Semiconductor Optoelectronics, *Vol. 42 No. 1 (2023), 525-534*
https://bdtgd.cn/

Semiconductor Optoelectronics ISSN: 1001-5868

APPLICATION OF ADAPTIVE LEARNING ALGORITHMS FOR REDUCTION OF THD IN NINE LEVEL CLOSED LOOP MULTILEVEL INVERTER.

Mohan S. Selokar[1], Dr. Manoj S. Sankhe[2]
[1] Research Scholar, EXTC department, MPSTME, Mumbai, India
[2]Professor, EXTC department, MPSTME, Mumbai, India
[1]ms.selokar@gmail.com
[2]manoj.sankhe@nmims.edu

Abstract
The goal is to create a multilevel converter with a controlling technique based on an artificial neural network that has a low THD in the output voltage and current.
Methods: Multilevel converters are commonly employed in industrial applications because they offer a number of benefits, including low distortion and high efficiency. The use of multilevel converters in the converter decreased the demand for high-capacity switches. When a high output voltage and current are required by an application, they can be obtained. It generates a range of output voltage and current levels. The output voltage was controlled via voltage feedback.
Findings: Usually, output voltage is managed by a PI controller in order to lower overall harmonic distortion. We substituted an artificial neural network instead of conventional PID controller in order to reduce THD (ANN). The learning process is carried out in a closed loop, and THD is reduced. THD is shown to be quite low in contrast.
Keywords: Total harmonic distortion, neural network, and sinusoidal pulse width modulation Multilevel Inverter, Cascaded H-Bridge Multilevel Inverter.

1. Introduction

There is a requirement of high and good quality power in industrial applications and therefore, 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. Because it can be utilized with unconventional energy sources like wind and solar energy, this technology is expanding extremely quickly. PV cells are now more often used as input sources for multilevel converters. Switching losses are smaller in multilevel converters. Low harmonics are a benefit of employing a multilevel converter. If the application calls for it, a multilevel converter can be used to provide high power. Power produced by multilevel converters has extremely high quality [4]. Multilevel converters employ PWM at both high and low frequencies. Low THD and increased switching losses come as a result of high frequency PWM. High THD and minimal switching losses are the effects of low frequency PWM [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 control 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]. For a single-phase cascaded H-bridge multilevel converter, a novel natural frame control approach is proposed [14]. In [15], a harmonic minimization technique is proposed. A combination of evolutionary algorithm and neural network is used [16]. A control loop algorithm is used to control the THD and stabilize the output. Natural frame control method is introduced in [17] to control the output voltage of inverter. Asymmetric DC sources can be used and harmonics are minimized[18]

Multilevel converters are converters that have many output levels. Where large switch ratings are needed, such as in AC traction and ship propulsion, multilevel converters have a wide range of uses. Three categories of multilevel converters are recognized. The typologies that will be studied are the cascaded H-bridge, flying capacitor, and neutral point clamped. The advantages of a cascaded H-bridge are its ease of design. Each bridge circuitry utilised in a multilevel converter should have sources of the same magnitude. Different magnitudes of sources can be used. Asymmetrical configuration occurs when sources of varying magnitudes are used. It's referred to as symmetrical configuration else. It is made up of a series of cascaded H-bridge circuits. There are more levels in output voltage when there are more cascaded H-bridges.

In order to maintain a consistent output voltage, voltage feedback must be used. The output voltage is modified without the usage of a controller as the load varies. P-I controllers are commonly used to achieve constant output voltage. The P-I controller is substituted by an artificial neural network in our research to address the limitations of the P-I controller. A neural network is utilized as a controller to reduce the error between the output voltage and the reference voltage. The essential data samples for training the Neural network are obtained by simulating a multilevel converter with a P-I controller. In the power electronics and drive domains, the use of a neural network as a controller has proven to be advantageous and reliable in reducing error and controlling output voltage. Inverters are used in AC drives to regulate the output voltage delivered to the load. This research proposes using a neural network controller to eliminate harmonics in a PWM inverter. The employment of the phase shift method to adjust the phase of each cascaded H-bridge circuit has been found to be effective. The modulating signal and neural network are used to create switching angles, and triggering pulses are applied to the gate of switches.

