Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 3, Issue 5, 2025

DESIGN AND PERFORMANCE ANALYSIS OF A MULTILEVEL INVERTER USING A BIPOLAR PWM SWITCHING SCHEME

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DOI: https://doi.org/10.5281/zenodo.15393100

Keywords
Multi-Level Inverter
Pulse Width Modulation
Power Quality
Total Harmonic Distortion
Phase DispositionModulation
Efficiency Optimization

Article History
Received on 04 April 2025
Accepted on 04 May 2025
Published on 12 May 2025

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Abstract
This paper focuses on the design and simulation of a single-phase PWM multi-level inverter using the bipolar switching scheme to improve efficiency and quality with the help of pulse width modulation (PWM) for DC to AC voltage converters. This research emphasizes on obtaining well defined output voltage, reduction of total harmonic distortion (THD), and enhancing energy conversion effectively and efficiently by utilizing multilevel inverter and phase disposition (PD) modulation techniques. The inverter shows outstanding results, achieving an efficiency of 96% and producing an output voltage of 110-Volts at 60 Hz from the 80-Volt DC input from each bridge. In this particular simulation in MATLAB, the inverter demonstrates a significant reduction in THD, with an output voltage THD of 1.36% and a current THD of 0.13%. Our approach is effective and has the potential to produce stable AC output even with RL loads and maintain high power quality. The paper highlights the significance of modulation techniques in increasing the performance of inverters and also underscores the importance of selecting suitable methods for different applications to ensure the best performance and efficiency.

INTRODUCTION

The demand of energy is growing with each passing day. To compare with traditional fossil fuel sources, renewable energy sources like wind, solar, and tidal have recently become much more important in providing limitless, pollution-free energy supplies. One of the important renewable energy sources created to efficiently take DC output from sunlight is photovoltaic (PV) energy systems, an inverter is needed to transform the PV's DC output into AC electricity. [1].

A power electronic circuit known as a multi-level inverter converts D.C voltage into A.C. voltage. The multi-level inverter helps in reduction of voltage and current THD. Thus, in high-power applications, multi-level voltage source converters are frequently used [2]. It has exciting features like high-voltage ability, reduced power device stress and approximately-sinusoidal output. Multilevel inverters are utilized for AC transmission systems, clean energy sources, and power supplies without disruption [3].

There are many techniques. Based on the idea of comparing a triangular carrier signal with a sinusoidal reference waveform, the most often used approach is called Sinusoidal Pulse Width Modulation (SPWM) [4].

1.1 H Bridge

H-Bridge inverters are popular because of their simplicity and high-power capacity. It obtained its name from its visual representation, which resembles the H shape. It consists of four switches and a voltage source as an input. It has four switches as well as a voltage source for the input. We obtain a square waveform by utilizing the input signal to electronic switches to close the appropriate pair of switches. We obtain +Vdc by closing S1 and S3, and -Vdc by closing S1 and S4, as shown in Fig.1. Despite the alternating output, it is not recommended to use it with electrical appliances due to its non-sinusoidal nature [5].

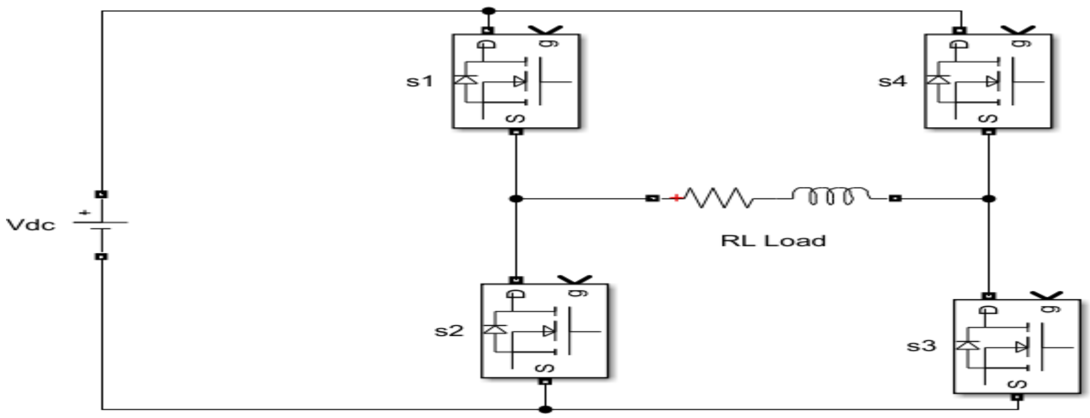

Fig. 1. Circuit of H-bridge with RL load

1.2 Square Wave Inverter

The simplest switching techniques for the full-bridge inverter produce a square wave output voltage. When S1 and S2 are closed, we get +Vdc, and closing S3 and S4 gives us -Vdc. A square wave voltage is produced at output when the load voltage changes between +Vdc and -Vdc. However, the alternating output is not sinusoidal. The load's current waveform is determined by its individual components. The current waveform for the resistive load is the same as the output voltage's shape. The current of an inductive load is more sinusoidal than its voltage due to the filtering effect of inductance. In case of inductive load, the switches must be bidirectional because current flows from either side [6]. The output of Square wave inverter is shown in Fig.2.

