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Seven Level Cascade H-Bridge Inverter Modelling using ANN based Selective Harmonic Elimination Technique

Abstract: Because of their efficiency and control methods, inverters have grown in popularity recently as the demand for high-quality power has increased. The main advantage of a multilevel inverter is the ability to generate sinusoidal waveforms. Because of their countless real advantages, these structures have recently gained popularity among industry and utilities. Several in recent years have proposed multilevel inverter topologies, such as a diode-clamped, flying capacitor, and H-bridge multilevel inverters. So, nowadays, cascaded h-bridge inverters are used due to various advantages such as simplicity, fewer components, and so on. With a single-phase cascaded five-level and seven-level inverter, our main objective is to produce an output voltage waveform with excellent quality. A technique known as Selective Harmonic Elimination (SHE) was used to accomplish the stated goal. The inverter is provided with the optimal switching angles during SHE. Artificial Neural Networks (ANN) can carry out this concept. ANN is highly recommended in this scenario because it replaces a memory-intensive look-up table. This method of estimating firing angles for a modulation index is quick and timesaving, increasing the task's effectiveness and efficiency. The ANN model is trained to output the optimal firing angles for a particular modulation index. The Neural Network Fitting Tool in MATLAB is used to train the ANN model. from the simulation results, the seven-level inverter is superior to the five-level inverter, so the hardware implementation of the seven-level cascaded H-bridge is tested for effectiveness and exactness of the results

Keywords: Multilevel Inverter (MLI), SHE-PWM, Total Harmonic Distortion (THD), ANN

I. INTRODUCTION

In general, inverters are used for converting dc power to ac power in the application and drive point; these were widely used in all medium power applications. Different topologies are used in implementing multilevel inverters for the respective application. The multilevel inverter consists of semiconductor devices and independent sources. The voltage sources will be increased by increasing the number of levels, and the output of the inverter voltage will also increase. In general, the multilevel inverter is used instead of the standard single-phase two-level inverter; in the single phase, 2 level inverter gives ac voltage with +vdc and –VDC only. However, from the application point of view, all our power applications have large ac required voltages, so the multilevel inverter is used, which gives the stepped waveform; by increasing the no of inverter levels, we get the output waveform as a sinusoidal wave and the output of the inverter voltage is also increased. Here, the pulse width modulation (PWM) technique is used for switching the devices, and the multilevel inverter's voltage has the desired output voltages. The 2-level inverter has the harmonics component and high dv/dt value, but in the case of multilevel the harmonic component and the dv/dt value will be less so that by increasing the no of voltage levels, the output ac waveform becomes smoother.

Some of the advantages of the multilevel inverter (MLI) are: .[1-25].
I. Common mode voltage can be achieved, and the stress of the motor can be reduced.
ii. Input current of the multilevel inverter will have less distortion.
iii. Inverter reaches the desired voltage and current and has less harmonic content.
iv. Switching the frequency of the inverter can have low and high switching.
v. Electromagnetic interference will be less for the MLI

II. MULTILEVEL INVERTER

The multilevel inverters are classified into three times, some the multilevel inverter topologies are. [13],[2],[11],[10],[1],[7].

1. DIODE CLAMPED MLI
2. FLYING CAPACITOR MLI
3. CASCADED H-BRIDGE MLI

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The cascaded multilevel inverter is used in many types of applications. It is mainly used in medium voltage and high-power applications. It is used in facts (Flexible ac transmission system controllers). These CHBMLI are primarily used because as the number of levels increases, the nature of the power waveforms will turn out to be better, and the harmonic content will decrease. Attentively, the MLI was introduced into the powerful electric drive applications. The various topologies are utilized in various applications. The cascaded multilevel inverters are most utilized in the FACTS and STATCOM applications. The unbiased point converters have their applications in the train drive frameworks, especially in trans-quick maglev trains. In the comparable design, the diode-clamped converters have applications in real-time power transformation. A CHB-based and an NPC-based multilevel multi-string photovoltaic topology have been created. Hydro-pumped voltage storage is one of the ongoing uses of multilevel converters. FC-based converters have constrained applications in photovoltaic topology, automobile applications, filter applications, UPFC, etc.

