter

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.

Output voltage waveform for an eleven level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Fig. 2. The phase voltage van = va1+va2+va3+va4+va5.
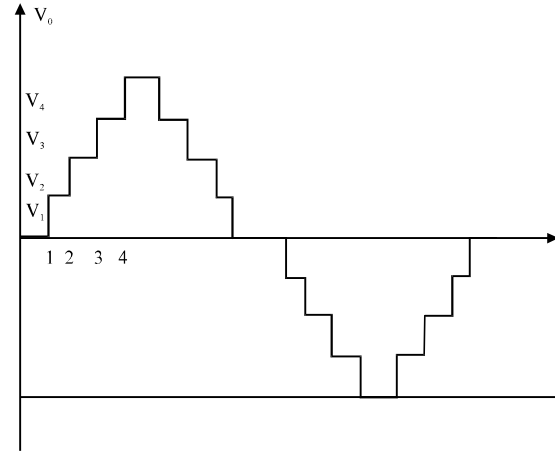

Fig. 3: Eleven-level OHSW output waveform

OPTIMIZED HARMONIC STEPPED WAVEFORM TECHNIQUE

The optimized harmonic stepped-waveform technique is very suitable for a multilevel inverter circuit. By employing this technique along with the multilevel topology, the low THD output waveform without any filter circuit is possible. Switching devices, in addition, turn on and off only one time per cycle. That can overcome the switching loss problem as well as EMI problem. Figure 3 shows a general quarter symmetric 11-level OHSW waveform.

Here, V_1-V_4 are dc voltage supplies which are from either regulated capacitors or separated dc sources. Consider the waveform, there are three possible optimization techniques for reducing the low-order harmonics: step heights are optimized with equally spaced steps; step spaces are optimized with the steps of equal height and optimizing both heights and spaces. In the fixed-input scheme, the second optimization technique is more feasible than the other two techniques (Hamman *et al.*, 1988; Carrara *et al.*, 1992; Pitel *et al.*, 1980). In this study, therefore, the second optimization technique will be proposed.

With the equal amplitude of all dc sources, the expression of the amplitude of the fundamental and all harmonic contents are given as:

$$H_n(a) = \begin{cases} \dfrac{4E^m}{np_k}\cos(na_k) & \text{for odd n} \\ 1 & \text{for even n} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

Where:
E = dc voltage supply
m = The number of dc sources
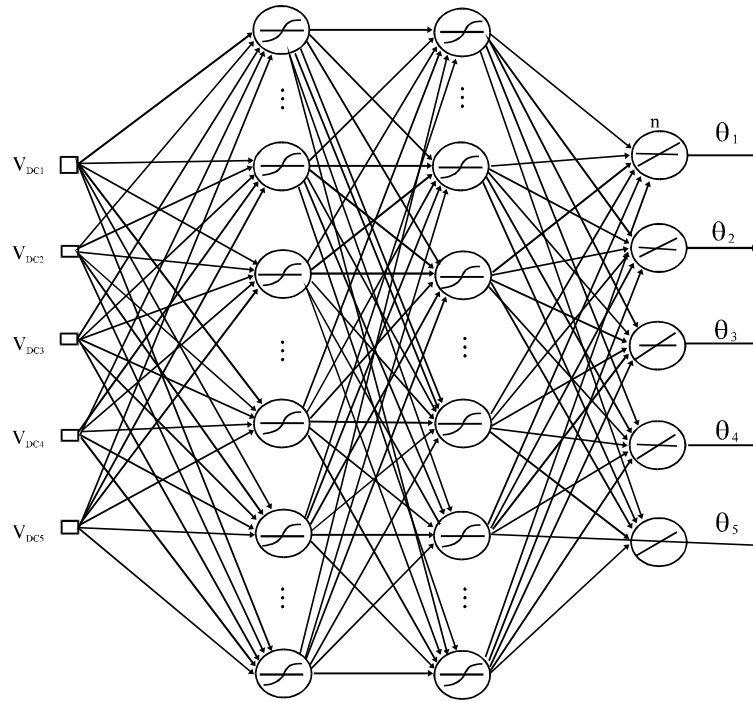a_k = The optimized harmonic switching angles