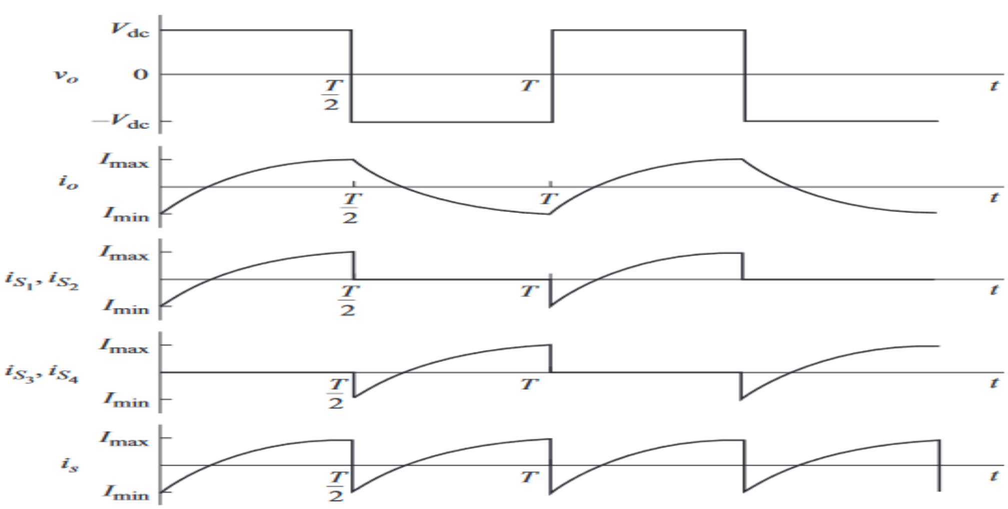

Fig. 2. Output waveform of Square-Wave Inverter using RLload [6]

1.3 Half-Wave Inverter

It is similar to the H bridge, but in this circuit, the number of switches is reduced to two by dividing the D.C source voltage into two parts with the capacitors. Each capacitor will have a voltage Vdc/2 across it. When S1 is closed, the load voltage is -Vdc/2. When S2 is closed, the load voltage is Vdc/2. Thus, we have a square wave output. The voltage across an open switch is twice the load voltage, or Vdc. The only drawback is that when the switch is open, the voltage across is twice the load voltage, or Vdc, and for inductive loads, we need a bi-directional switch and the circuit of half-wave is demonstrated below [6].

