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# Implementation of ANN Based Closed Loop Multilevel Inverter

Mohan S. Selokar
Research scholar, MPSTME, Mumbai

Dr. Manoj S. Sankhe
Professor, MPSTME, EXTC Deptartment, Mumbai

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***Abstract*-Multilevel converters are very widely used for industrial applications as it has various advantages like less distortion and high efficiency. High value of output voltage and high value of current can be obtained whenever required by application. It produces multiple levels in output voltage and output current. We used Voltage feedback for the control of the output voltage. Usually PI controller is used for the control of output voltage in order to reduce total harmonic distortion. We replaced PI controller with artificial neural network (ANN) to reduce THD. Hardware is implemented with raspberry pi 4, drivers for MOSFETS TLP 250. Implemented multilevel converter can be used for AC motor. This implementation reduces RF/EMI effect.**

*Index Terms*-**Cascaded H-Bridge multilevel inverter, Multilevel inverter, Neural Network, PI controller Sinusoidal pulse width modulation, Total harmonic distortion.**

## INTRODUCTON

As there is a requirement of high quality power in industrial applications, the use of multilevel converters is increased very widely [1]. A multilevel converter delivers the output voltage consisting of multiple levels. Change in output level at consecutive level is equal to the input voltage applied to each bridge. This technology is growing very rapidly as it can be used with non-conventional energy sources like wind, solar energy. The use of PV cells has been increased as an input source to multilevel converter.

Multilevel converter has lower switching losses. The advantage of using multilevel converter is low harmonics. The high power can be generated with the help of multilevel converter if required by the application. The quality of power generated using multilevel converter is very high [4]. High frequency and low frequency PWM is used with multilevel converters. High frequency PWM results in low THD and more switching losses. Low frequency PWM results in high THD and low swithing losses. [5]

There is necessity of control mechanism to control the DC input power. Novel technique is proposed. Mathematical model is proposed for multilevel converter [6]. There are controls mechanisms suggested based on learning algorithm which are evolutionary algorithms [7]. Particle swarm optimization is proposed [8]. Various conventional methods like space vector is suggested [8]. Artificial neural network technique to calculate switching angles is explained [9].

There are various dynamics occurs in multilevel converter. Technique to overcome the fast dynamics is explained and suggested. Estimation of reference vector is forwarded[10]. Selective harmonic elimination is suggested to calculate the switching angles by taking into account mathematical equations of output voltage [11]. Real time selective harmonic elimination is forwarded for the multilevel converter in which there are DC inputs sources with different magnitudes are used [12]. Model predictive model based on state space model is suggested [13]. Novel natural frame control method is presented for single phase cascaded H-bridge multilevel converter [14].

A single phase nine level inverter uses full bridge configuration with compatible sinusoidal modulation method. In positive half cycle, output voltage is increased form zero to $4V_{dc}$ in step of $V_{dc}$. After the peak, again voltage is decreased from $4V_{dc}$ to zero. In negative half cycle output voltage is decreased from zero to $-4V_{dc}$ and again increased from $-4V_{dc}$ to zero. By selecting suitable frequency for carrier and modulation index, output voltage and current signal can be generated with significant reduction.

We used cascaded H- bridge inverter topology and SPWM

(Sine wave pulse width modulation) control strategy. PWM signals are obtained from four reference signals to gate the power electronic devices used in the circuit. With the small changes in the load output voltage is being varied. To obtain constant output voltage, generally P-I controller is used. P-I controller is replaced with neural network to overcome the limiatations encountered with it. To minimise the error between output voltage and reference voltage, Neural network is used as a controller. Data samples required to train the Neural network are obtained by the simulation of multilevel converter in which P-I controller is used. We use voltage controlled feedback to control the output voltage to the reference value and to minimised the error. The use of neural network is proved to be beneficial and faithful in the power electronics and drive areas. In AC drives inverters are used to cntrol . Harmonic elimination in PWM inverter is suggested in this paper with the help of neural network controller. The switching anglesare calculated and triggering pulses are applied with the modulating signal generated with the help of neural network .

