

## Artificial Intelligence Technique to Real-Time Based on Selective Harmonic Elimination in Modified Multilevel Inverter

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**Abstract:** In this study, Artificial Intelligence (AI) technique is applied to determine the switching angles for a uniform step asymmetrical modified multilevel inverter by eliminating specified higher-order harmonics while maintaining the required fundamental voltage and current waveform. Artificial intelligence technique based on Selective Harmonic Elimination (SHE) method in a modified multilevel inverter has been proposed in this study. The Selective Harmonic Elimination Pulse-Width Modulation (SHE-PWM) is a powerful technique for harmonic minimization in multilevel inverter. The proposed a five-level Modified Cascaded H-Bridge Multilevel Inverter (M-CHBMLI) with Artificial Neural Network (ANN) controller to improve the output voltage and current performance and achieve a lower Total Harmonic Distortion (THD). The main aims of this study cover design, modeling, prediction for real-time generation of optimal switching angles in five level modified topology of the CHB-MLI for a single-phase. Real-time application of Selective Harmonic Elimination-Pulse Width Modulation (SHE-PWM) technique is limited due to the heavy computational cost involved in solving aspecified number of transcendental nonlinear equations known as Selective Harmonic Elimination (SHE) equations that contain trigonometric functions. Simulation of a 5-level inverter in MATLAB/Simulink reveals that the proposed method is highly efficient for harmonic reduction in modified multilevel inverter.

**Key words:** Harmonics, artificial intelligence, modified multilevel inverters, five level, fundamental voltage, modulation

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### INTRODUCTION

With the advent of fast switching semiconductor devices with high power handling capability real-time multilevel power conversion has become a rapidly growing area of power electronics with good potential for further development. In multilevel inverter can be generate AC voltage based on DC source from PV, winding and battery application. The multilevel inverter has three advantage, converted DC to AC voltage, reduce Total Harmonic Distortion (THD) and less number of switches component (Rasheed *et al.*, 2019). In multilevel inverter have been three type of topologies clamped capacitor (DC) Flying Capacitor (FC) Cascaded H-Bridge (CHB) (Rasheed *et al.*, 2018). The structure of multilevel inverter for consist eight switching drive can be generated five level inverters. Therefore, increase number of switching PWM leads to increase output voltage level and then leads to high cost for circuit (Omar *et al.*, 2019). However, the multilevel inverter has limitation harmonic order in

7-level 3th, 5th by using optimization technique are PSO, NR and GA algorithms are present by Salleh *et al.* (2011). In nine level multilevel inverter with Phase Disposition (PD) PWM scheme can be generated waveform voltage and current based on Transistor Clamped H-Bridge multilevel inverter (TCHB) with DC supply equal 500 V signal frequency is 50 Hz, modulation index and carrier frequency 2000 Hz in this circuit done by simulation MATLAB for produce lower (THD) (Reddy *et al.*, 2010). The harmonic elimination technique applies to multilevel inverter of seven and eleven level for elimination 3rd, 5th and 3rd, 5th and 7th, respectively have been explanation by Parkash *et al.* (2014). For optimization control have different type can be applied to multilevel inverter to optimized switching angle for capability of THD minimization. The optimization PSO and GA and HSA techniques have been used for computing switching angle via. solved non-liner transcendental equation drive from Selective Harmonic Elimination (SHE) for output voltage based on 7-level cascaded H-bridge multilevel

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inverter have been present by Colak and Kabalci (2013). The (SHE) considered low-frequency technique in order to elimination 3rd and 5th based on 7-level inverter with different Modulation Index (MI) equal to 0.65-1.0, the optimum harmonic reduction have been present by Xiao *et al.* (2012). PSO algorithm implementation for decrease THD of CHB-MLI compare five and seven level can be observe that THD for 7-level much better than 5-level inverter have been live in Subramanian and Rasheed (2013) and Demirdelen *et al.* (2017). According to the conventional circuit using in CHB-MLI consist eight switching PWM for produce five level inverter and then twelve switching PWM for generate seven level inverters (Bodo *et al.*, 2012 and Hosseini *et al.*, 2011). The iteration solved number of switching angle by non-linear equation was achieve by PSO technique. The optimization switching angle by PSO technique equal 3 angles based on 7-level inverter with reduce harmonic distortion 3rd and 5th odd has monic order. NR and PSO have been achieve by excremental and simulation result (Nedumgatt *et al.*, 2012). For improving the quality of the output voltage inverter for two types of MLI as symmetrical and asymmetrical, both types are very effective and efficient for multilevel inverter utilize reduced number of switching devices with Hybrid topologies for the conventional and non-conventional multilevel inverter topologies to create a specified number of output voltage levels in operating in higher voltage levels based on DC voltage supply (Ahmed *et al.*, 2010).