Table 1| Simulation parameters

Sr. No.	Parameter	Values
1	Levels in output voltage	9

2	Number of switches	16
3	DC source for each CHB bridge	50
4	Fundamental Frequency	50 Hz
5	Filter capacitor	100 micro-farad
6	Load inductor	40 mH
7	Filter inductor	30 mH
8	Load resistor	100 ohm
9	Switching frequency	1350 Hz

Following the introduction in Section I, Section II explains the cascaded h-bridge multilevel inverter architecture. Section III explains how an ANN-based controller generates trigger pulses, and Section IV displays the simulation results. Section V, which ensures the inverter and neural network perform effectively together, covers parasitic impact on the switches and total harmonic distortion. The work that has been done so far is finished, and Section VI includes the use of fuzzy logic controller

2. Cascaded nine level H-bridge inverter

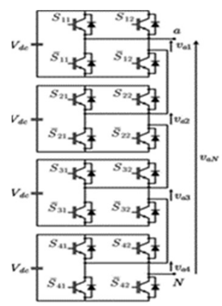


Figure 1| diagram of a single-phase cascaded H-connections bridge's Inverter with nine levels

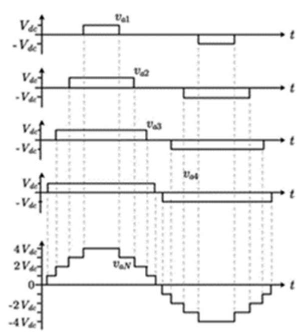


Figure 2| Waveform of a cascaded nine-level inverter's load voltage

The sum of the output voltages from each bridge is the output voltage. Each converter has an impact on the output voltage at the middle of each half cycle. For the output voltage waveform, each bridge circuit produces one voltage level in positive half cycle of output voltage waveform and one voltage level in negative half cycle of applied voltage to each CHB cell.

A constant voltage level is applied to each cascaded h-bridge. Two switches, S11 and S12, in the upper bridge circuit are gated, or switched on, to produce particular voltage level of applied voltage of each cell, in positive half-cycle of output voltage. The switches (S12, S11) continue to be in the off position because they lack gating pulses. (S11, S12) are gated and continue to be in the on state to generate an output voltage that is half-negative. S12 and S11remains in off state in negative half cycle of output voltage waveform. This cascaded H-bridge inverter has a nine-stage output voltage waveform. In a positive half cycle, the output voltage is constant and peaks at n times Vdc.

Each component needs to be able to produce both positive and negative voltage levels for a half-cycle. The sum of the voltage levels in the positive half cycle and the sum of the levels in the negative half cycle, including the zero voltage level, can be calculated using the equations below.

$$2n+1 = m \ldots\ldots\ldots.(i)$$

Where n denotes the number of cascaded H-bridge circuits and m denotes the total number of levels.

3. Adaptive learning algorithm methods

3.1Neural network using ANN

To create various controlling methods utilized in multilevel inverters, we used MATLAB Simulink. There are numerous advantages of using MATLAB. External hardware, such as a Raspberry Pi controller, can be simply connected. Pulses can be generated using the Raspberry Pi controller. The switches of a multilevel inverter are gated using generated pulses. Switches in MATLAB have a snubber circuit across them. When simulating and creating waveforms, The on state resistance of the switches is taken into account. As stated in the introduction, we utilize a PI controller to reduce error. It does, however, have certain restrictions. It is noted that the PI controller's output is continuous. The amount of THD (total harmonic distortion) is seen to rise with load voltage and load current. A little change in the load has no impact on the error signal when a PI controller is used. As a result, there is no output voltage adjustment. Based on the output voltage waveform, data samples of the PI controller's input and output are collected in a.mat file. From the P-I controller simulation, we sought to collect more samples. A larger number of data samples were used, which improved ANN training. The gathered data samples are used to train the formed neural network structure. The neural network functions similarly to the brain found in human that it makes decisions based on the input it receives. The desired output of a neural network is formed based on the data samples, training and validation, and the input. With a very small interval, input output combinations can be used. A vast number of data samples are required to train the neural network. A sizable collection of sample data values is obtained after simulating a multilevel converter with a PI controller. The simulation is done using Matlab. The PI controller's input is represented by the x variable, while its output is represented by the y variable. The ANN is trained, validated, and tested using a combination of x and y at various time intervals (Artificial neural network). We recommend that the PI controller be replaced with an ANN-based controller.