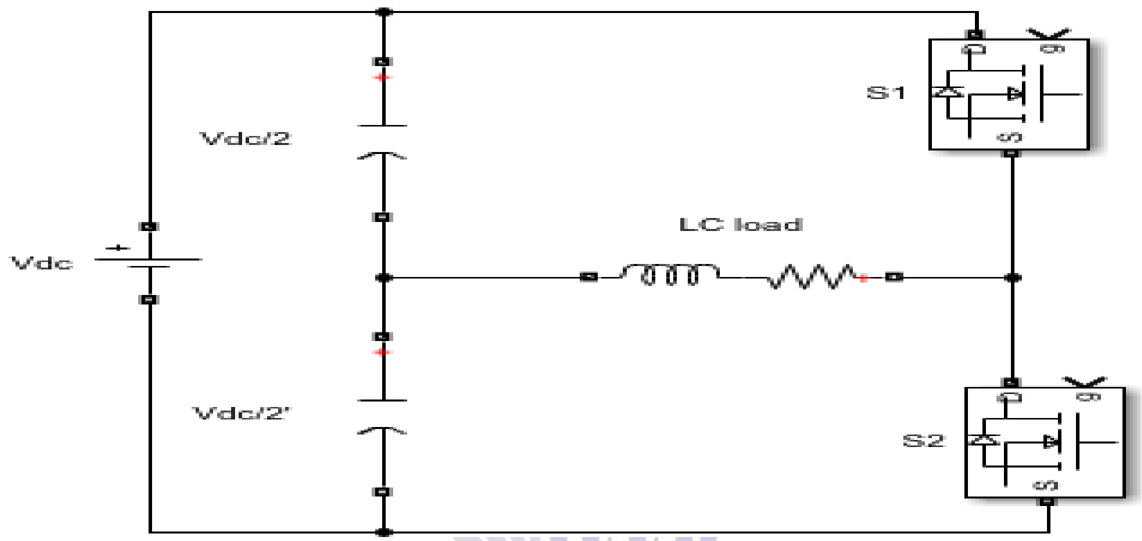

Fig. 3. Circuit of half wave inverter with RL load

1.4 Diode-Clamp Inverter

In power systems, a diode-clamped inverter, also known as a multilevel inverter, achieves different voltage levels. This topology generates stepped output voltages by using diodes as clamping devices to regulate the DC bus voltage. Switches, diodes, and capacitors are the main parts of a diode-clamped inverter. These parts are connected to generate various voltage levels. Phases are connected to aseries of capacitors to produce different output voltage levels. By adding more capacitors, the diode-clamped inverter concept can be expanded to new heights and provide more control over voltage. Due to advancements, the three-level inverter has become increasingly popular, with industrial applications being one area where this inverter has been extensively used [7] and the circuit diagram is shown in Fig. 4 .

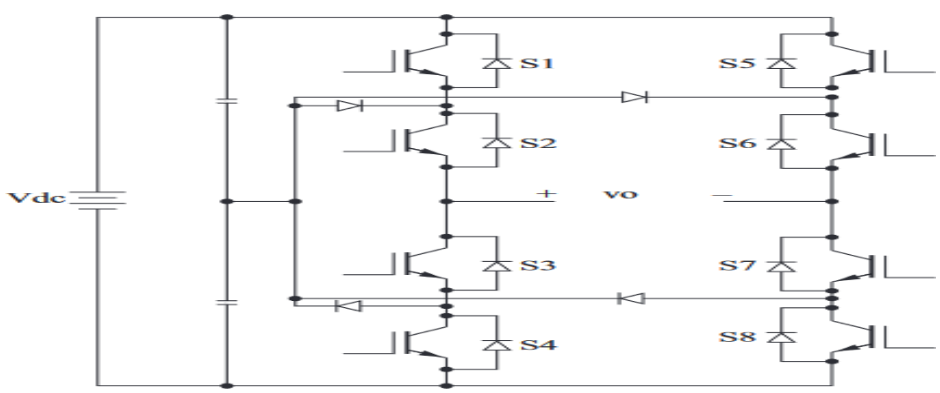

Fig. 4. Circuit of diode-clamp inverter [7]

Multi-Level Inverter

The output voltages of the H bridge inverter are Vdc,0 Vdc, and -Vdc. It is possible to extend the fundamental H-bridge switching idea to other circuits that have different output voltage levels. These multilevel output voltages have a lower harmonic content because they have a more sine-like quality [6]. Applications for the multilevel inverter include connecting renewable energy sources, like photovoltaics, to the electrical grid and enabling variable-speed motor drives. Fig. 5 represents circuit diagram of MLI.

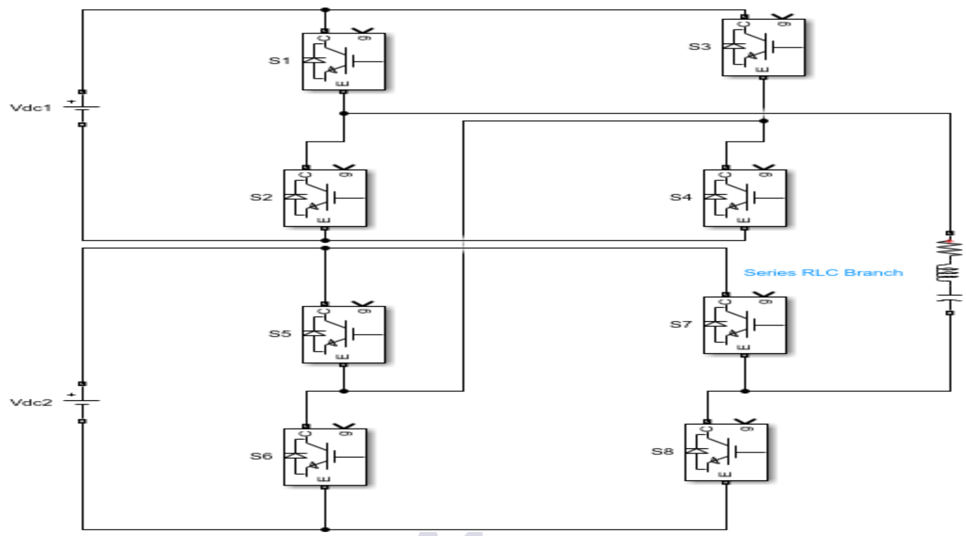

Fig. 5. Circuit of multilevel inverter with RLC load

The purpose of this research is to design a single-phase PWM multi-level inverter by applying the bipolar switching scheme in order to improve power quality and efficiency when applying pulse width modulation (PWM) to convert DC voltage to AC voltage. The approach helps applications like renewable energy systems, UPS, etc. by offering features such as better output quality, lower component stress, and higher voltage capabilities.Key objectives include: Achieving accurate voltage control, minimizing total harmonic distortion, and maximizing energy conversion for several kinds of power electronics applications are important goals that will ultimately contribute to the field's technological developments.