The research proposal of a five-level Modified Cascaded H-Bridge Multilevel Inverter (M-CHBMI) with Artificial Neural Network (ANN) controller has been improve the output voltage and current performance and achieve a lower Total Harmonic Distortion (THD). The ANN controller has been covered design, modeling, prediction for real-time generation of optimal switching angles in five level modified topology of the CHB-MLI for a single-phase. The study is design to simulate the 5-level M-CHBMI using MATLAB Simulink and to develop a proposed ANN controller algorithm for the 5-level CHBMI to achieve lower output voltage THD and improve the output voltage and current performance.

**MATERIALS AND METHODS**

**The modified of a CHB-MLIs**

**Five-level configuration:** The output voltage's of switching functions determine its harmonic components, thus, to some degree, reduction of harmonics is limited. Figure 1 shows the proposed single-phase five-level-

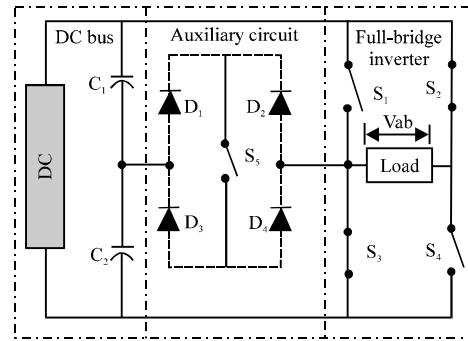


Fig. 1: Proposal modified of a CHB-MLI, single-phase five-level topology

Table 1: Output voltage for five level to the switche's on = 1-off = 0 condition

State	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	V <sub>o</sub>
A	1	0	0	1	0	Vdc
B	0	0	0	1	1	Vdc/2
C	0	0	1	1	0	0
D	1	1	0	0	0	0*
E	0	1	0	0	1	-Vdc/2
F	0	1	1	0	0	-Vdc

\* Significant value

inverter topology. As a solution, this work presents of switching pattern a five-level PWM inverter with output voltages zero, +1/2Vdc, Vdc, -1/2Vdc and -Vdc as shown in Fig. 2 based on Table 1. Increased number of output levels reduces harmonic content. It adopts a full-bridge configuration with an auxiliary circuit comprising four diodes and a switch and generates half-level of DC bus voltage. The block diagram of a modified CHB-MLIs with SC source based on controller ANN algorithm as shown in Fig. 3 and 4.

**Harmonic minimization problem:** The equations for 5-levels based on the are described below (Vijaykumar *et al.*, 2015; Rodriguez *et al.*, 2007 and Tipsuwanporn *et al.*, 2011):

$$f(t) = f_{\theta_1}(t) + f_{\theta_2}(t) \sum_{n=1,2,5}^{\infty} \frac{2V_{dc}}{n\pi} (V_{dc1} \cos(n\alpha_1) + V_{dc2} \cos(n\alpha_2)) \sin(n\omega t) \quad (1)$$

Where:

Vdc = Voltage of each voltage source that was in unity

θ<sub>1</sub> = The switching angles

From Eq. 1 and 2, four equations were resulted in eliminating the 5th harmonic:

$$V_{AN} = V_{dc1} \quad b_n = \frac{2V_{dc}}{\pi} \{ \cos(n\alpha_1) + \cos(n\alpha_2) \} \quad n = 1, 3, 2 \quad (2)$$