Fig. 4: Feed forward ANN topology for five dc sources

Basically, the low-order surplus harmonics needed to be eliminated. Equation 1 shows that M-1 odd harmonics (3rd, 5th, ...) and M-1 non-triplen odd harmonics (5th, 7th, ...) can be eliminated from single-phase output waveform and three-phase output.

ARTIFICIAL NEURAL APPROACH

ANNs are computational models that were inspired by the biological neurons. It has a series of nodes with interconnections where mathematical functions are applied to do an Input/Output (I/O) mapping. An important feature of an ANN that made it suitable for this problem is its flexibility to lead in its domain and outside it as well as work with the nonlinear nature of the problem (Bose, 2007; Jain *et al.*, 1996; Haykin, 1998; Hassoun, 1995; Huang and Tan, 2012). ANNs are generally time consuming to train but fast to run and can be easily parallelized once it is accordingly trained. The proposed ANN topology is shown in Fig. 4. In an 11-level cascade inverter, the data set to be used for the ANN for training consists of five input voltages that are related to five output switching angles (Filho *et al.*, 2013).

It is a feed forward ANN with a tangent-sigmoid function activation hidden layer and a linear activation function output layer. Different feed forward topologies were taken under different training methods to investigate which one fits for this application. This ANN takes the real dc source values and gives the switching angles for the control system. The 11-level output waveform simulation using the feed forward trained ANN is shown for a random value chosen for the dc input voltages. This ANN updates the angles during each cycle of the fundamental frequency.