MLI can decrease the size and weight of the compensator. And furthermore, improves the exhibition of the compensator during power system qualities. The utilization of a multiple voltage DC-AC converter makes direct contact with the extensive voltage distribution network, and to taking out the low auxiliary voltage transformer and decreasing the cost of the network. Adding to that, the harmonic wave substance of the inverter waveform can be decreased with advantageous adjustment control methods and consequently improve system efficiency. Some of the applications of MLI are (1) Reactive power control, (2) Back-to-Back frequency, (3) used for speed variations in motor drives, and (4) DC power source utilization..

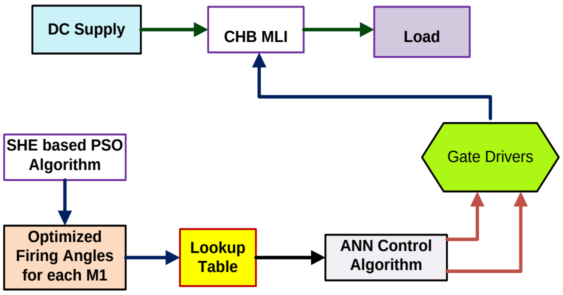

Fig.1. Proposed Diagram of ANN-controlled power converters for Electric Vehicles.[12]

III. CASCADED H-BRIDGE INVERTER.

The number of levels of CHMLI can increase by connecting H- bridges in series. The n number of output voltage levels CHMLI with s separate dc sources is given by N=2S+1. Where S= no of H-bridges,.

N=((3*2)+1------------------(1)

N=7 for seven level two H-bridges are required .

The Table.1 explains about the switching table of seven level cascaded multilevel inveter. The below output voltage waveform is obtained by applying the above sequence to the 7-Level CHB inverter

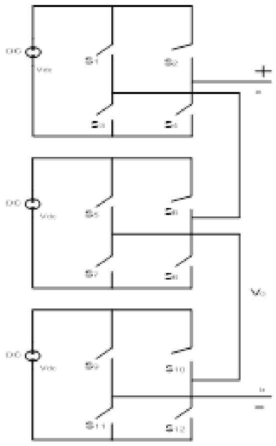

Fig 2. Seven-level inverter.[8]

S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	V_o
1	1	0	0	1	1	0	0	1	1	0	0	$3V_{dc}$
1	1	0	0	1	1	0	0	0	1	0	1	$2V_{dc}$
1	1	0	0	0	1	0	1	0	1	0	1	V_{dc}
0	1	0	1	0	1	0	1	0	1	0	1	0
0	0	1	1	1	0	1	0	1	0	1	0	$-V_{dc}$
0	0	1	1	0	0	1	1	1	0	1	0	$-2V_{dc}$
0	0	1	1	0	0	1	1	0	0	1	1	$-3V_{dc}$

Table1.Switching sequence of 7-level inverter.

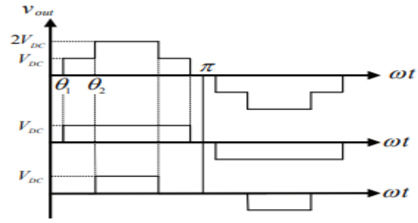

Figure.2. Staircase waveform [10].

Fourier series expressions are required for optimizing the harmonics in multilevel inverters, but as the number of levels increases, the complexity of the expression also increases. To solve such equations, iterative methods like NR are not suitable. Therefore, evolutionary algorithms like GA, BEE, and PS (particle swarm optimization) can give optimum values.

The Fourier analysis of the output voltage of multilevel inverter is given below.

$$V\text{out}(wt) = \sum_{n=1}^{\infty} v_{nout} \sin(\text{n}wt) \qquad \text{-------------------------(2)}$$

Where n=harmonic number

Vnout=amplitude of the harmonic order

$$v_{nout} = \frac{4v_{dc}}{n\pi}\cos(n\alpha) \qquad \text{---------------------------(3)}$$

where n=1,3,5..