Various strategies, such as the L-M algorithm, the Basian algorithm, and scaled gradient algorithms, are available to train the ANN. We picked the L-M algorithm since it produces an MSE value of zero. Other two algorithms were used in the simulation. NARX (non linear auto regression with external input) is employed in this study. A voltage feedback approach is used to give a consistent output voltage, which is required by certain types of loads such as single phase AC motors. Our goal is to reduce present THD. Torque pulsations are caused by THD in current. Heat is generated in the motor winding as a result of torque pulsation. Artificial neural network (ANN)-based controllers have proven to be an effective replacement for traditional P-I controllers. Two hidden layers, one input layer, and one output layer make up

the ANN employed here. There are ten neurons and two delays in the hidden layer. The value of MSE is found to be 0 in this case, as shown in figure 5. The MSE value of 0 indicates that the mean squared error between targets and outputs is zero. Figure 5 shows the co-relation of regression between targets and outputs as a value of R. The approximate zero value of R can be seen here. Ten neurons make up the ANN structure that forms after the simulation. There are neurons in both the input and output layers. The input data set for ANN is the error signal obtained by comparing the reference signal with the inverter output. The output data set of the P-I controller is the output data set. The data samples created in this way are used to train, validate, and test the ANN. In the SPWM approach, the output of the ANN controller is used as a reference signal to the PWM generator. In ANN, we utilize the NARX (Nonlinear Auto-regressive with external Input) model to create the pulses that activate the MOSFETS used in the CHB converter. A dynamic time series with feedback model is used in this approach. The modulation index has been set to 0.8. The output of a multilevel converter is simulated and controlled using MATLAB simulink. There are a total of 29981 samples used.
Figures 5 and 6 demonstrate the data samples and error histograms that were obtained. The error histogram shows that the error is within acceptable limits. The probable output values of an ANN controller are estimated using this controller for any value of error input. Validation and testing are also successfully completed. The output of the tested data is extremely close to the calculated data. Table 1 lists the settings for the Matlab simulation that was used. The LC filter, which consists of a filter inductor of 30 mH and a filter capacitor of 100 microfarad, is used to shape the output voltage waveform and reduce ripples. The PWM generator receives the output from the ANN controller and modulates all four bridge circuits. The frequency carrier signal is kept extremely high, on the order of 27 * 50 Hz, to produce the gating pulses. THD is reduced when the number of gating pulses is increased. When high frequency pulses are applied, the odd order harmonics of surrounding odd harmonic frequencies are reduced to the fundamental frequency. It can be simulated and examined using FFT analysis on the resulting waveform. THD is reduced in output voltage and output current in the generated waveform, according to the simulation and FFT analysis. Figure 4 shows the ANN structure that was created and used in simulation.

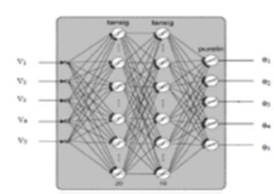


Figure 3| Structure of Neural Network

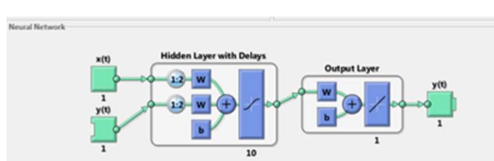
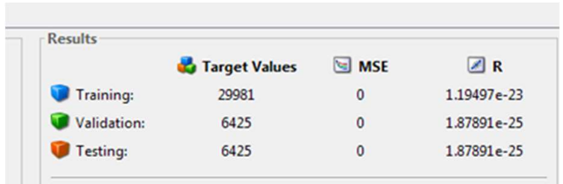


Figure 4| Used Neural Network structure


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| Distribution of Data samples