**Table 1** Parameter specifications

| Sr. No. | Parameter | Values |
|---|---|---|
| 1 | Levels in load voltage | 9 |
| 2 | Number of switches | 16 |
| 3 | DC source for each CHB bridge | 50 |
| 4 | Fundamental Frequency | 50 Hz |
| 5 | Switching frequency | 1350 Hz |
| 6 | Load resistor | 100 ohm |
| 7 | Load inductor | 40 mH |
| 8 | Filter inductor | 30 mH |
| 9 | Filter capacitor | 100 micro-farad |

After the introduction in section I, Section II explains cascaded h-bridge multilevel inverter topology. The two sections III and IV show the simulation results that ensures the correct functioning of the inverter with the neural network. Hardware implementation is explained in section V. Conclusion of the work done so far and final remarks are made in Section VI.

## CASCADED NINELEVEL H-BRIDGE INVERTR

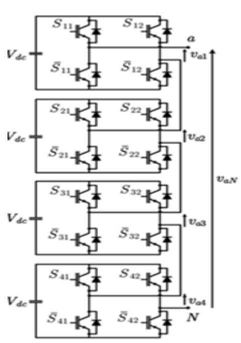


FIGURE 1
CONNECTION SCHEMATIC CASCADED H-BRIDGE INVERTER

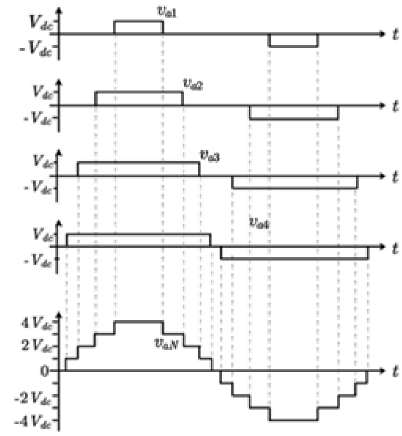


FIGURE 2
VOLTAGE WAVEFORM OF CASCADED NINE LEVEL INVERTER

Above fig.1 represents the schematic diagram of single phase cascaded h-bridge nine level inverter. Fig.2 represents the load voltage waveform of single phase nine level multilevel inverter. In this inverter four identical units of cascaded h-bridge are used. All four converter units are connected in series. Voltage of same magnitude is applied to each cascaded h-bridge. To obtain positive half cycle of output voltage two switches namely *(S11,* $\bar{S}12$ *)* are gated and therefore these two switches are turned. Switches namely (S12, $\bar{S}11$) are not provided with gating pulses and therefore these two switches remains in off state. To obtain negative half cycle of output voltage (S11, $\bar{S}12$) are not gated so that these two switches remain in off state. The other two switches (S12, $\bar{S}$ 11) triggered so that these two switches goes to into the on-state and vice versa. The load voltage of multilevel converter consists of nine voltage levels. Four voltage levels are in positive half cycle and four voltage are in negative half cycle. In positive half cycle output voltages
levels are $V_{dc}$, $2V_{dc}$, $3V_{dc}$ and $4V_{dc}$. In negative half cycle output increases from zero to -4Vdc and again back to zero in step of $V_{dc}$.

Each unit is responsible to generate one voltage level in positive half cycle and one voltage level in negative half cycle. Total number of levels in positive half cycle and number of levels in negative half cycle including zero voltage level are given by the following equation

$$m = 2n+1 \qquad (1)$$

## GENERATION OF PULSES USING NEURAL NETWORK

PI controller can be used as a controller. But it has few limitations. The output of PI controller is continuous. l. So, small change in the load doen not cause a change in the error signal. Therefor correction in the output voltage is not taken place. Therefore data samples of input and output of PI controller are collected in .mat file. The data samples collectes are used to train the neural network. The neural network works similar to human brain and take a decesion for the input applied to the neural network. Depending on the input and training, the desired output of neural network is generated.. Input output combinations can be used with very small interval. Huge amount of sample data values are collected after the simulation of multilevel converter with PI controller. Matlab is used for simulation. The input to PI controller is labeled as x variable and output of PI controller is labeled as y variable. The combination of x and y at different values of time is used for training, validation and testing the ANN(Artificial neural network). We suggest the replacement of PI controller with the controller based on ANN.

