

# Harmonic Minimization in a Modified Cascaded Multilevel Inverter for Islanded Microgrid using two Switching Techniques

Mamatha Sandhu and Tilak Thakur

*Chitkara university, Punjab Campus, PEC University of Technology,  
Chandigarh, India  
mamatha.sandhu@chitkara.edu.in, tilak20042005@yahoo.co.in*

## **Abstract**

*Renewable energy sources are playing very wide role for their abundant availability. Photovoltaic systems are widely used for their cleanliness and less maintenance. Multilevel inverter technology has become an emerging technology with renewable energy sources and are playing a wide role in designing various topologies. In this paper, an islanded microgrid from a remote area fed from solar PV system through a modified topology of 7 level 6 switches cascaded H bridge multilevel inverter using two different switching techniques are presented. A solar photovoltaic (PV) system and an energy storage is fed through DC-DC boost converter which is equipped with incremental conductance maximum power point tracking (MPPT) algorithm to extract maximum solar energy is considered in the islanded microgrid. A comparison of Sinusoidal Pulse Width Modulation (SPWM) using Particle Swarm Optimization (PSO) and Artificial Neural Network (ANN) switching techniques which leads to the improvement of total harmonic distortion (THD) for power quality applications is carried out. Due to modified topology reductions in the number of power switches, losses are obtained. To verify the performance of the switching techniques simulations are carried out using MATLAB/SIMULINK and the total harmonic distortion is calculated.*

**Keywords:** PV, SPWM, CHBMLI, MPPT, ANN, PSO, THD

## **1. Introduction**

Ever increasing in the energy demand, fossil fuels exhausting nature and growing prices, environmental problems caused like CO<sub>2</sub> emissions from conventional power plants have made more research to be carried out on renewable energy based distributed power generation systems. Various renewable energy sources are available among them the wind and photovoltaic are very promising and popular around the globe. Microgrid can be framed with intelligent control using both renewable sources wind and solar with energy storage. These type of microgrids at a remote location can help to depend less on the power grids. Microgrid fed from renewable energy resources is discussed in [1-3]. These papers are not including the performance of system parameters such as power quality, efficiency of the system, under various operating conditions. The place is very much important for the availability of the renewable resources for continuous generation of electricity supply. It is very much required that the system must be used at optimum point to harness maximum energy and in turn reduce the cost price. Multilevel inverters are attracting the industries due to their ability to produce smooth sinusoidal output voltage waveforms with lower switching frequency. It has spread in the research areas for studying higher voltages and power applications [4] due to the lower switching losses, higher efficiency and EMI inference. Multilevel inverters are available for both high switching and low switching configurations. With high switching means lower efficiency

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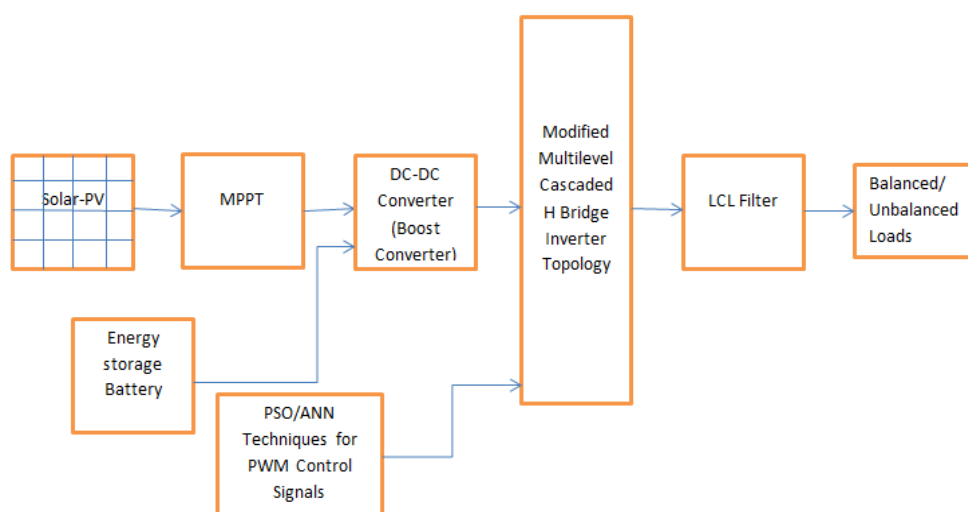
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and higher switching losses and low switching frequency means higher efficiency and low switching losses as seen in the literature work. In this paper, in order to generate the switching signals for the multilevel inverter a sinusoidal pulse-width modulation (SPWM) technique is implemented using Particle Swarm Optimization (PSO) PID and Artificial Neural Network (ANN) techniques.