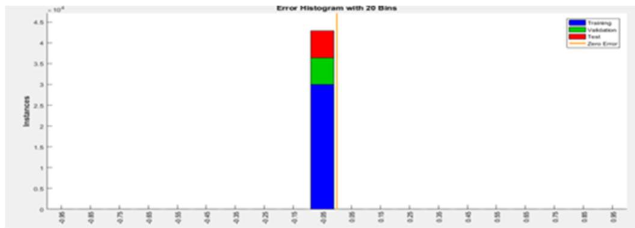


Figure 6| Error Histogram formed after training

3.2 Fuzzy logic controller

The fuzzy logic controller can be used as a closed loop controller. The Fuzzy logic controller is adaptive in nature to operate in closed loop environment without any mathematical model. The Phase Disposition (PD) Pulse width modulation (PWM) technique is used for generating triggering pulses to the switches in the inverter. The OR logic is used to implement FLC.

The out RMS voltage is compared with the reference value to generate error. Mamdani type Fuzzy Logic Controller (FLC) is used for control operation according to the error value. We used seven functions from extreme low to extreme high in fuzzy controller. Input and output of PID controller is divided into seven ranges. OR rule is used between input and output values.

4. Simulation results

4.1 ANN method

Simulations are carried out using MATLAB simulink. The purpose of using MATLAB simulink is that the switches used are incorporated with protection circuit called as snubber circuit. Resistance during on time of the power devices are considered as in the case of practical situations. Add on hardware can be incorporated and can be used as subsystem. In this research work we carried two different simulations. One simulation is with P-I controller ans one with the the use of ANN controller replacing P-I controller. After a certain number of trials, the Kp and Ki values utilized in the simulation are set. The simulated output waveform of current and voltage is used to calculate the value of THD using FFT analysis. The difference between the obtained THD values is tabulated. The samples of data are collected and saved in a.mat file. The ANN block is trained with 70% of the data samples available. 15% of the data samples are used for testing, while the remaining 15% are used for testing. A PWM generating block is used, which produces a carrier signal internally with an extremely high carrier frequency of around 27*50 Hz. To construct the error signal, a signal with a peak voltage of 200V and a frequency of 50 Hz is utilised as the reference signal. A voltage source provides a 50 V dc input voltage to each cascaded H-bridge circuit. The MATLAB/ SIMULINK programme is used to evaluate the performance of an ANN-based cascaded H-bridge nine-level inverter with isolated dc sources. To reduce ripples, a filter is utilised at the inverter's output. Table 1 lists the simulation parameters utilised in the simulation. For comparison, simulations without and with ANN are conducted done.

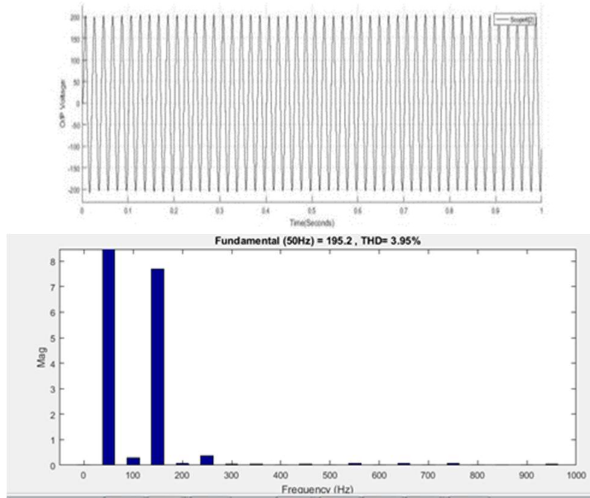


Figure 7| Analysis of the load voltage waveform and FFT (PI controller)

The output voltage is nine levels stepped. The output voltage's overall harmonic distortion is significantly reduced. With the use of FFT analysis, THD is determined.