Our aim is to provide a constant output voltage which is the requirement of certain kind of loads like single phase AC motor. Controller based on artificial neural network (ANN) proved to be a good replacement in place of conventional P-I controller. The ANN used here has two hidden layer, one input layer and one output layer. ANN structure formed in the simulation consists of ten neurons, whereas input and output layer consists of five neurons each. Error signal generated out of the comparison of reference signal and inverter output is the input data set for ANN. P-I controller output is the output data set. Data samples thus formed are used train, validation and testing of ANN. Basically the output of ANN controller is used as a reference signal to the PWM generator. PWM generator generates the pulses to trigger the MOSFETS used in CHB converter,

In ANN we use NARX (Nonlinear Auto-regressive with external Input) model. The modulation index set is to the value of 0.8. ANN dynamic time series model is used in our project. MATLAB simulink is used for the simulation and controlling the output of multilevel converter. Total 29981 samples are used.

Data samples and error histogram obtained are shown in fig. 5 and Fig. 6 respectively. Error histogram indicates that error is in the range of acceptable limits. The tested data gives the output very close the calculated data. The parameters for the Matlab simulation used are shown in Table 1. The LC filter consisting of filter inductor of 30 mH and filter capacitor of 100 microfarad is used.. The neural network output is applied to the PWM generator as modulating signal. Very high frequency carrier signal of 27 *50 Hz is used to generate the gating pulses. The very high frequency gating pulses are generated to minimize amplitude of nearby odd order harmonics. It is proved with the help of FFT analysis that THD is reduced in output voltage and output current.

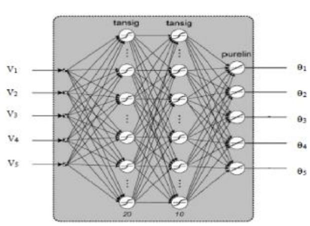



FIGURE 3
NEURAL NETWORK STRUCTURE

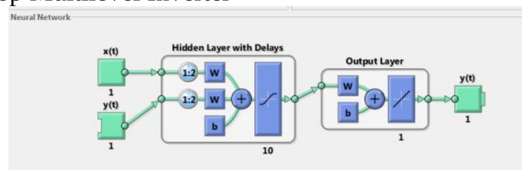
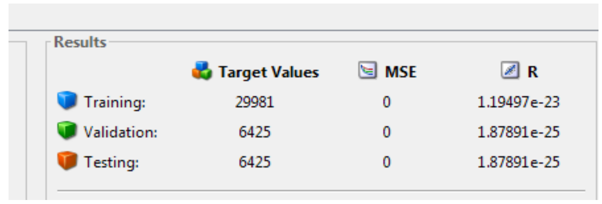



FIGURE 4
NEURAL NETWORK STRUCTURE USED



Results

| | Target Values | MSE | R |
|---|---|---|---|
| Training: | 29981 | 0 | 1.19497e-23 |
| Validation: | 6425 | 0 | 1.87891e-25 |
| Testing: | 6425 | 0 | 1.87891e-25 |

FIGURE 5
DATA SAMPLES USED

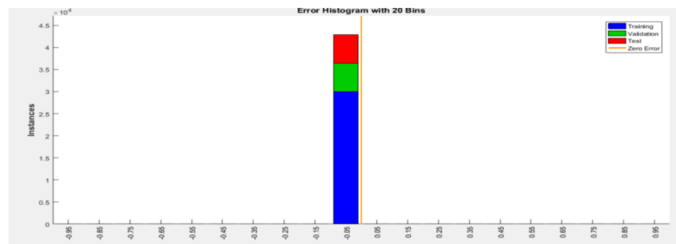
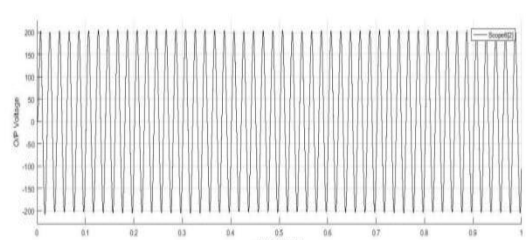



FIGURE 6
ERROR HISTOGRAM

NARX model is used for neural network.