This paper presents two different switching techniques which compares the improvement in the total harmonic distortion and also can be seen that maximum power point technique improves the THD along with these techniques. The paper is divided in five sections as Section-II is covered with overall scheme of the system description of components. Section-III is covered with the switching techniques used for the multilevel inverter of the microgrid. Section-IV presents the simulation diagram of the microgrid for all the switching techniques simulated using MATLAB/SIMULINK. Section -V presents result analysis of the above models.

## 2. Design of the Overall System of Isolated Microgrid

The photovoltaic system converts the light energy of sun into electrical energy with the help of solar stages. The generated electricity is in direct current (DC) form. An energy storage battery is used for continuous power supply. A DC-DC boost converter is connected to the solar PV system along with battery storage and is equipped with maximum power point tracking (MPPT) – Incremental Conductance algorithm for extracting maximum energy. In [5], maximum power point (MPP) changes continuously because of continuous changes in the irradiance level of the sun, P&O takes a wrong calculation due to perturbation, but Incremental Conductance improves due to the samples taken for voltage and current for MPP calculation. With the multilevel inverters the harmonic distortions can be reduced with the increase in the higher levels of output. With separate dc sources the cascaded multilevel inverters are used [13], in our research a modified topology of 7 level 6 switches cascaded multilevel inverter [7] is used. Switching power devices causes harmonics in the sensitive equipments which are connected to the non-linear loads for the applications of higher kilowatts, hence an LCL-filter is connected at the output of modified multilevel inverter to reduce the total harmonic distortion (THD) in the isolated microgrid as shown in the block diagram of Figure 1 below [1]. An LCL filter is used in the circuit due to good attenuation capacity for higher-order harmonics and dynamic characteristics [6].



**Figure 1. Schematic Diagram of Isolated Microgrid Network Fed By Renewable Energy Source (PV)**

## 2.1. Modified Cascaded H Bridge Multilevel Inverter (CHBMLI)

A modified topology of 7-level 6 switches inverter as shown in Figure 2. chooses suitable sinusoidal modulation technique as the power circuits [10]. The output voltage has seven levels: zero, positive ( $+V_{dc}, +2V_{dc}, +3V_{dc}$ ) and negative ( $-V_{dc}, -2V_{dc}, -3V_{dc}$ ) supply dc voltage,  $V_{dc}$  as the supply voltage. By comparing the carrier frequency and switching functions, the harmonic components of the output voltage are calculated.

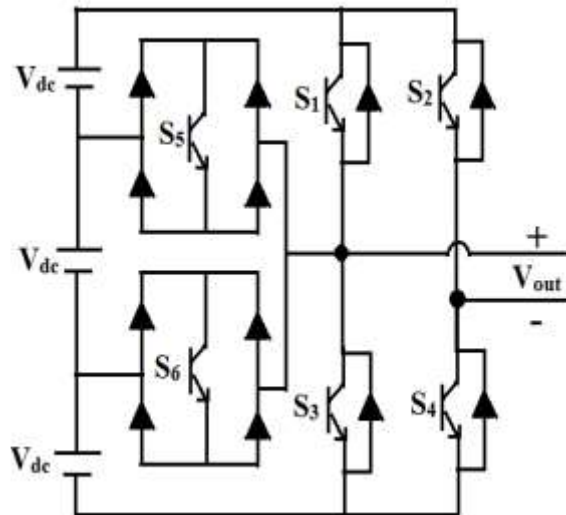


Figure 2. Modified 7 Level 6 Switches Topology [10]

## 3. Sinusoidal Pulse Width Modulation (SPWM) Switching Techniques

In order to digitize the power widely used in power electronics sinusoidal pulse width modulation generates the sequence of pulses of voltage by switching on and off the power switches. SPWM technique is mainly used in industrial applications. Here, constant amplitude pulses with various duty cycle for every period is considered. Modulation of the width is carried out to acquire the output voltage control there by reducing its harmonic contents. Most commonly used the Sinusoidal pulse width modulation or SPWM method is used in motor control and inverter applications [5].