SIMULATION RESULTS

To validate the computational results for switching angles, a simulation is carried out in MATLAB/SIMULINK Software for a 11-level cascaded H-bridge inverter shown in Fig. 5. This method uses the initial guess values and the objective function, to get the optimum values of switching angles and total harmonic distortion at the same time. The DC source for each H-bridge unit is considered to be 65 V. Figure 6 and 7 shows the output voltage and output current waveform. Figure 8 shows the generated gate pulses using optimized harmonic stepped waveform technique to the multilevel inverter switches. From the gate pulse turn on period it is observed that each switches turned on at different time period to synthesize required output voltage. The frequency spectrum of the output voltage is shown in Fig. 9 for a cycle of the fundamental frequency. It can be seen that the 5th, 7th, 9th, 11th and 13th harmonics are greatly minimized using the angles provided by the ANN. The simulated value of THD is 21.92%.
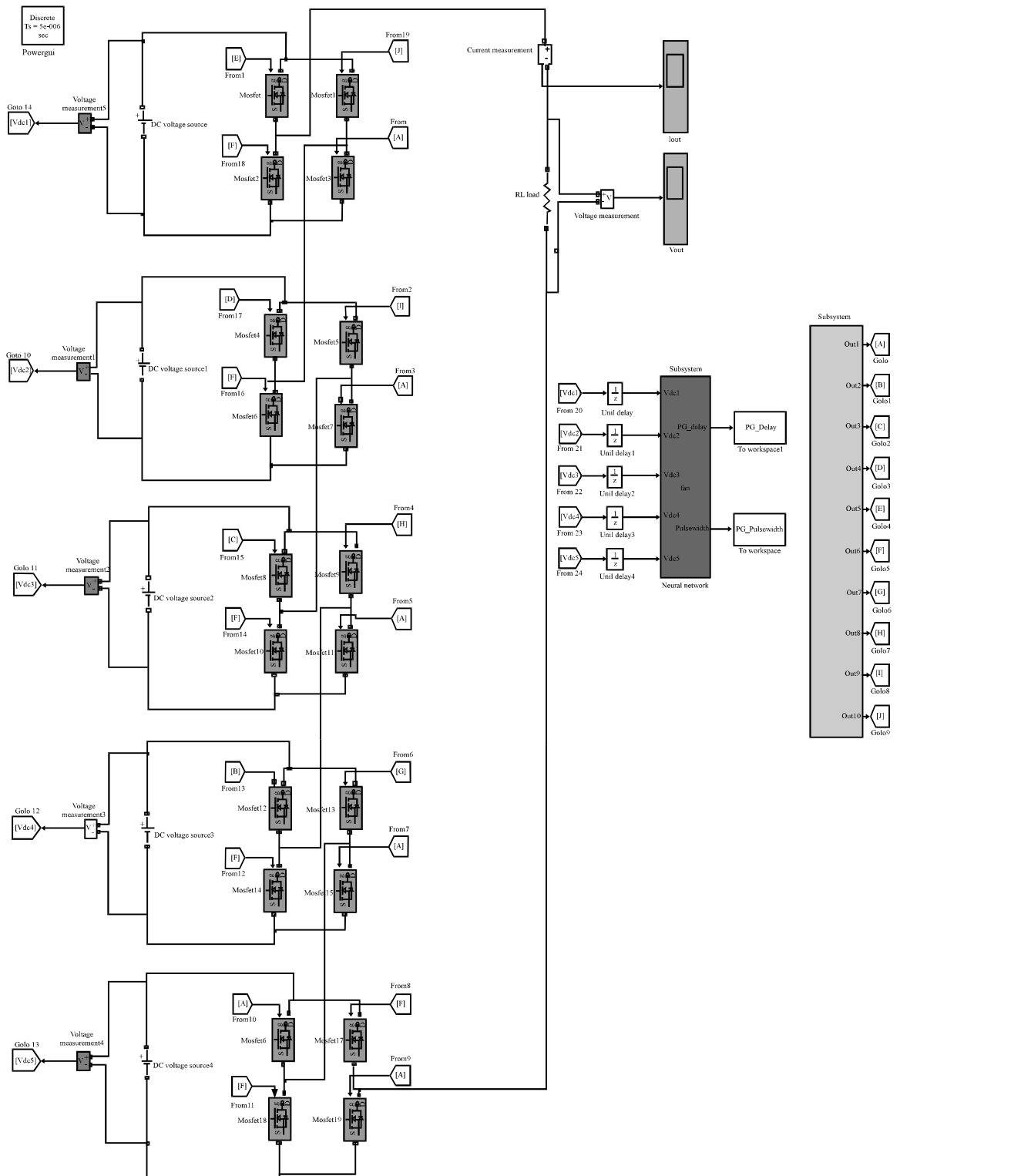
Fig. 5: Simulink model of eleven level inverter (closed loop)