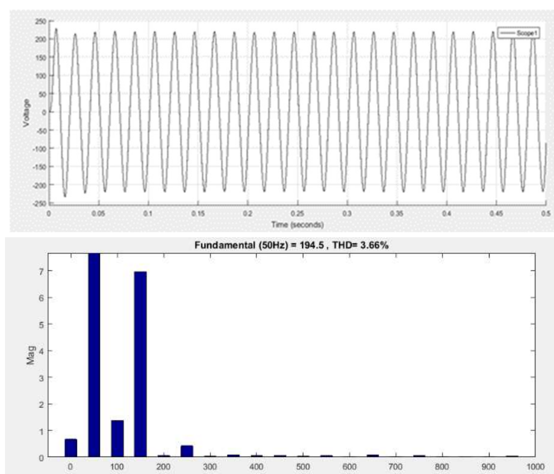


Figure 8| Load voltage waveform and its FFT analysis of closed loop ANN based control method

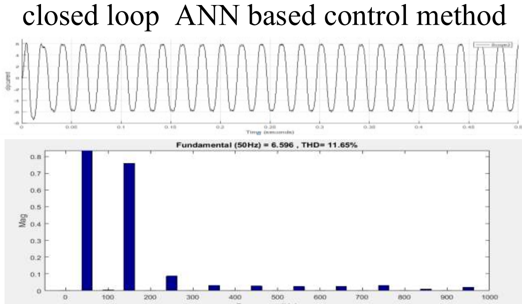


Figure 9| Analyzing the current waveform and FFT of an ANN-based converter

A modulation index, which is the ratio of the peak of the modulating signal to the peak of the carrier signal is set by using PWM generator block and in result THD is adjusted. In our study, it is set to a value of 0.8. Using the parameters on the PWM generator block, the phase delay to each converter can be changed. The full 180 degrees of each half cycle are distributed across

four cascaded H-bridge circuits. The settings of the PWM block control the type of output voltage waveform. The output voltage reduces THD and ripples. As a result, the efficiency of the DC to AC conversion increases. With the help of ANN by using as a closed loop controller, very high voltage and high current can be obtained. It also reduces odd harmonics resulting in a very less values of THD in load voltage and load current.

Smaller filters can be applied to the entire load when using ANN. The nine-level H-bridge inverter is connected in cascade with the resistive-inductive loads. The output voltage is kept constant at the reference level. The total harmonic distortion of the voltage is 3.70 percent. Total harmonic distortion (THD) in the current waveform with the PI controller is 3.47 percent, whereas with ANN, THD is 3.66 percent and 2.40 percent in the voltage and current waveform, respectively. Power factor is approaching to the value of 1. Capacitor connected across load is contributing for power factor correction. Due to the power factor correction, losses are minimized and efficiency is increased. Due to high power factor losses are minimum and efficiency is increased.

Table 2| Comparison of result of different control techniques.

Sr. No.	Techniques simulated	THD in current	THD in Voltage
1	Closed loop PWM using PID	3.47%	3.70%
2	Closed loop PWM using ANN	2.40%	3.66%

4.2 Fuzzy logic control Method

Table 3| comparison in result of closed loop technique using different adaptive learning algorithms

Sr. No.	Techniques simulated	THD in load current	THD in load voltage
1	Closed loop PWM using FLC	2.39%	3.61%
2	Closed loop PWM using ANN	2.40%	3.66%

5. Parasitic effect

Below is a list of the advantages of utilizing POWERSIM.

A software programme called PSIM may be used to simulate any electronic circuit, although it was designed with power electronics and motor drive simulations in mind. The simulation algorithm used by PSIM is based on trapezoidal rule integration and nodal analysis. The parasitic impact (parasitic inductance and capacitance) is taken into account in power electronic switches. PSIM simulates much more quickly than SPICE-based simulators because it employs the ideal switch. Mosfet models may be used to represent the gate drive circuitry, reverse recovery effects, and switch transition. The parameters tdr, tr, tdf, and tf are taken into consideration. In the MATLAB simulation, the switches are assumed to be perfect switches with a resistance ron and a snubber circuit. The output voltage and current total harmonics are recorded and decreased to 3.66 percent and 2.40 percent, respectively, after simulating the circuits.

6. Conclusion

We modeled a nine-level multilevel converter in our research. The output voltage for the R-L load was controlled using a PI controller. Samples taken from a simulation of a P-I controller. To train the neural network, a pair of different combinations of P-I controller input and output are used. In place of a P-I controller, a neural network is employed as a controller. It is possible to implement hardware that will reduce THD in output voltage and output current. To reduce ripples, an output filter is utilized across the load. The simulation circuits are tested for different RL loads of different power factor and wattage. Output voltage is stabilized to the reference value in all the three closed loop techniques simulated. The use of fuzzy logic controller and ANN based controller gives rise to very low value of total harmonic distortion in load current and load voltage. Fuzzy logic controller and ANN based can be used to implement the hardware as both results in improved performance in the form of total harmonic distortion and efficiency. Power factor is approaching to the value of one due to the power factor correction by the the use of shunt capacitor. Parasitic effect is the part of our study to understand the effect of high switching frequency.