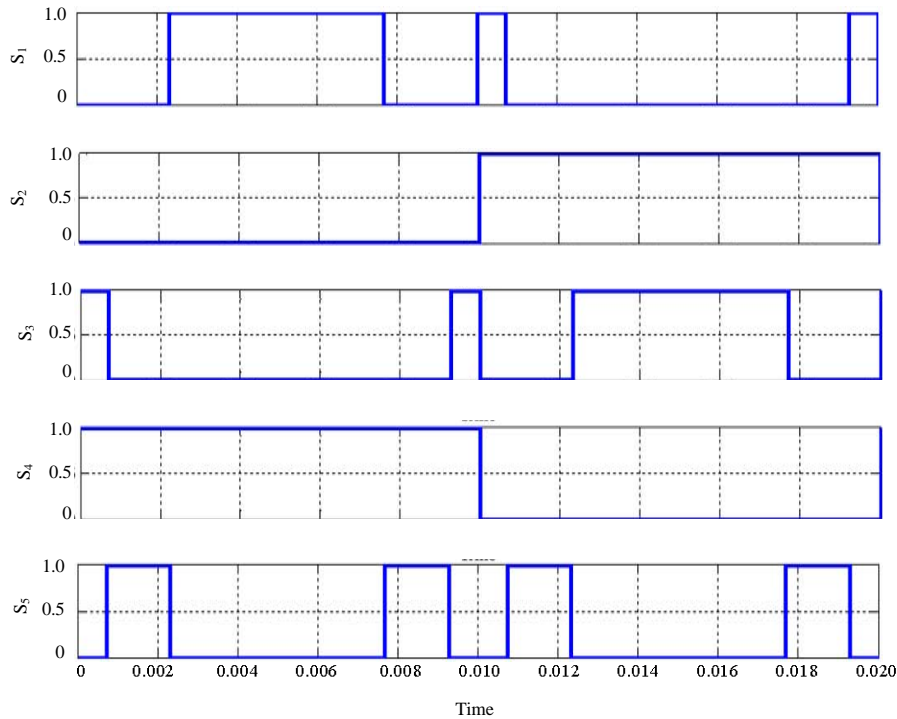


Fig. 2: Switching pattern for 5-level modified of a CHB-MLI

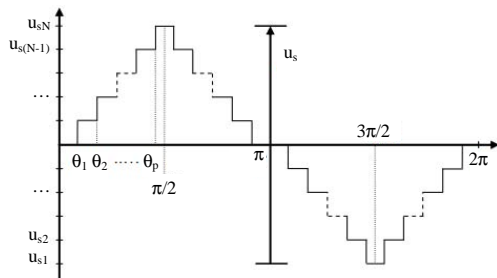


Fig. 3: \$u\_{ab}\$ at low switching frequency CHB-MLIs for 5-levels

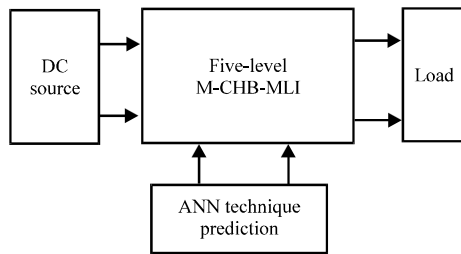


Fig. 4: Block diagram of a modified CHB-MLIs with DC source using ANN algorithm

Equation 2 has  $s$  variables  $(\theta_1, \theta_2)$  where  $0 < \theta_1 < \theta_2 < \pi/2$  and a solution set is obtained by assigning a specific value to the fundamental component,  $V_f$  and equating  $s-1$  harmonics to zero as given below:

$$\begin{aligned} V_1 \cos(\theta_1) + V_2 \cos(\theta_2) 2m & \\ V_1 \cos(3\theta_1) + V_2 \cos(3\theta_2) = 0 & \end{aligned} \quad (3)$$

where,  $m = V_f / (2V_{dc} / \pi)$  and it is related to the modulation index  $m_i$  by  $m_i = m / \text{sec}$  where  $0 < m_i < 1$ . An objective function is then needed for the optimisation procedure selected as a measure of effectiveness of eliminating selected order of harmonics while maintaining the fundamental component at a pre-specified value. Therefore, this objective function is defined as:

$$\begin{aligned} F(\theta_1, \theta_2, \dots, \theta_s) = & \left[ \sum_{n=1}^s V_1 \cos(\theta_n) - m \right]^2 + \\ & \left[ \sum_{n=1}^s V_2 \cos(3\theta_n) \right]^2 + \left[ \sum_{n=1}^s V_s \cos(2s-1)\theta_s \right]^2 \end{aligned} \quad (4)$$