## SIMULATION RESULTS

There are two different kind of simulations are performed. Initially P-I controller is used. The value of K and $K_i$ is chosen by error and trial method to obtain sinusoidal output voltage. From the simulated output waveforms of current and voltage, the value of THD is obtained using FFT analysis. The values of THD obtained are tabulated in table 2. The data samples are collected and stored in .mat file. Database stored in .mat file is used to train the ANN block. PWM generator block with internal generation of carrier signal with very high value of carrier frequency in the order of 27*50 Hz is used. The reference signal of 50 Hz frequency and peak amplitude of 200V is used. The voltage source of e 50 V is applied as dc input voltage to each converter. The performance of the ANN based cascaded H-bridge nine level inverter with isolated dc sources is determined through MATLAB/ SIMULINK software. The elements and the parameters considered for simulation are presented in table 1. The simulation without ANN and with ANN is carried out for comparison.



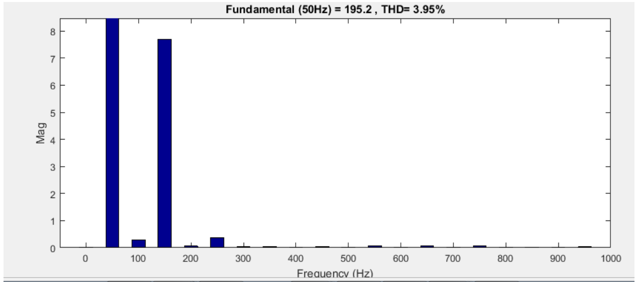
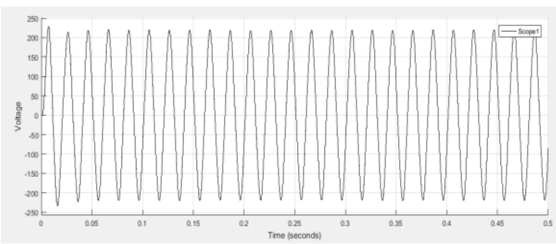



FIGURE 7
VOLTAGE WAVEFORM AND FFT ANALYSIS(PI)

The main power circuit consists of four H-bridges. The dc voltage used for each cascaded H-bridge module is 50 V and the nine level stepped output voltage is achieved. The total harmonic distortion present in output voltage is decreased by a great extent. The calculation of THD is calculated using FFT analysis.