### 3.1. Particle Swarm Optimization (PSO) Technique with PID controller

The particle swarm optimization (PSO) is an effective and fastest optimization algorithm to define the optimal solution for the non-linear issues. Each time particles can be created with new values to calculate the approximate solution w.r.t both position and velocity of vectors. In enter search space, position vectors said to be  $Y_i = [y_1, y_2, \dots, y_D]$  and the velocity vector  $V_i = [v_1, v_2, \dots, v_D]$ . As discussed in [8] the flowchart is used for the optimal solution to calculate the switching angles using PID controller. The cascaded H-bridge multilevel inverter with PID controller is shown in [10]. A linear combination of the P, I and D contributions carried out on the error is the PID controlled gate signals which are generated by sinusoidal pulse width modulation technique. The three isolated dc power sources are connected to the cascaded H-bridge seven level inverter. The output of the PID controller is multiplied with the unit reference signal to provide the required modulating signal (ms) and is used to produce the gating pulses in association with a carrier. The output of the cascaded H-bridge 7 level 6 switches inverter is given to the load through LCL filter to obtain sinusoidal output ( $V_o$ ) and is compared with the reference voltage ( $V_{ref}$ ) to produce the error signal ( $e$ ).

### 3.2. Artificial Neural Network (ANN):

The ANN is used to generate optimal switching angles in which an input neuron is fed by the modulation index, where a single hidden layer and multiple outputs represents a switching angle. To learn the switching patterns; and trained ANN used to estimate the optimum switching angles of inverter are discussed [9]. In the field of power electronics and electric drives section the application of ANN is growing very fastly. In controlling dc-ac inverters for controlling the voltage of inverters for ac motor drives ANNs are being used. Non-linear input-output mapping is implemented in feed forward ANN. Any objective function can be selected for the optimal switching pattern which depends on the desired modulation index.

In the presented paper, an alternative switching angles look-up table to generate the optimum switching angles for multilevel inverters is developed using neural network predictive control simulink library of MATLAB. Multi layered feed forward propagation network is used where the output voltage is controlled continuously with the modulation indexes which helps in not using the memory for look-up table after training the ANN [11].

## 4. Matlab/Simulink Simulations

### 4.1. Overall Design Model using PSO-PID Technique

Modified topology of 7 level 6 switches cascaded multilevel inverter with non-linear loads and an LCL-filter is connected at the output of modified multilevel inverter of islanded microgrid model using MATLAB/SIMULINK as shown in the Figure 3 below. PV Solar Voltage :-  $I_{max} = 9A$ ,  $V_{max} = 1.88kV$  DC, Power = 16.92kW. Battery = 100Ah, Grid output voltage = 173.20kV AC.