The optimal switching angles are obtained by minimizing Eq. 4 subject to the constraint  $0 < \theta_1 < \theta_2 < \pi/2$  and consequently the required harmonic profile is achieved. The main challenge is the non-linearity of the transcendental set of Eq. 3 as most iterative techniques can be used with five levels of the modified CHB-MLIs as shown in Fig. 4 and each step is explained below:

The values of the conducting angles  $\theta_1, \theta_2$  can be chosen by solving the transcendental equations using a modulation index formula Eq. 5 to obtain the suitable:

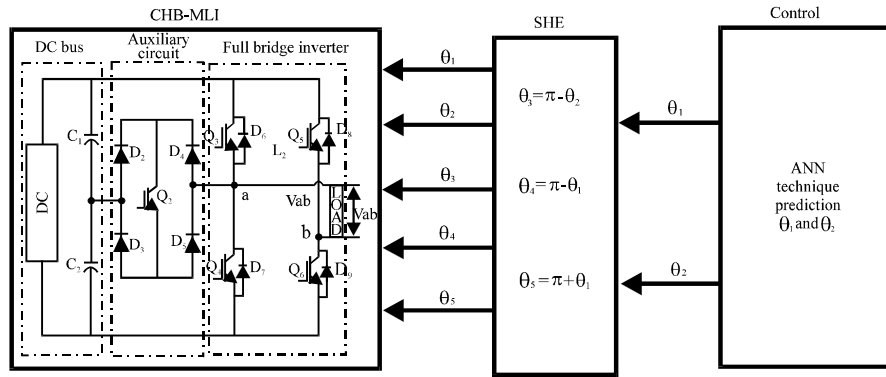


Fig. 5: Model of a single phase of modified CHB-MLIs and its controller using ANN algorithm

$$M = \frac{\pi V_f}{2V_{dc}} (0 \leq M \leq 1) \quad (5)$$

where, modulation index values  $m$ . Other angles which are  $\theta_3$  until  $\theta_8$  can be obtained by referring the output waveform of 5-levels of a modified CHB-MLIs theory in Fig. 3. The procedure of detecting attributes and configuration of a system is called optimisation. For only 3rd harmonics can be eliminated chosen to be removed. Thus, the switching angle can be found by solving transcendental equations by using ANN technique. In order to generate  $S_1, S_2, S_3, S_4$ , for 5-levels inverter, the switching pattern as shown in Fig. 2 are turned on and off in the right sequence in order to produce 5-level output voltage waveform of a modified CHB-MLIs. These switching angles are then examined for their corresponding THD given by:

$$THD_v = \frac{\sqrt{\sum_{n=1}^{\infty} V_n^2}}{V_1} \quad (6)$$

The effect of predicted angles for five-levels are  $\alpha_1$  and  $\alpha_2$ , on the THD and the modulation index is shown in Fig. 3. By using MATLAB coding for number of iterations, it can be easily concluded that the modulation index equal 0.949. However, the THD value of five-levels equal to 14.48 %.

Based on the diagram as shown in Fig. 1 the specified diagram has been modelled using MATLAB/Simulink. Finally, the model of a single phase of modified CHB-MLIs and its controller using ANN algorithm based on MATLAB/Simulink can be illustrated in Fig. 5.

**ANN performance evaluation:** ANN is a powerful tool to control an online system that is very complex in nature.

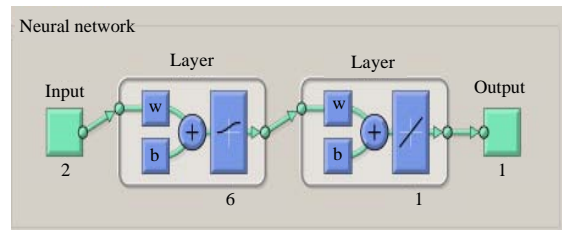


Fig. 6: ANN controller block diagram

A well-designed ANN can be used to replace the look up table and to generate optimal switching angles in a real-time manner (Zhang, 2017).

A typical two-layer feed-forward network shown in Fig. 6 with sigmoid hidden neurons and linear output neurons can fit multidimensional mapping problems arbitrarily well. There are  $n_{in}$  inputs and vectors pin an input layer,  $t_1$  sigmoid hidden neurons in hidden layer and  $t_2$  linear output neurons in output layer.