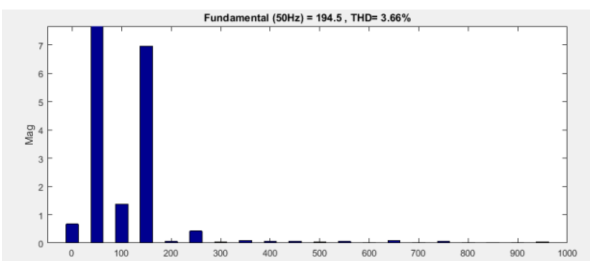




FIGURE 8
.VOLTAGE WAVEFORM AND FFT ANALYSIS ANN BASED

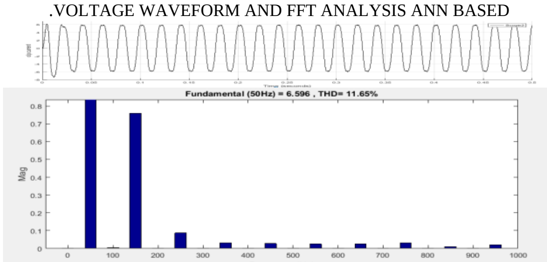



FIGURE 9
CURRENT WAVEFORM AND FFT ANALYSIS AAN BASED

Modulation index which is the ratio of peak of modulating signal to peak of the carrier signal can be adjusted with the help of selected PWM generator block. In our research work it is set to the value of 0.8 Phase delay to each converter can be changed with the setting in PWM generator block. The nature of output voltage waveform is decided by selection the parameters of the PWM block. THD and Ripples are reduced in the output voltage. As a result efficiency of the DC to AC conversion is increased. In Multilevel converter it is possible to deliver very high voltage and good quality of power with less harmonics with the help of Neural Network. The resistive-inductive loads are connected across the cascaded H- bridge nine level inverter. Output voltage remains constant to the reference value. The total harmonic distortion in voltage is 5.39 %. The total harmonic distortion in current waveform is 12. 38 % with the PI controller whereas with the help of ANN, the THD content in voltage and current waveform is reduced to 11.65 % and 3.66 respectively.

**Table 2** Comparasion of different techniques

| Sr. No . | Techniques implemented | THD in current | THD in Voltage |
|---|---|---|---|
| 1 | Voltage feedback PWM | 12.38% | 5.39% |
| 2 | Voltage feedback PWM using ANN | 11.65% | 3.66% |

## HARDWARE IMPLEMENTATION

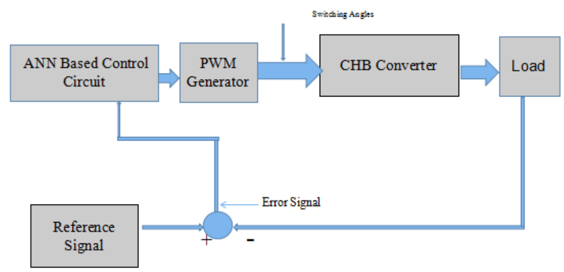



FIGURE 10
BLOCK DIAGRAM OF HARDWARE

The above diagram shows the shows the schematic of implementation of ANN based closed loop

**Table 3** Comparasion of simulated and practical res.

multilevel inverter. The simulation of ANN based multilevel inverter is simulated and run using MATLAB. Raspberry pi is subsystem added in existing simulation model .xslx file. The purpose of using pi subsystem is to deliver the pulses to the GPIO pins of raspberry pi. The switching pulses are generated by the Raspberry pi. Sixteen switching pulses are generated for sixteen MOSFETS used in cascaded H-bridge multilevel inverter. The switching pulses generated are of low magnitude. To increase the magnitude to 5V for switching pulses to drive the MOSFETS, TLP 250 drivers are used. Here we use voltage feedback. Output voltage is feedback and compared with the reference signal. Corresponding error signal is generated to change the switching angles to adjust the peak output voltage of 24 V. .

Each cascaded H-bridge inverter uses 6 V as a input . As we use four cascaded H-bridge inverters to obtain 24 V peak voltage, we require four 6V power supplies. Filter inductor of 100mH and filter capacitor of 50 microfarad is used to reduce ripples.