Vn = 0 for even Harmonics ---------------------------(4)

Modulation index = $M = \dfrac{v_{1out}}{\frac{8v_{dc}}{\pi}}$ -------------------------(5)

The range of modulation index is 0 to 1and firing values are lies in between o to $\pi/2$. Calculation of optimum firing angles from eq-2 is not simple .In order to solve this evolutionary algorithms are more suitable The firing scheme of the h-bridge inverter is the signals coming from the firing circuit so that the switches are turned on accordingly as planned. Here the switching and the conduction losses are high in odd no IGBT, so the design of the switch should be taken that the on-time resistance of the device should be less to reduce the damage, and the system's reliability should be increased. The firing scheme of the inverter is shown in the figure below

The signals x1,x2,x3, and x4 are analyzed from the digital logic taken from ANN. The seven-level cascaded multilevel inverter is designed and controlled in the same manner as represented in figure.3. The firing angles are taken from the artificial neural network, which is used to solve the nonlinear characteristic equation. The angles obtained by the ANN will be in radians, but the firing angle given to the inverter should be of the same value; thus, this conversion can be performed by the triangle pulse modulation and obtain the excellent value of the ANN, and it is given to the h-bridge inverter. By controlling the firing pulses of the individual inverter to synthesize the duty cycle of the individual output waveform. By interconnecting all the outputs of the individual inverter, the seven-level cascaded H-bridge inverter with the respective selective harmonics is eliminated in the output of the inverter. The control strategy of the multilevel inverter's firing circuit is represented in the figure.4 below.

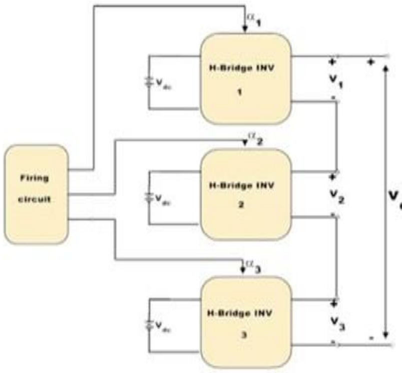

Figure 3. Cascaded h bridge inverter.[1,7,9]

In the above block diagram, the firing angles are to each of the cascaded h-bridge inverters for which the respective source voltage is present to each h-bridge from which the output voltage is obtained and synthesized. Using this type, the main advantage is that there will be no constraints in the switching devices of the order of magnitude in the h-bridge multilevel inverter.

IV. Artificial Neural Network

An adaptive neural network, sometimes called an artificial neural network, learns by using linked nodes or neurons in a layered structure like the human brain. A neural network may be trained to recognize patterns, categorize data, and predict upcoming events by learning from data. The input is divided into layers of abstraction using a neural network. It may be trained to recognize the voice or visual patterns using numerous instances, just like the human brain. Its behavior is determined by how its numerous components are connected and by how strong or significant those connections are. A predetermined learning rule automatically adjusts these weights during training until the artificial neural network completes the intended job. The neural network is trained based on the dataset. The Neural Fitting Tool is used to train the data. The dataset consists of angles and a modulation index, which will be uploaded in the neural fitting tool. This tool obtains the required dataset after training.

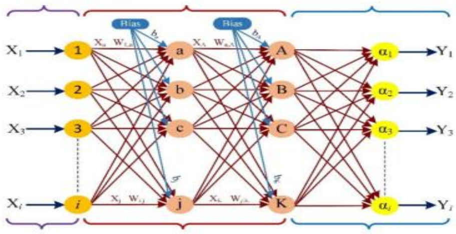

Figure .4.ANN architecture.

4.1 IMPLEMENTATION OF ANN.

The ANN implementation mainly consists of the Selection of Data, Validation and Test Data, Configuration of Network Architecture, and Data Training. The dataset consists of values collected and saved in a spreadsheet to be fed to the tool. In order to train the network, we used 70% of the dataset samples,15% of the remaining samples were used for validation, and 15% were used for research. The proper quantity of neurons facilitates the set of rules to apprehend the samples higher such that the MSE (Mean Square Error) is near zero. Post the training, if the cost of the MSE is high, the number of neurons may be changed. This trial and mistakes approach is used to check for the greater variety of neurons that must be gifted within the hidden layer. MSE is calculated by using below equations.