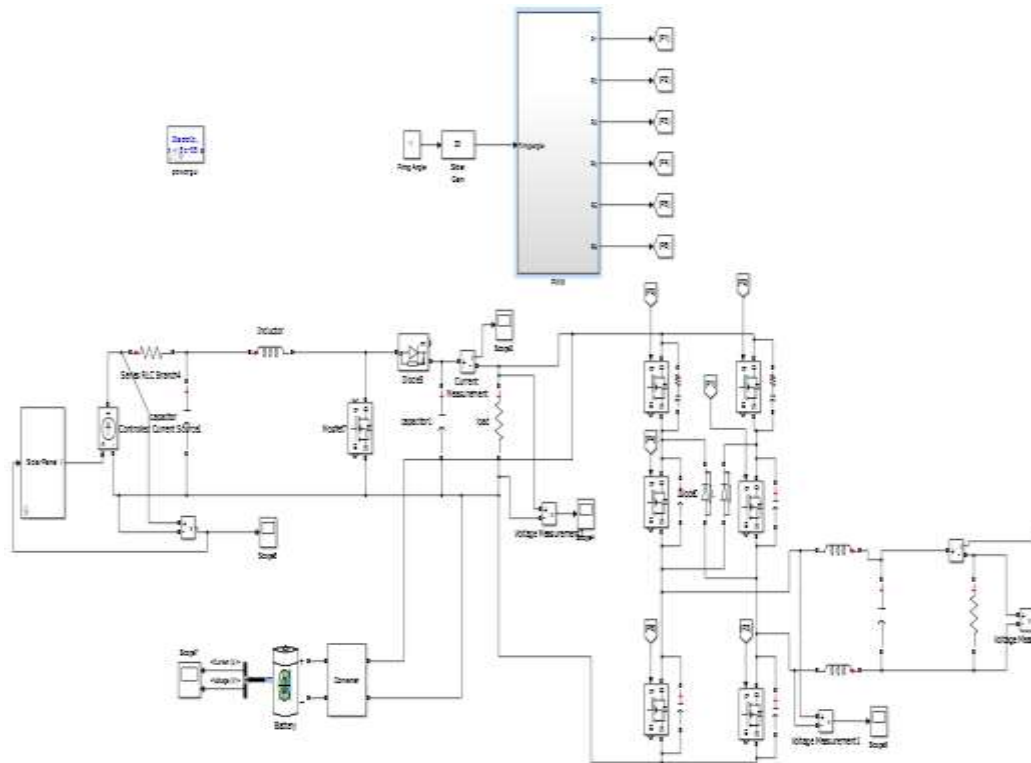


Figure 3. Overall System Design using PSO –PID Technique

#### 4.2. PSO-PID Controller

The input of the PID controller is error  $e$ . The designed values of  $K_p$ ,  $K_i$  and  $K_d$  are 10, 0 and 1 respectively. This paper chooses the sinusoidal PWM control strategy each pulse width is varied in proportion to the sine wave amplitude determined at the same pulse [10]. Specifications: Type; SPWM Carrier frequency = 3Khz, Operetaing Frequency=50Hz, Gain= $K=6500$  Phase delay= 0 as shown in Figure 4.