Our purposed method has the lowest current and voltage total harmonic distortion (THD) even under RL load conditions, compared with other suggested methods that are primarily designed for purely resistive loads, which highlights its effectiveness in real-world operating conditions.

2. Related Work

Nowadays, industries prefer MLI's over square wave inverters & half-bridge inverters because of reduce harmonics and sinusoidal property of output waveform and greater voltage levels. However, the performance of these inverters is heavily dependent on the modulation technique used.

In this section, all the related research papers have been carefully studied to analyze how well single-phase inverters perform when using unipolar and bipolar switching techniques to reduce total harmonic distortion (THD) and improve efficiency. In their comparison of the SPWM unipolar and bipolar SPWM techniques, Nurul Farhana Abdul Hamid et al. found that the unipolar SPWM technique demonstrated reduced THD levels, particularly when filters were applied (THD: 2.95% with filter, 53.97% without filter) [4]. Similarly, through advanced modulation techniques and filter integration, Abhishek Azad et al. were able to achieve notable THD reductions in hybrid and asymmetric multilevel inverters (current THD: 2.64%, 4.36% current THD without filter) (Voltage THD: 8.77% without filter, 1.17% with filter) [9,10].

J. Gowri Shankar et al. proposed a 31-level asymmetric cascaded multilevel inverter (MLI) for PV systems, emphasizing the importance of THD analysis in renewable energy applications (10.2% voltage THD). Despite finding moderate THD levels, their study indicated the need for additional optimization [11]. R. Venkatesh, R. Anandha Kumar, and G. Renukadevi presented a technique for lowering THD in multilevel inverters that used a fuzzy logic controller and significantly improved voltage THD levels (3.06%) & Current THD (3.17%) [12].

Bipolar and unipolar schemes for PWM-based inverters were investigated by Hussain Attia et al. The authors showed that the THD levels varied based on the modulation technique (bipolar voltage THD: 103.37%, current THD: 21.84%; unipolar voltage THD: 54.6%, current THD: 5.24%) [13]. Senoaji and Irna Tri Yuniahastuti emphasized the importance of harmonic reduction methods such as LCL filters while concentrating on the application of bipolar SPWM in voltage source inverters [14]. A 21-level bipolar single-phase modular MLI was proposed by Sidharth Sabyasachi et al., and from their study, they obtained low THD levels in the output voltage (Voltage THD: 2.38% , Voltage THD: 11.07% without filter) [15].

In addition, a study comparing full and half bridge inverters, as well as unipolar and bipolar PWM techniques, was conducted by Jahangeer Soomro et al. Their results indicated how effective some configurations and modulation methods are at minimizing THD and improving the overall performance of the inverters [16].

The literature review shows the importance of modulation techniques in reducing THD and improving performance in inverters. Research indicates that advanced modulation techniques, such as fuzzy logic control, PWM schemes, and SPWM, can significantly reduce total harmonic distortion (THD) and improve efficiency. Further study needs to be conducted to optimize these methods for specific applications as well as to address issues suchas grid stability and renewable energy integration. Overall, the findings emphasize the importance of selecting the appropriate modulation technique when producing high-performance single-phase inverters for a variety of commercial and residential applications.

3. Methodology

3.1 MATLAB Circuit Simulation

The circuit diagram of the Inverter is presented in Fig. 6 , it consists of the following components:

- Two H-Bridges
- Multicarrier triangle wave generators
- Sine wave generator
- LC low pass filter