The ANN architecture is illustrated by Fig. 6 including an input layer with two inputs, a hidden layer with two hidden neurons and an output layer with two outputs. A Simulink Model is created using the ANN with delayed feed-back loop as shown in Fig. 7.

ANN controller network structure is defined based on the number of neurons in the input layer, hidden layer and output layer, respectively. The first neuron of the output layer is used as input to feed the PWM generator to generate switching signal for the proposed M-CHBMLI.

The connections weight parameter between  $j$ th and  $i$ th neuron at  $m$ th layer is given by  $w_{mij}$ , while bias parameter of this layer at  $i$ th neuron is given by  $b_{mi}$ . Transfer function of the network at  $i$ th neuron in  $m$ th layer is defined by:

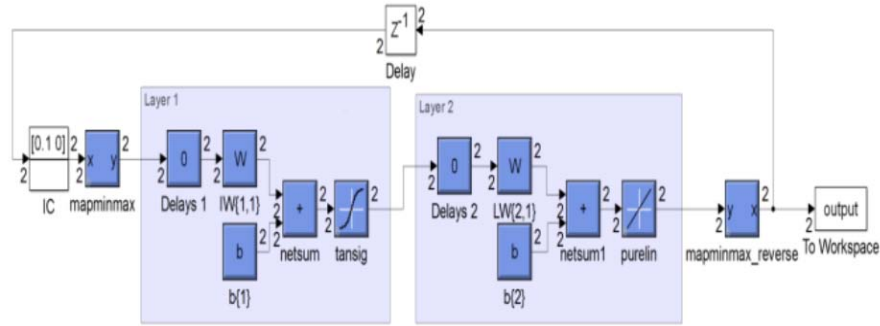


Fig. 7: Simulink Model for ANN-based Henon map chaotic system

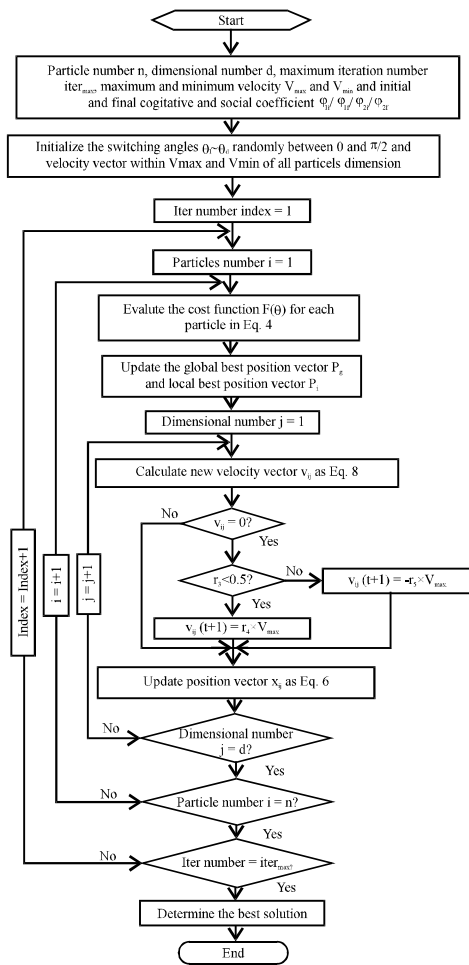


Fig. 8: Flow chart of ANN applying to harmonic minimization problem

$$n_i^m = \sum_{j=1}^{s^{m-1}} W_{ij}^m a_j^{m-1} + b_i^m$$

The output function of neuron at mth layer is given by:

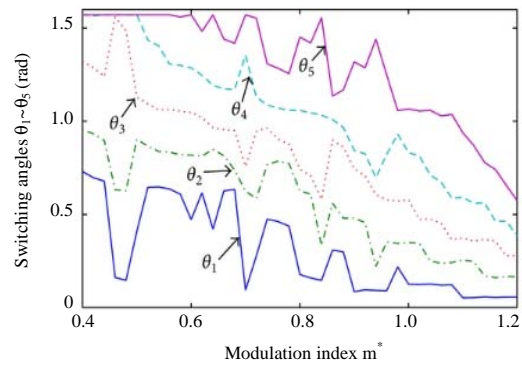


Fig. 9: Calculated switching angles  $\theta_1$  and  $\theta_2$

$$a_i^m = f^m(n_i^m)$$

where,  $f$  is activation function of the neuron. In this design the activation function of the output layer is unity and for the hidden layer is a tangent hyperbolic function given by:

$$f^m(n_i^m) = \frac{2}{1 + e^{-2n_i^m}} - 1$$

Applying ANN to the harmonic minimization problem described in above section, the procedure is presented in Fig. 8 and the results of optimal switching angles are presented in Fig. 9.

The training performances and training states for the three training functions of the selected architecture with 2 hidden neurons are plotted in Fig. 10a. As Fig. 10b, illustrates the mean squared error below  $10^{-7}$  for gradient, for  $Mu10^{-9}$  and validation 0 with 1000 iteration. Although, the overall performance is improving with increasing number of hidden neurons, it is hard to predict accurately whether the performance can be improved by adding one more neuron for an individual iteration.

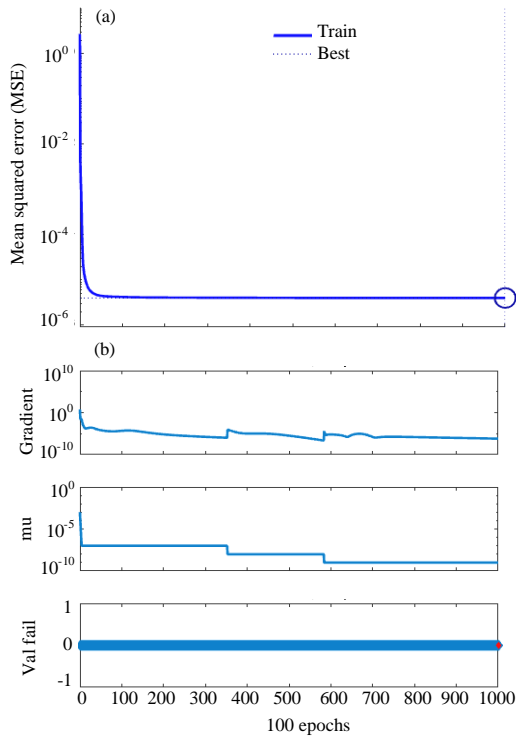


Fig. 10: ANN training performance with 2 hidden neurons. a) Best training performance is 3.9784e-06 at epoch 1000 and b) Gradient = 6.3219e-07 at epoch 1000, Mu = 1e-09 at epoch 1000, validation checks = 0 at epoch 1000

**RESULTS AND DISCUSSION**

Modified CHB-MLIs by artificial neural network technique is designed and simulated using the MATLAB/Simulink Software. Based on DC source. The simulations work has been carried out of a single phase of modified CHB-MLIs for value of switching frequency 2500 Hz. The load used is single-phase with 20 Ω and 5 mH. The DC capacitor voltage Vdc = 300 V. In this simulation operation, the duration of time was equal to 0.02 sec for each cycle. The value of MI = 0.949 was used and the switching angles were calculated and simulated which were equal to θ<sub>1</sub> = 11.54 and θ<sub>2</sub> = 39.21 at the switches of a single-phase modified CHB-MLIs of five levels. In Fig. 11 as can be observed of predicted data and original data for the THD with test values.

The training set is used for computing the gradient and updating the network weight and bias values. The validation set is used to monitor the error during training process in order to avoid overfitting. The test set is used to test the training performance training: R = 0.99995 as shown in Fig. 12.

The simulation model of output voltage waveform is as shown in Fig. 13 for timing diagram of optimisation