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{n}(y_i - \breve{y}_i)^2 \quad \text{--------------------------------------(6)}$$

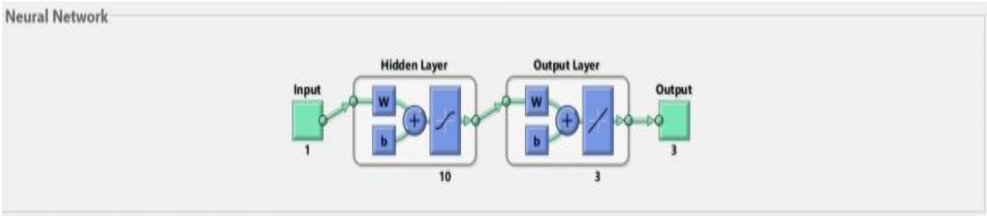

Fig 5. Network architecture.

The dataset at this stage will be determined by the set of instructions that will be used to teach them. In this instance, they were given three choices, and they decided to use the Bayesian Regularization set of rules for educational reasons. Although this requires many rounds, it is the better option for small and noisy datasets. The rules educate the records, and we can even use the rules to re-educate them. These values for Training, Validation and Testing's MSE and Regression are shown. The trained network is now re-trained till the Mean Square error is less and the Regression value is close to 1. The resulting plot is shown in Figs. 6.

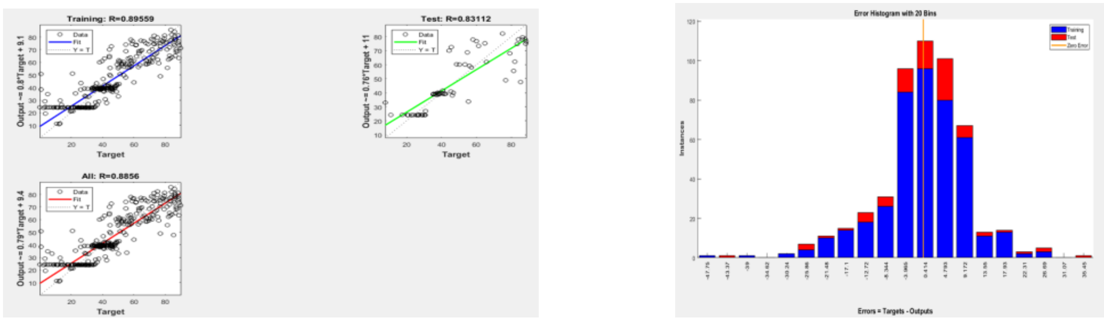

Fig 6. Neural Network Training Regression and Error Histogram.

Initially, data sets for a 5-level and 7-level inverter are obtained, using which the ANN algorithm is trained. The input given to the ANN Algorithm is the modulation index, and the output is firing angles. The algorithm is trained in such a way that it produces the most optimum firing angles for the given modulation index. These optimum angles are used to obtain a quality output waveform in a CHB inverter (5-level and 7- level).

4.2 IMPLEMANTION IN MATLAB

The CHBMLIs are designed in the Simulink using IGBTs, pulse generators, and DC input voltages. The number of bridges can be known using the formula (m-1)/2, where m is the level of the inverter. By arranging the elements in the Simulink environment and setting the run time, the model is made to run, and the output waveforms are obtained. The THD is calculated using FFT analysis.

Initially, the inverter uses the pulse generators to give the phase delays. The pulse generators are connected to each switch of the inverter. Switches at the top of the bridge are given a pulse value, and switches below are given the inverted values as the above ones. The input from each of the DC inputs is 100V. The load is connected to the inverter with a voltage measurement block connected parallel to it. A scope is considered to check the output waveform of the setup. After arranging the blocks, the model is made to run, and output is obtained. The 5-level CHB inverter's final output waveforms when utilizing the PSO method

Below is a list of the obtained dataset, the ANN-trained dataset, and the observed result.