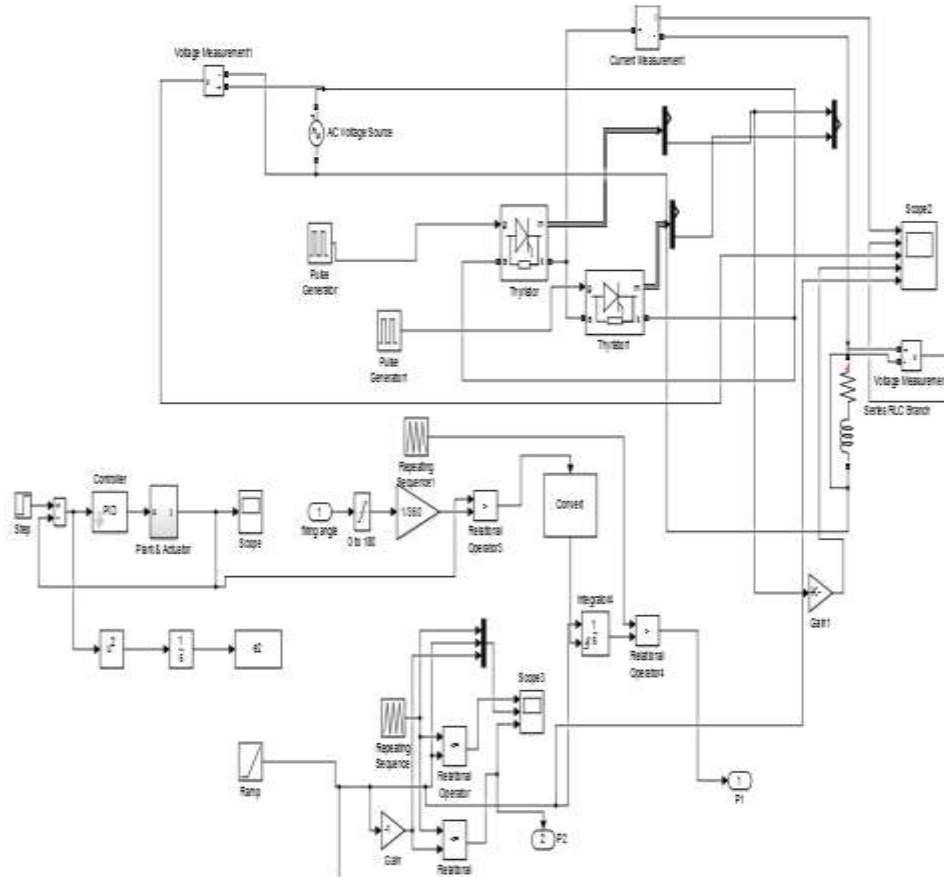
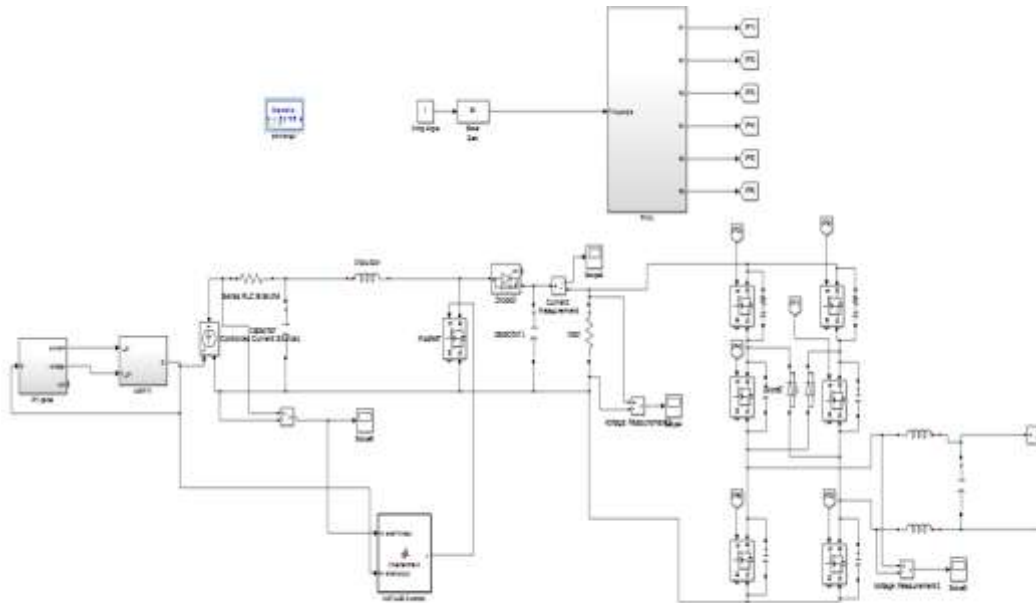


Figure 4. PWM Switching Gate Signals for CHBMLI using PSO-PID

#### 4.3 Artificial Neural Network (ANN) Matlab/Simulink Model

The network model is integrated with 7 level 6 switches modified cascaded H Bridge multilevel inverter to generate the switching angles using the MATLAB/SIMULINK. [11] Hidden layers and activation functions which optimize the performance are used for training. Sigmoid activation function is used here. Once the training pulse is terminated, the control sequence of the inverter obtained by ANN is generated. For a given set of input values to the ANN, step wise calculations are carried out in the forward direction to obtain the output pattern. The gradient descent method is used to alter the weights at the starting time from the output layer to generate the mean square error(MSE) for a set of input patterns to be minimized.

PV Solar :  $I_{max} = 9A$ ,  $V_{max} = 4.5kV$  DC, Power = 40.5kW, Open circuit voltage - 64.2V, Short circuit current= 5.96. Grid output Voltage = 216.25KV AC.