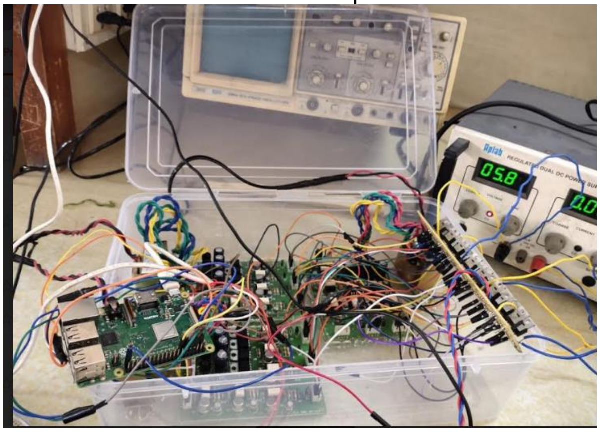


FIGURE 11
HARDWARE SETUP

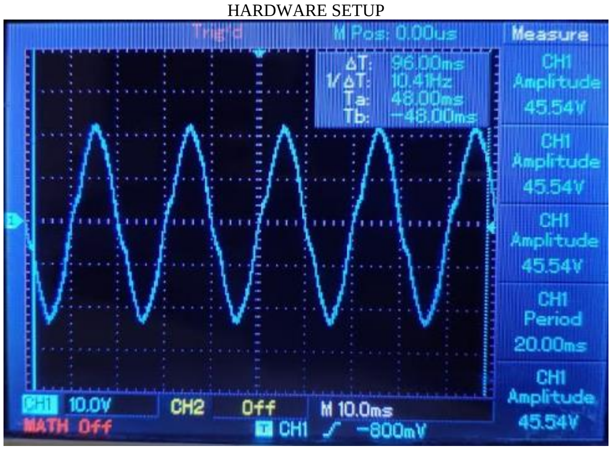



FIGURE 12
OUTPUT VOLTAGE WAVEFORM.

## CONCLUSION

| Sr. No . | Techniques implemented | THD in current by simulation | THD in current by hardware | THD in Voltage by simulation | THD in Voltage by hardware |
|---|---|---|---|---|---|
| 1 | Voltage feedback PWM | 12.38% | 12.50 % | 5.39% | 5.50% |
| 2 | Voltage feedback PWM using ANN | 11.65% | 11.75% | 3.66% | 3.75% |

In our reseach work we simulated nine level multilevel converter. We used PI controllerto control the output volatage for R-L load. Samples collected out of the simulation of P-I controller. Pair of various combinations of input and output of P-I controller are used to train the neural network. Neural Network is used as a controller in place of P-I controller. Raspberry pi is controller in hardware implementation. Raspberry pi receives the PWM signals and gated to the power electronic switches used. Hardware implementation deduce the value of THD in output voltage and output current is 3.75% and 11.75% respectively.

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**Mohan S. Selokar:** Mohan S. Selokar obtained B.E. (Electronics) from Dr. BAMU Aurangabad. He obtained post graduate degree of M.E. from university of Mumbai. He has teaching experience of 23 years.

He has published various research papers in international conferences. He is a life member of the Indian Society of Technical education (ISTE). His current research interests include power electronics and controls.

**Manoj Sankhe--**Dr. Manoj S. Sankhe has received B.E in electronics Engineering from Pune University in 1996, M.E. in Digital Electronics from Amravati University in 2002, and Ph.D degree in Electronics engineering from NMIMS in 2014. He has more than 23 years of experience in teaching & 1.5 years of experience in industry. He is currently working as the Professor & Head of Department of Electronics & Telecommunications and I/C Head of Electrical Engineering Department at Mukesh Patel School of Technology Management and Engineering, SVKM'S NMIMS University, Mumbai. He is a life member of the Indian Society of Technical education (ISTE). His current research interests include power electronics and drives, Biomedical Electronics, Optical communication Networks and Electronics Circuit Design. He has published 25 papers in National / International Conferences and Journals, one book chapter and one patent to his credit.

He has been awarded the "Best Concept Note" under the theme Technology Innovations in Diagnostic / Prognostic, Health Tech Innovations – 2015 Conference, organised by Society Applied Microwave Electronics Engineering & Research (SAMEER), IIT Bombay under the aegis of Department of Electronics and Information Technology, Government of India in technical collaboration with National Health Systems Resource Center (NHSRC) & Indian Council of Medical Research (ICMR).

He has been awarded the "Best Faculty '' award from the auspious hands of Dr. Sekar Basu, Director BARC and Dr. Rajan Saxena, Vice Chancellor, NMIMS, in SVKM'S NMIMS, Mukesh Patel School of Technology Management and Engineering, Convocation, 8th August 2015 for the academic year 2014-2015.