References

1. J. Rodriguez, J. S. Lai and F. Z. Peng,: Multilevel inverters: Survey of typologies, controls, and applications. IEEE Trans. Ind. Elect., vol. 49, no. 4, pp. 724-738, Aug. 2002.
2. Beser, E.; Camur, S.; Arifoglu, B.: Beser, E.K..: De-sign and application of a novel structure and topology for multilevel inverter. IEEE SPEEDAM, Tenerife, Spain, 2008, pp. 969 – 974.
3. R.H. Baker.: High-Voltage Converter Circuit. U.S. Patent Number 4,203,151, May 1980.
4. S. Mekhilef and M. N. Abdul Kadir.: Voltage control of three-stage hybrid multilevel inverter using vector transformation. IEEE Trans. Power Electron.,vol.25,no.10,pp 2599-2606, Oct. 2010.
5. L.M. Tolbert, F. Z. Peng, T. G. Habetler.: Multilevel PWM Methods at Low Modulation Indices. IEEE Trans. Power Electron.,vol. 15, no. 4, pp. 719-725, July 2000.
6. Zongbin.: A Novel DC-Power Control Method for cascaded H-Bridge Multilevel Inverter. IEEE Trans. On industrial Electronics 2017 .
7. Jeyabharath Rajaiah.: Harmonic Minimization in seven level cascaded multilevel Inverter using Evolutionary Algorithm. Circuits and Systems , 2016, pp2309- 2322.
8. Li C. H. Ynag et al.: A self Learning Particle swarm optimizer for global Optimization. IEEE Transactions on Systems, Man and Cybernetics(2012).
9. Rodriguez, J., Lai, J.-S. and Peng, F.Z. (2002,).: Multilevel Inverters: A Survey of typologies, Controls, and Applications.. IEEE Transactions on Industrial Electronics, 49, 724-738
10. Taghizadeh, H. and Tarafdar Hagh, M. (2010).: Harmonic Elimination of Cascade Multilevel Inverters with Non Equal DC Sources Using Particle Swarm Optimization. IEEE

Transactions on Industrial Electronics, 57, 3678-3684.

11. Roh Chan.: Simple Algorithm with fast dynamics for cascaded H-bridge Multilevel Inverter based on Model Predictive Control Method. IEEE Conference Proceedings(2017)

12. F. J. t. Filho.: Real time Selective Harmonic Minimization in cascaded Multilevel Inverters with varying DC sources." IEEE Power Electronics specialists Conference (2008).

13. Ricardo P. Aguilera et al.: Model Predictive Control of cascaded H-Bridge Inverters based on a Fast-optimization Algorithm. IEEE Conference(2015).

14. Daliang Yang et al.: Natural Frame Control of Single-Phase Cascaded H-Bridge multilevel Converter Based on Fictive-Phases Construction.", IEEE transactions on Industrial Electronics(2018)

15. Mohan Selokar, Manoj Sankhe: Harmonic in multilevel converter using an adaptive learning algorithm", International journal of engineering and applied physics, vol 1 No-3,pp. 311-318 .

16. Libing Wang et al, " A Real-Time and closed-Loop Control Algorithm for Cascaded Multilevel Inverter Based on Artificial Neural Network.", Hindawi Publishing Corporation The Scientific World Journal Volume 2014, Article ID 508163

17. Daliang Yang et al, "Natural Frame Control of Single-Phase Cascaded H-Bridge multilevel Converter Based on Fictive-Phases construction," IEEE transactions on Industrial Electronics(2018)

18. Tarmizi Tarmizi, " Design and verification of improved cascaded multilevel inverter topology with asymmetric DC sources," Journal of Power Electronics, Vol 19, No 5 pp 1074-1086, septemeber 2019