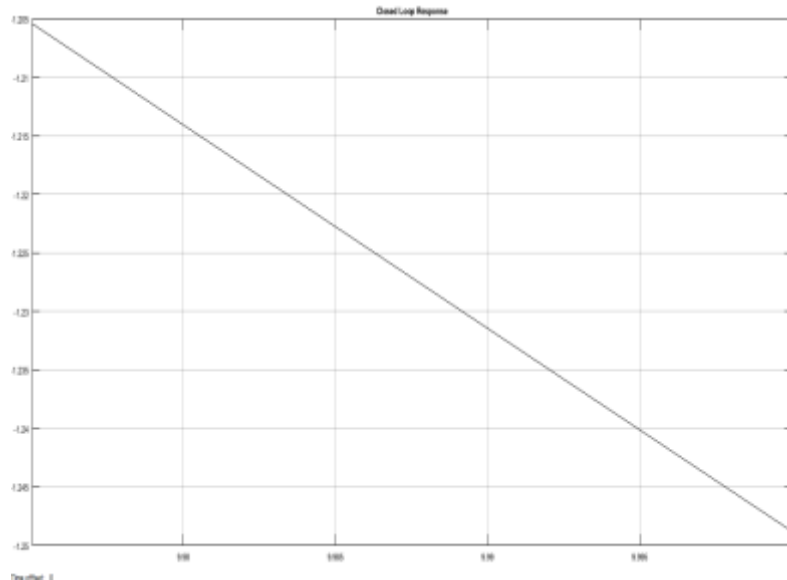


**Figure 5.Overall System design of Artificial Neural Network using Matlab/Simulink**

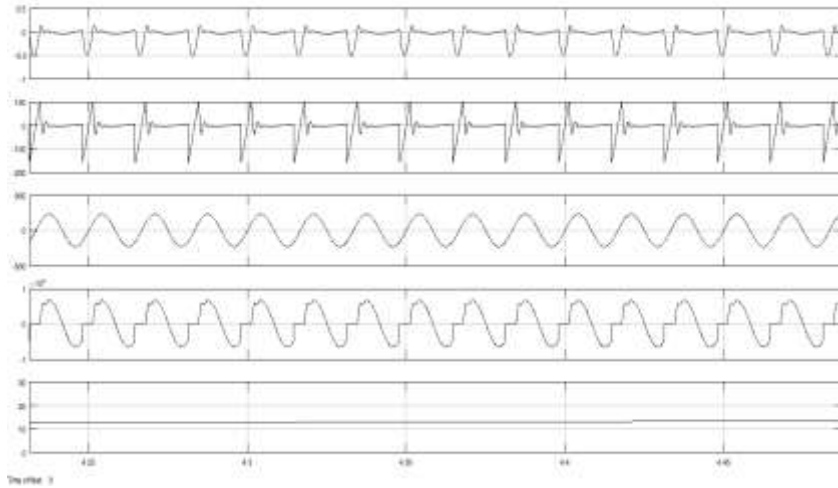
## 5. Result Analysis of PSO AND ANN Techniques

### 5.1. PSO Technique

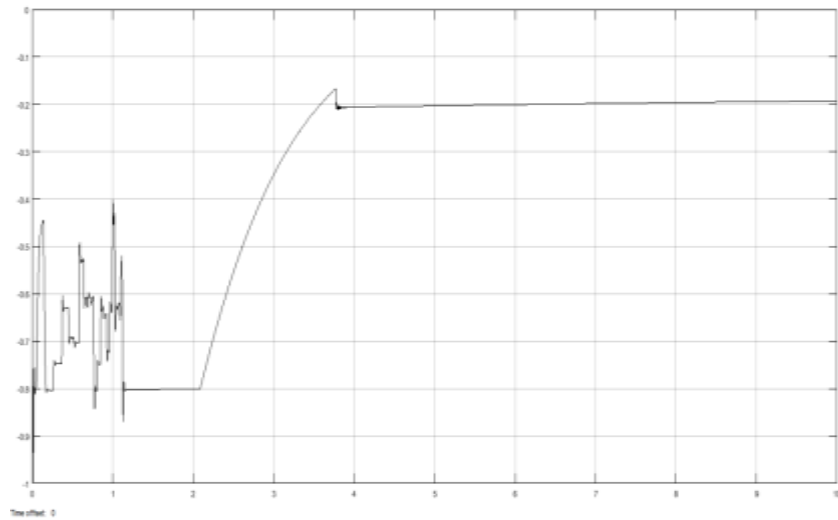
Closed loop response of PID Controller is as shown in Figure 6. and voltage and current measurements with gain are shown in Figure 7. The output voltage of the microgrid is 216.25KV AC as shown in Figure 8. The total harmonic distortion obtained is with the value of 70.29% as seen in Figure 9 for the Fundamental frequency of 50Hz.