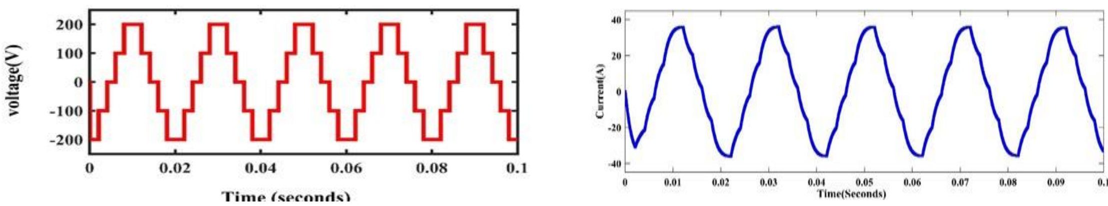

Figure.7. output voltage and current waveform for 5-level inverter using ANN

FFT analysis is done to observe the THD of the model's output. The FFT is done for both without ANN and with ANN methods in the Figures. The THD of the 5-level inverter is as follows.

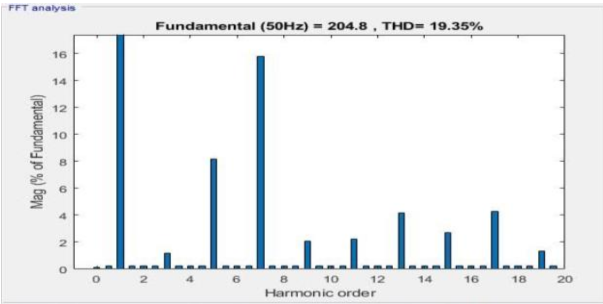

Figure.8. FFT analysis for Five level inverter without ANN.

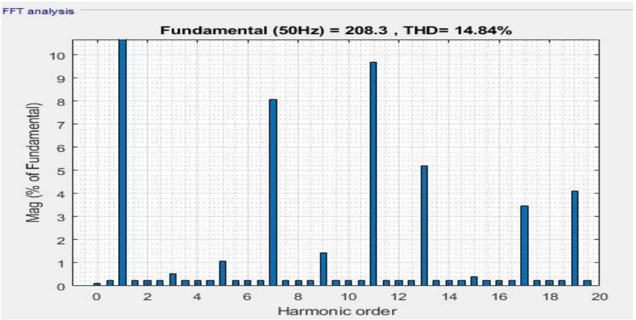

Figure.9. FFT analysis for Five level inverter with ANN

By comparing the fifth harmonic component in figure 12 above to those in figure 11, it can be seen that THD has decreased from 19.35% to 14.84%. Using an artificial neural network resulted in the lower-level odd harmonics (fifth and seventh) being reduced to lower values and removed from the output waveform. Additionally, lower-order harmonics connected to the fundamental were reduced entirely, and the multilevel inverter's total harmonic content decreased, as shown in the FFT analysis. The following tables list the results of ANN-based firing angle for a seven-level inverter. The angles produced for various modulation settings are listed and shown in the tables below.

Table II. Switching values for 7-level inverter using ANN

Modulation index	*Switching angles*			*THD*
	$\theta 1$	$\theta 2$	$\theta 3$	
0.1	*66.24*	*85.71*	*219.3*	*61.11%*
0.2	*57.39*	*70.27*	*94.54*	*16.76%*
0.3	*65.28*	*74.32*	*74.81*	*23.84%*
0.4	*62.92*	*64.83*	*67.18*	*25.33%*
0.4	*36.28*	*63.03*	*80.71*	*8.77%*
0.5	*27.22*	*51.62*	*79.85*	*13.61%*
0.6	*29.28*	*47.15*	*70.77*	*20.04%*
0.7	*19.86*	*41.23*	*67.65*	*25.83%*
0.8	*17.31*	*28.93*	*147.9*	*78.1%*
0.9	*72.82*	*90.31*	*257.4*	*40.71%*

Considering the above table, valves in the seven-level inverter get the following voltage and current waveforms shown in the figure.

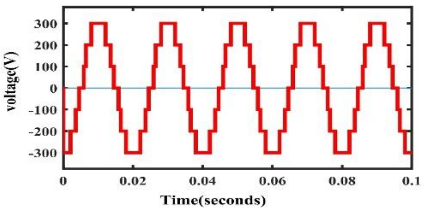

Figure.10. output voltage waveform for 7-level inverter using ANN.

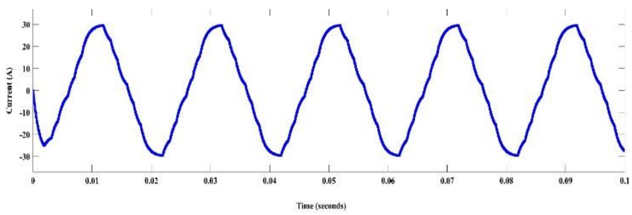

Figure.11. output current waveform for a 7-level inverter using ANN.