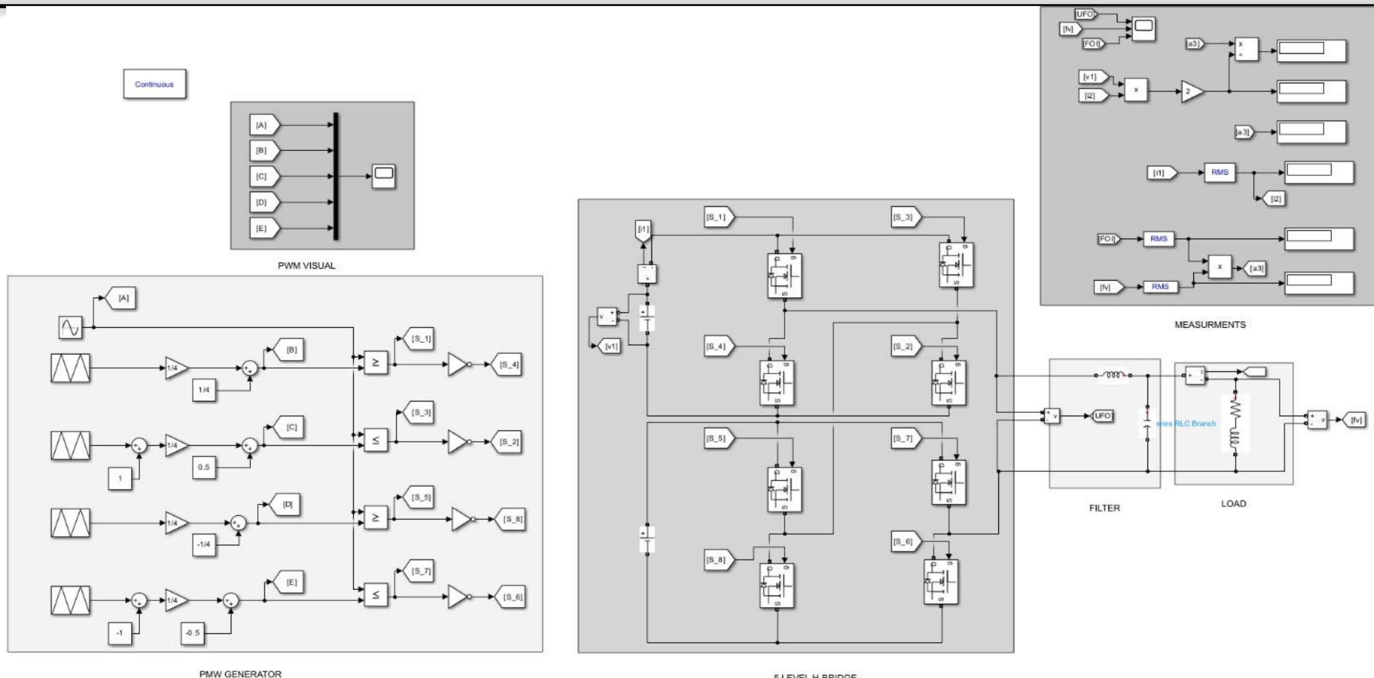

Fig. 6 MATLAB Simulation of Inverter

3.2 H-Bridges Connection

Two H-Bridges in a cascaded connection is shown in Fig. 7 for the staircase output waveform with five levels, this configuration is in order to meet the requirement of the desired waveform output.

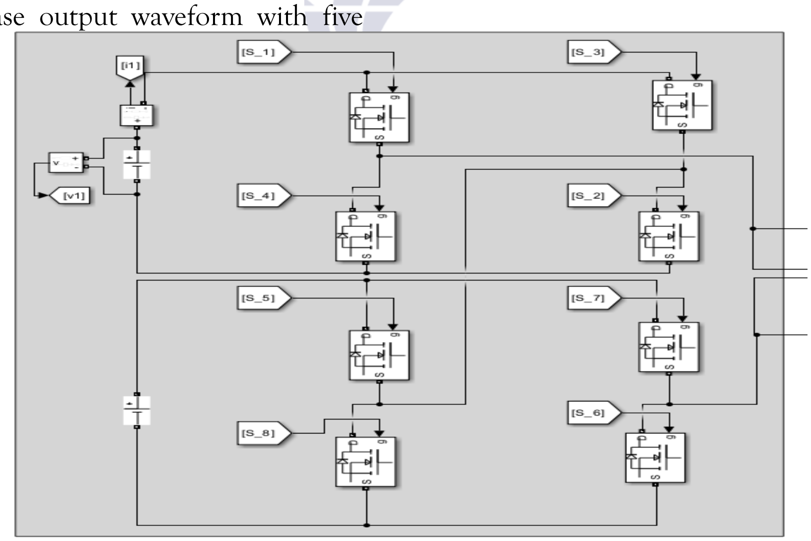

Fig. 7 5 level H-Bridge

3.3 PWM Signal Generation

The PWM signal for the inverter is made using a comparison of the sine wave and a number of triangular waves in a comparator. The results of the comparison are a multi PWM signals, which are then later fed to the corresponding MOSFET in the H-Bridges. As demonstrated in Fig. 8.