From the above simulated it is observed that the desired low order harmonics are eliminated efficiently and eventually the Total Harmonic Distortion (THD) of the output voltage is improved better than the traditional
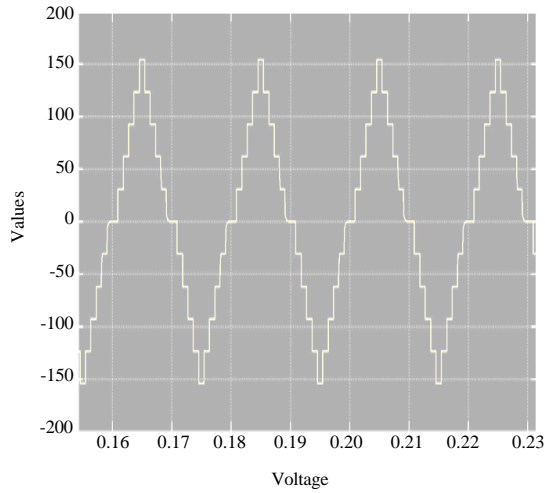
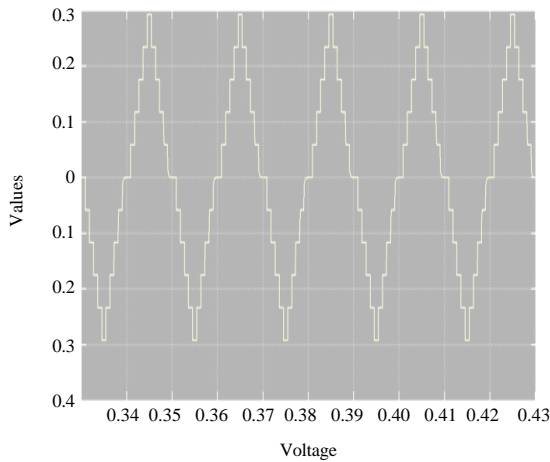Fig. 6: Output voltage waveform
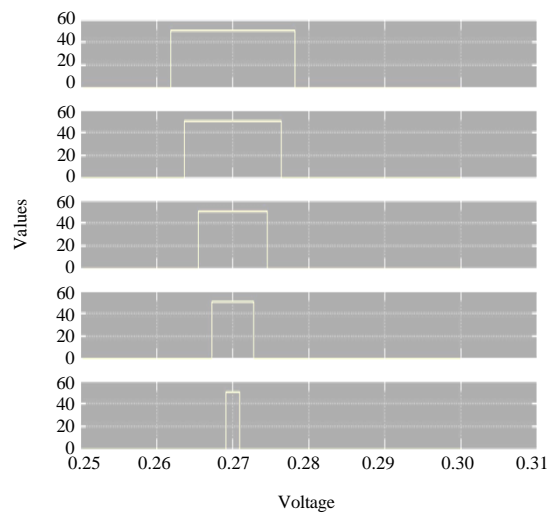

Fig. 7: Output current waveform
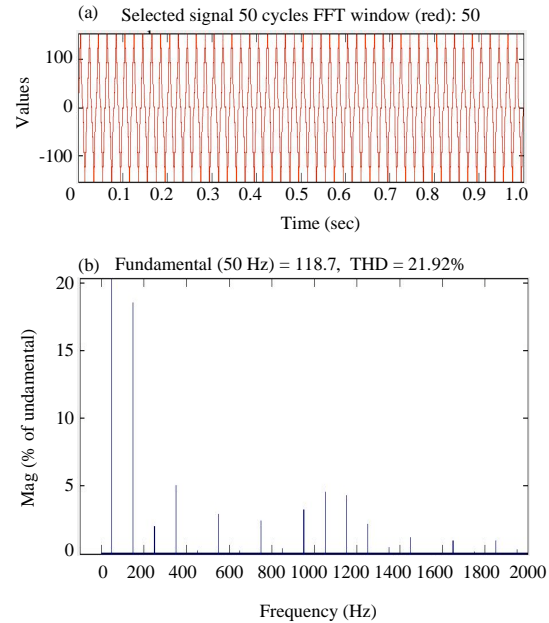

Fig. 8: Gating pulses

Fig. 9: Output voltage frequency spectrum

switching schemes and hence the efficiency of the system will be improved. Therefore, the proficiency of the proposed switching scheme using artificial neural approach is shown to be better than the conventional switching scheme.

CONCLUSION

In this study, a new concept of the Optimized Harmonic Stepped-Waveform (OHSW), one of the multilevel modulation techniques has been presented. The 5th, 7th, 9th, 11th and 13th harmonics are greatly minimized using the angles provided by the artificial neural network. Simulation results also show that the line voltage THD of the OHSW can be reduced by increasing the number of the switching angles. The total harmonics distortion is reduced to 21.92% and staircase voltage waveform is obtained which is much closer to sinusoidal waveform. The results prove that the artificial neural approach converges successfully to the global solution faster than other algorithms.

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