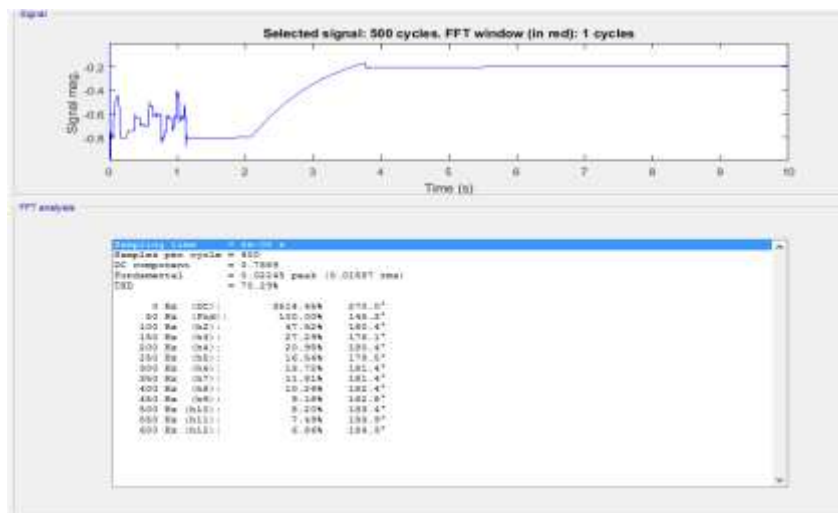
**Figure 6. Closed Loop Response of PID Control using PSO Technique**



**Figure 7. PSO-PID Voltage and Current Measurements With Gain and Ramp Output**



**Figure 8. Load Output Voltage using PSO Technique of the Microgrid**



**Figure 9. Power GUI FFT Analysis for PSO Technique**

### 5.2. Artificial Neural Network (ANN) Technique

A Multi- Layer Perceptrons (MLP) neural network concept is applied to map between the modulation rate and switching angles to be used further. Thus, neural network generates the appropriate switching angles for the inverter later by learning. The Modulation Index table is as shown in the Table 1 to obtain the switching angles. The load output voltage is as shown in Figure 9 with the output voltage of 200KV AC and the total harmonic distortion is 42.96% which is reduced as compared to PSO technique as tabulated in Table 2.