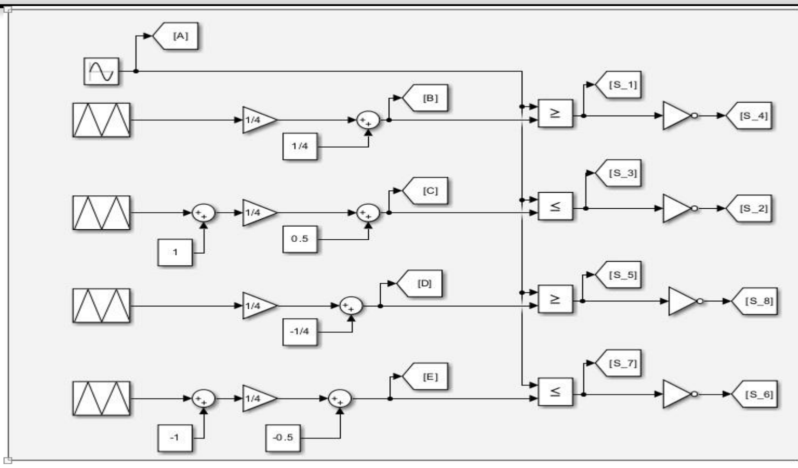

Fig. 8 PWM Generator

3.4 Phase Disposition (PD) Modulation

We have used the Phase Disposition (PD) modulation method as demonstrated in Fig. 9, we have selected the PD method because it has a lower Total Harmonic Distortion (THD) compared to other methods like the Phase Opposite Disposition (POD) and Alternate Phase Opposite Disposition (APOD). There is no phase shift among all the triangular waves in PD waveforms and all the triangular waves are equal to one another.

3.5 Switching Sequence

The sine wave is compared to the triangular waves for the switching sequence of the H-Bridges. The switching scheme has been detailed in the following table:

Table 1
Switching Scheme

Waves comparison	SW to be closed
Vsin > Vtri 1	1
Vsin <	4
Vtri 1	2
Vsin >	3
Vtri 2	5
Vsin <	8
Vtri 2	6
Vsin >	7
Vtri 3	
Vsin <	
Vtri 3	
Vsin <	
Vtri 4	
Vsin <	
Vtri 4	

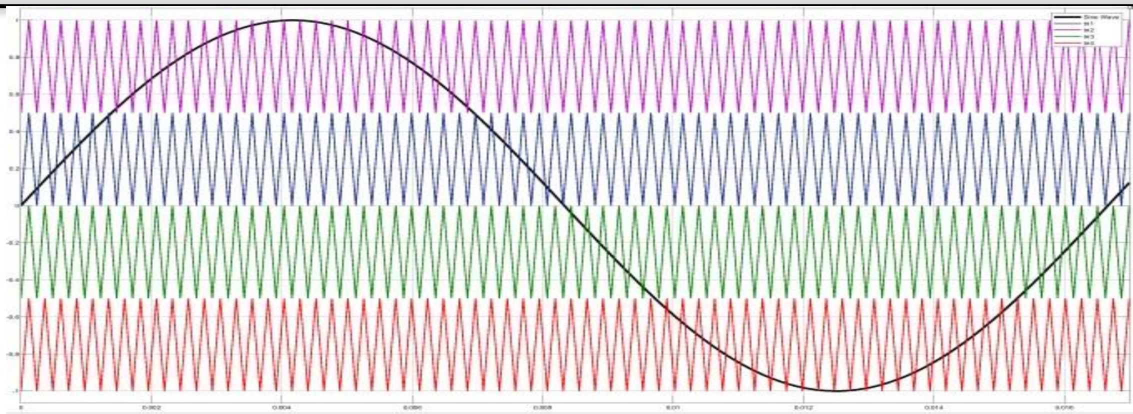

Fig.9 Multicarrier Phase Disposition PWM

3.6 Inverter Operation

The operation of the inverter is given below:
SPWM

1. Generation: A comparison between the multicarrier triangular waves and the sine wave leads to Sinusoidal Pulse Width Modulated (SPWM) signals.
2. Switching: Correct turning off of the MOSFETs as per the SPWM signals.
3. Output Waveform: The output is a staircase waveform, as given in Fig. 10.
4. Filtering: The high harmonic components produced are filtered by the LC low pass filter, leading to the sinusoidal wave shown in Fig. 10.

This methodology gives steps involved in simulating and analyzing the circuit in MATLAB, setting up of H-Bridges, generation of the PWM signal, and modulation technique used. There is a switching sequence and operation of the inverter to achieve reduced THDs and importance of an inverter-based single-phase system using the phase disposition modulation technique for resulting a low percent THD, and use of the LC low-pass filter in order to getclean sinusoidal output.

4. Simulation and Results

Simulation of the 5-level Multilevel Inverter (MLI) in MATLAB/Simulink Designed on the basis of the methodology, it gives us impressive output. the output waveforms both for current and voltage with using filter and without employing filters is shown in Fig. 10, It gives an efficiency rating of 96%, and the inverter also shows its potential to convert 80 Volt D.C input from each H-bridge into 110 Volt RMS at 60 Hz at output.