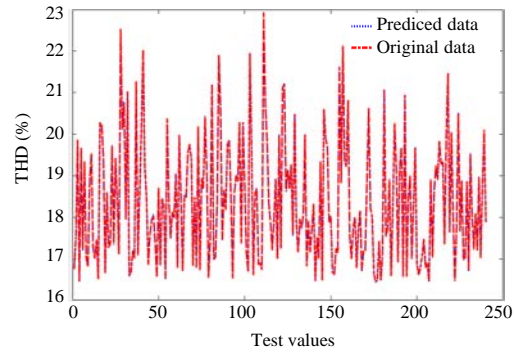


Fig. 11: Predicted data and original data for THD

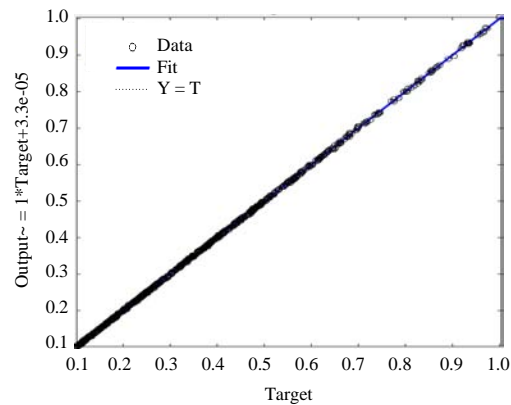


Fig. 12: Training performance angles for ANN (Training: R = 0.99995)

Table 2: Overall values of MI, switching angles and THD for voltage and current of modified CHB-MLI for five-levels based on proposal ANN and PSO techniques

Five-level	MI	θ <sub>1</sub>	θ <sub>2</sub>	THD <sub>v</sub> (%)	THD <sub>i</sub> (%)
PSO	0.949	31.41	41.93	15.30	3.80
Proposal ANN	0.949	11.54	39.21	14.48	2.05

ANN consist S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>, S<sub>4</sub> and bi-directional S<sub>5</sub> of modified CHB-MLIs of five levels. The optimisation of output voltage waveforms is based on the accurate calculation of switching angles obtained which are θ<sub>1</sub> = 11.54 and θ<sub>2</sub> = 39.21 with MI = 0.949 as shown in Fig. 14. Using the ANN technique, (Fig. 15) shows the harmonic spectrum of the optimisation of output voltage waveform of a modified CHB-MLIs of five levels with THD values equivalent to 14.3%.

The simulation result of a single-phase modified CHB-MLI for the output voltage and current waveform using ANN. Figure 16 and 17 shows the harmonic spectrum of the ANN optimisation of output current waveform of a single-phase modified CHB-MLI with THD values equivalent to 0.9%.

As shown in Table 2 overall values of MI, switching angles and THD for voltage of modified CHB-MLI for five-levels based on proposal ANN and PSO techniques. Figure 18 shows the MATLAB plotting output for

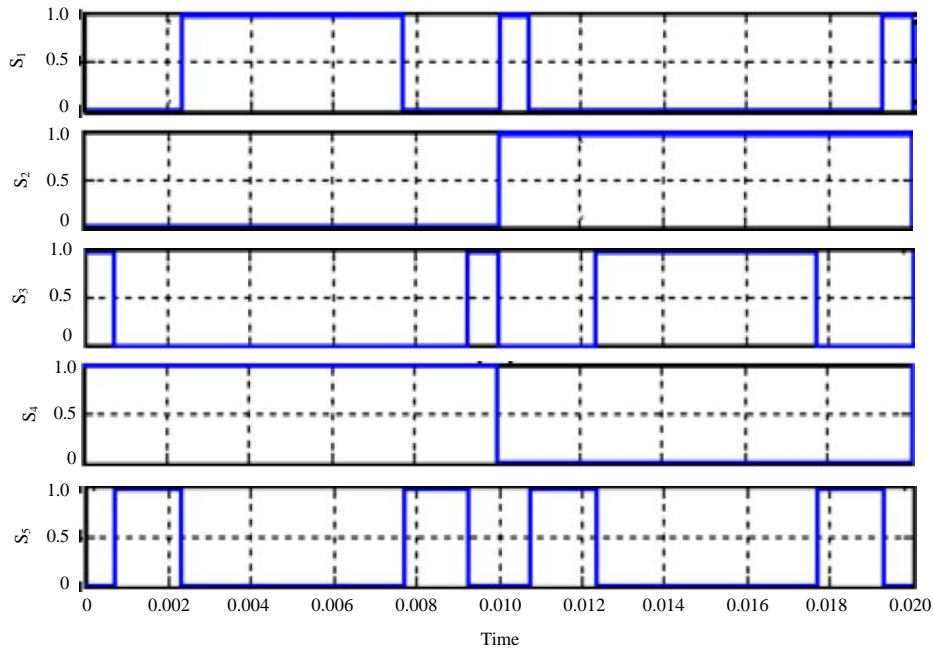


Fig. 13: Timing diagram for  $S_1$ ,  $S_2$ ,  $S_3$ ,  $S_4$  and bi-directional  $S_5$  using ANN technique