FFT analysis is done to observe the THD of the model's output. The FFT is done for both without ANN and with ANN methods in the Figures. The THD of the 7-level inverter is as follows

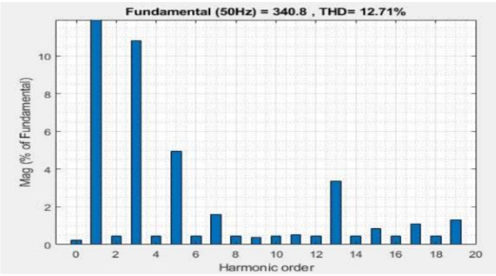

Figure.12. FFT analysis for Five level inverter without ANN.

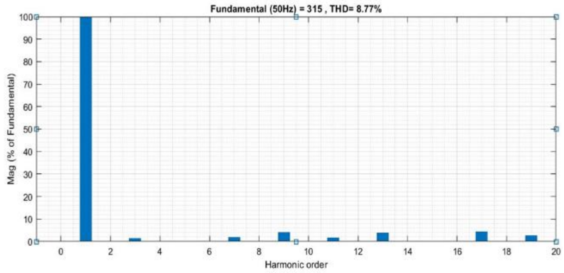

Figure.13. FFT analysis for Five level inverter with ANN

By comparing the fifth and seventh harmonic components in figure 12 above to those in figure 13, it can be seen that THD has decreased from 12.71% to 8.77%. Using an artificial neural network resulted in the lower-level odd harmonics (fifth and seventh) being reduced to lower values and removed from the output waveform. Additionally, lower-order harmonics connected to the fundamental were reduced entirely, and the multilevel inverter's total harmonic content decreased, as shown in the FFT analysis. This study used MATLAB to simulate a five-level and seven-level CHBMLI.The artificial neural network is trained on a large dataset using MATLAB's Neural Net Fitting tool. The ANN output model is implemented as a Simulink block and a MATLAB function. The ideal firing angles determined by the ANN model are shown in the results. THD is assessed after applying the Bayesian regularization algorithm; the ANN results are fed into a 5-level and 7-level

Table. III Comparison of THD of 5-level inverter using different algorithms in ANN

Sno	Algorithm	Angle-1	Angle-2	THD
1	Quasi-Newton	80.2637	20.37	37.46%
2	Levenberg-Marquardt	74	68.6	26.18%
3	**Bayesian Regularization**	**77**	**42**	**14.84%**

Table.IV.Comparison of THD of 7-level inverter using different algorithms in ANN.

Sno	Algorithm	Angle-1	Angle-2	Angle-3	THD
1	Quasi-Newton	45.5	51.8	55.8	33%
2	Levenberg-Marquardt	55.5	61.3	64.8	24.46%
3	**Bayesian Regularization**	**36.28**	**63.03**	**80.71**	**8.77%**

The results of the Bayesian algorithm for seven-level inverters are superior to those of other algorithms, as shown by the two tables III & IV above.

Table.V Comparison of simulation Results

Inverter Level	THD without ANN	THD with ANN
5-level	19.35%	14.84%
7-level	12.71%	8.77%

4.3. EXPERIMENTAL VALIDATION.

The Simulink model used in the simulation is now brought into practice by using hardware components and their proper arrangement to bring out a seven-level AC output from the given DC input source

1.MOSFETs (IR740)
2. Optocouplers (MCT2E)
3. Micro controller

4. Transformer (230V/12-0-12)

The transformer is used to step down the supply voltage to around 48V. This AC voltage from the transformer is fed into the rectifier circuit and is converted into DC voltage. This same voltage is used as the bridge's input, around 5V DC for each bridge. The Arduino has been configured well with the Simulink model, and the parameters are adjusted to provide proper gate pulses. The gate pulses are now given to the MOSFETs via the Optocouplers for isolation. The digital output pins of the Arduino are connected to the Optocouplers. The phase delay for each MOSFET is given as per the calculations. The output of the cascaded H-bridge (end terminals across the three arms) is now the final output of our inverter. We have given this output voltage as a supply to a light bulb(resistive load) via connecting wires. The voltage profile corresponding to the output has been verified to be a seven-level AC voltage by connecting the output terminals to a CRO. The THD can be calculated.