Moreover, after filtration using a low-pass LC filter, the total harmonic distortion (THD) reduces quite significantly. The voltage THD of the filtered output waveform is at 1.36% as demonstrated in Fig. 11, and the current THD of the filtered output as can be seen in Fig. 12 is 0.13%. This low THD value makes the inverter compatible with sensitive electronic equipment. And maintain high power quality standards. Achieving such a low THD is due to using a multi-level inverter and selecting the phase displacement (PD) modulation technique, which helps reduce THD and hence improve output waveform quality.

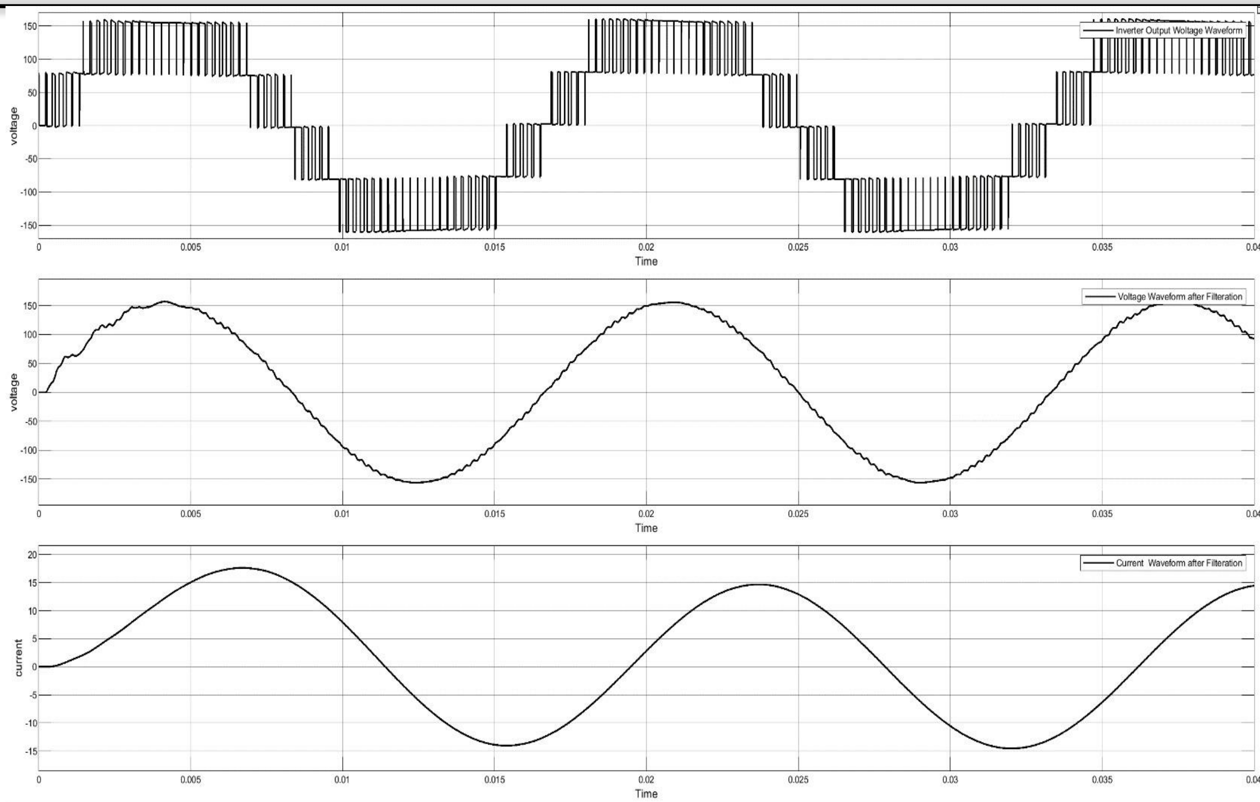

Fig.10 *Unfiltered voltage, filtered voltage, filtered current*

Table 2
Multilevel Inverter Input Parameter

Multilevel Inverter Input Parameter	Value
Fundamental Frequency (f)	60 Hz
Carrier Frequency (fc)	4.089 KHz
Amplitude modulation (ma)	1
Input Dc Voltage to Each H-Bridge (V)	80V

Multilevel Inverter Output Parameter	Value
Output Voltage	110 V RMS
Output Frequency	60Hz
Voltage THD	1.36%
Current THD	0.13%
Efficiency	96%