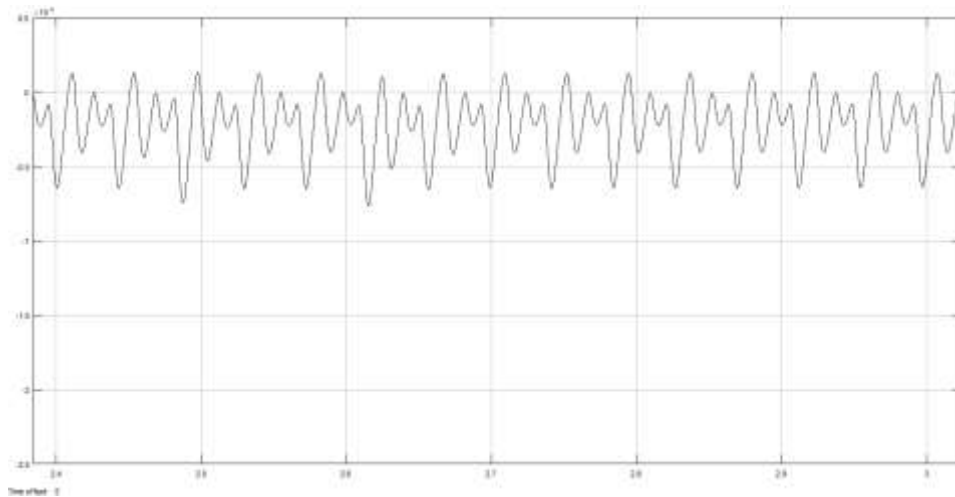


Figure 10. Load Output Voltage of ANN Technique

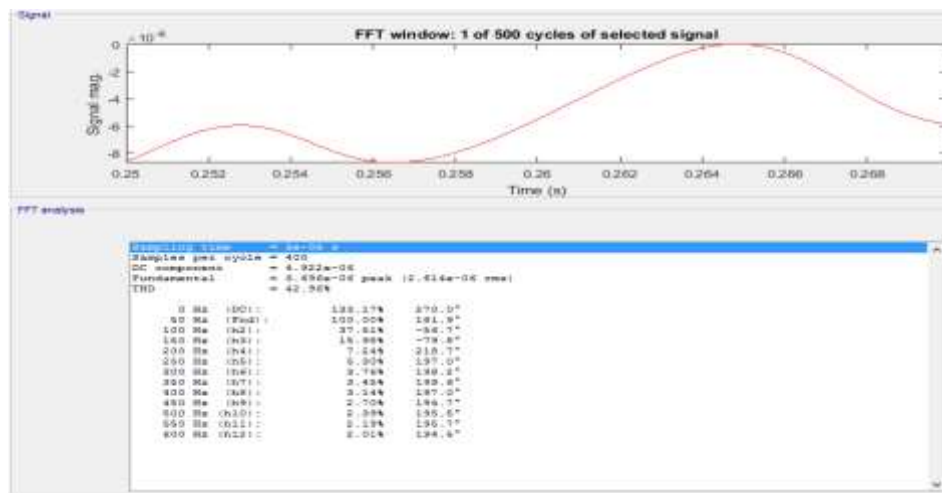


Figure 11. Power GUI FFT Analysis of ANN Technique

### 5.3. Comparative Analysis

As discussed in [12], the comparative analysis of the simulation of SPWM PSO -PID Technique and ANN technique for 7 level 6 switches modified cascaded H bridge multilevel inverter using MATLAB/Simulink system is carried out. The total harmonic distortion of the ANN technique is improved compared with the PSO-PID technique as shown in Table.2, thus can be seen that power quality of the microgrid in terms of total harmonic distortion (THD) is improved.



**Table 1. Modulation Index Table**

Modulation Index (M)	Switching angles					
	$\theta_1$ (rad)	$\theta_2$ (rad)	$\theta_3$ (rad)	$\theta_4$ (rad)	$\theta_5$ (rad)	$\theta_6$ (rad)
0.6	0.0153	0.5	0.152	0.95	0	0
0.85	0.1	0.155	0.23	0.35	0	0
0.7	0.01	0.639	0.0011	0.57	0	0
0.75	0.02	0.32	0.258	0.125	0.012	0.013
0.8	0.0132	0.3	1.438	0.023	0.045	0.112
0.85	0.015	0.25	0.184	0.19	0.05	0.02
0.9	0.018	0.875	0.02	0.334	0.023	0.013
0.95	0.0123	0.269	0.145	0.12	0.02	0.05
1	0.011	0.5	1.25	0	0	0

**Table 2. Comparison of the Values of Modified Chbml**

Switching Techniques	Total Harmonic Distortion
SPWM PSO -PID	70.29%
ANN	42.96%

## 6. Conclusion

In this paper, a design comparison analysis using MATLAB/SIMULINK of SPWM based PSO-PID and ANN techniques are carried out, the approach is suggested using 7 level 6 switches modified cascaded H bridge multilevel inverter. In this comparative analysis it is found that the SPWM technique is not easy compared with ANN Technique. SPWM based on PSO-PID controller and ANN techniques are used to enhance the power quality and optimize the harmonic problems for high power application systems. An approach for the computation of switching angles using artificial neural networks is seen much easier and the solutions are found better. PSO here, is used to improve approximate solutions. The trained neural network were simulated in MATLAB for online determination of the angles. As a result, total harmonic distortion is improved using ANN technique to attain the global solution by modified cascaded H bridge multilevel inverter.

## 7. Future Scope

The paper has limited the work to MPPT solar renewable energy source only. Many other renewable energy sources will be implemented in the future. Design of new topologies will be carried out to reduce the switches and DC sources for cascaded multilevel inverters for various voltage levels and artificial intelligent techniques will be applied for power quality improvement with grid integration.

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