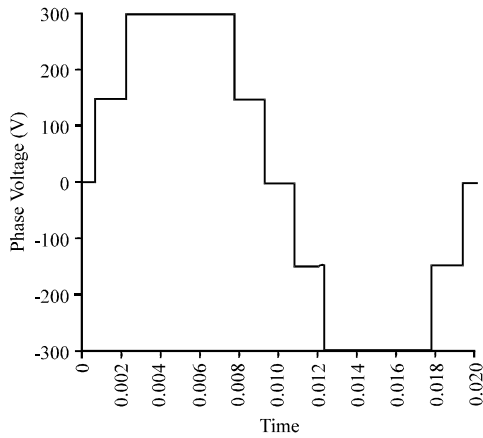


Fig. 14: Five-level output voltage using ANN technique

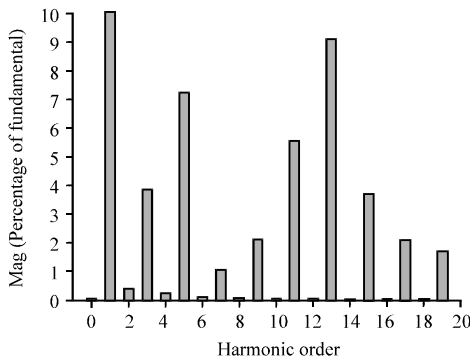


Fig. 15: Harmonic spectrum for output voltage waveform using ANN technique (Fundamental (50 Hz) = 318.1, THD = 14.48%)

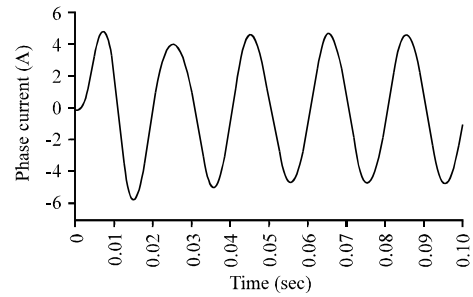


Fig. 16: Optimization harmonic spectrum of output voltage waveform using ANN technique

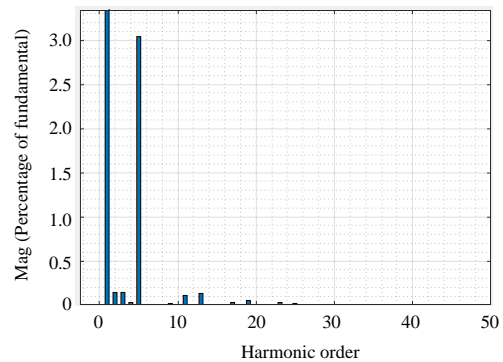


Fig. 17: Optimization harmonic spectrum of output current waveform using ANN technique (Fundamental (50 Hz) = 2.913, THD = 2.05%)

switching angles and the THD values for voltage and current based on proposal ANN and PSO techniques.

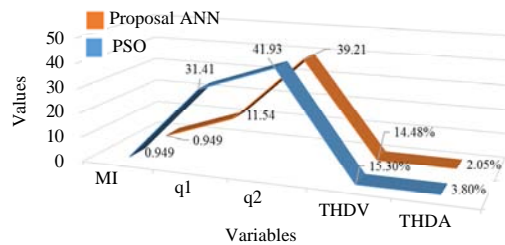


Fig. 18: Overall values of MI, versus the switching angles and the values of THD for voltage and current of modified CHB-MLI of five-levels based on proposal ANN and PSO techniques

### CONCLUSION

The simulation results showed that the higher level of inverter it will produce lower harmonics contents of the modified CHB-MLIs using the both techniques. The five-level M-CHBMLI with ANN controller has been improve the output voltage and current performance and achieve a lower THD. However, ANN technique produces lower content of THD of the modified CHB-MLIs output voltage and current waveform compared to PSO technique due to switching angles of the ANN technique is simple and efficient.

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