Fig. 11 FFT Analysis of Voltage THD

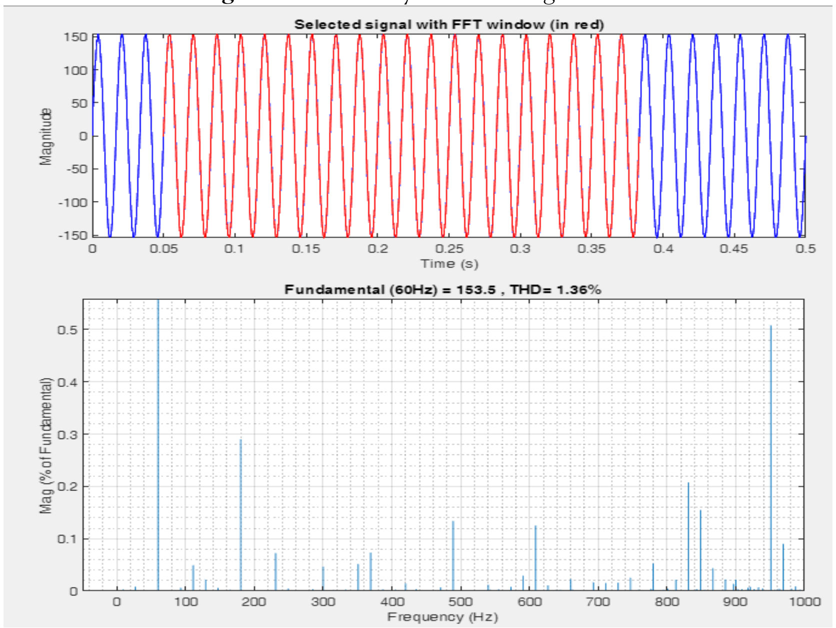

Fig. 12 FFT Analysis of Current THD

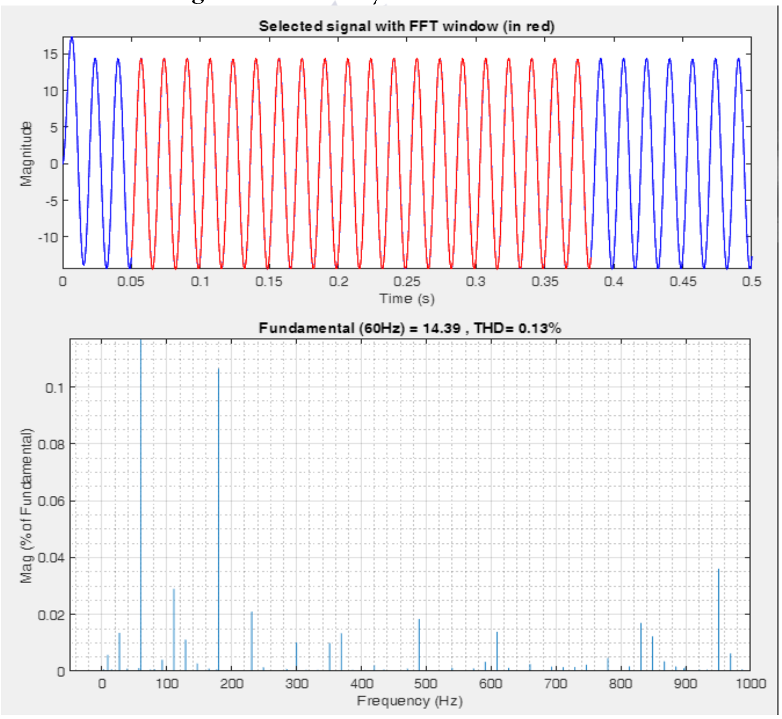

Table 3
Comparative analysis of THD with some ref. papers

Reference	Year	Current THD	Voltage THD
Asymmetric 15-Level Multilevel Inverter with Fuzzy Controller Using Super Imposed Carrier PWM	2017	NIL	1.17%
A 31-level asymmetrical cascaded multilevel inverter with DC-DC flyback converter for photovoltaic system	2017	NIL	10.02%
THD Minimization in 15- Level Hybrid Multilevel Inverter Using Harmonic Minimization Technique	2018	2.64%	NIL
Design and simulation of single-phase inverter using SPWM unipolar technique	2020	2.95%	NIL
A 21-Level bipolar Single- Phase modular multilevel inverter	2020	2.38%	11.07%
Multilevel inverter design with reduced switches & THD using fuzzy logic controller	2022	3.17%	3.06%
Our proposed work	2025	0.13%	1.36%

In table 3 Our 5-level MLI was put to the test againstother designs in terms of THD.

5. Conclusion

In conclusion, this study on designing a single phase PWM multi-level inverter using a Comparative analysis of THD with some ref. papers PWM multi-level inverter using the bipolar method has shown a good result. We were able to indicate the ability and efficiency of our designed inverter via simulation in MATLAB to effectively convert DC input to stable AC output at our desired frequency. By including a low-pass LC filter, the quality of the output waveform further increases, leading to a significant reduction in total harmonic distortion (THD). Our proposed methodology of using the phase displacement (PD) modulation technique with a multi-level inverter gives low THD and makes it compatible with sensitive electronic devices. Overall, this study highlights the ability of this approach to obtain reliable and high-performance single-phase inverters for different applications.

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