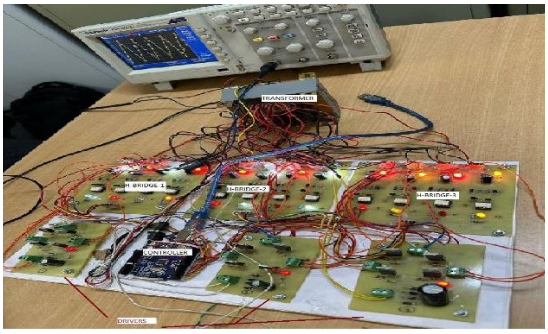

Figure .14 Hardware setup of 7-level CHMLI

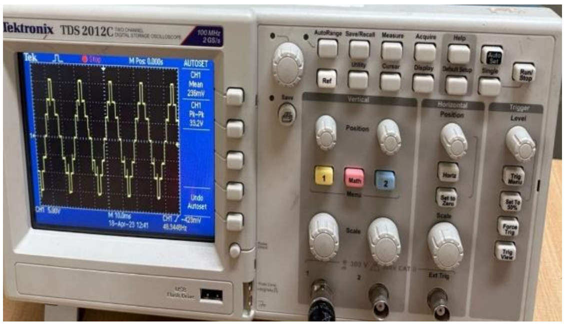

Fig.15. Hardware output of 7-level CHMLI in CRO

By observing the table-v seven level inverter gives the more smooth voltage compared to five level with this for validation of simulation results for seven level inverter experimental setup has been developed.

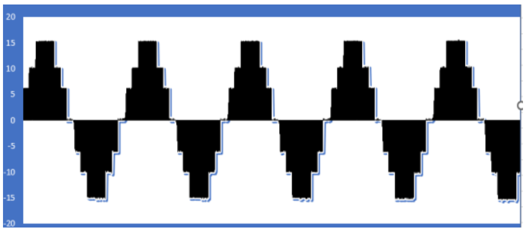

Fig.16. Experimental output voltage waveform of seven-level CHMLI.

A 7-level CHMLI is verified experimental and the 7-level output waveform obtained in CRO is shown in above figure.15 for the both the methods.

V. RESULTS AND DISCUSSIONS.

This study used MATLAB to simulate a five-level and seven-level CHBMLI. The artificial neural network is trained on a large dataset using MATLAB's Neural Net Fitting tool. The ANN output model is implemented as a Simulink block and a MATLAB function. The ideal firing angles determined by the ANN model are shown in the results. THD is assessed after the ANN results are fed into a 5-level and 7-level inverter.

For hardware 7-level CHMLI using ANN and without ANN , THD obtained is 14.35% and 13.6% THD is obtained by eliminating lower order harmonics. Figure.16 shows the seven level output voltage obtained from proposed methods .

Table.VI Comparison Table for simulation and hardware results.

Proposed Methods	Simulation	Experimental
With out ANN(PSO)	12.77%	14.35%
ANN	8.77%	13.6%

Table.VI shows the Comparison between the simulation and experimental values of THD for seven level cascaded inverter .

VI. Conclusion.

In this Paper, optimization of 5-level and 7-level single-phase CHMLI is presented using SHE-PWM. Different ANN algorithm is used to remove lower-order harmonics and reduce THD. The fifth harmonic is dangerous among odd harmonics that are eliminated and obtain less THD. Bayesian Regularization based optimization technique is proposed to make THD low and eliminate lower order harmonics. The work is done in MATLAB/SIMULINK. Data set are developed from PSO algorithm for implementation ANN.After compassion of simulation results seven level inverter is more superior than five level inverter. An experimental comparative study among 7-level CHMLI-based ANN and 7-level CHMLI based PSO is done. When ANN is compared with PSO(14.35%), gives that ANN(13.6%) can reduce more THD. This concludes that ANN is more advantageous i.e. it can reduce more THD, has less number of variables, and has a high convergence rate.

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