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Single phase inverter using Unipolar Sinusoidal Pulse Width Modulation

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ABSTRACT

As the population grows and energy demands increase, various resources are needed, including human resources, fossil-based natural resources, and renewable energy sources. An inverter is a crucial device in electrical power generation systems, functioning to convert direct current (DC) voltage into alternating current (AC) voltage in optimizing the performance of the inverter. An efficient switching method can reduce switching losses, minimize electromagnetic interference (EMI), allow the use of smaller filters, and result in lower Total Harmonic Distortion (THD). This research focuses on the simulation of a single-phase inverter employing the unipolar Sinusoidal Pulse Width Modulation (SPWM) technique. The working principle of SPWM involves comparing a reference waveform with a carrier waveform using a comparator in order to generate an ideal sinusoidal output, it was found that this switching technique is capable to producing an output waveform that closely resembles a sinusoidal wave. Without the use of an LC filter, the Total Harmonic Distortion (THD) was relatively high, reaching 120.27% at a frequency of 50 Hz. However, after applying an LC filter in a series-parallel configuration, the THD was successfully reduced to 14.78% at a frequency of 55 Hz. This demonstrates that the combination of the unipolar SPWM method and an LC filter is effective in improving the quality of the inverter output power and significantly reducing harmonic distortion.

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1. INTRODUCTION

As the population grows and energy demands increase, various resources are needed, including human resources, fossil-based natural resources, and renewable energy sources [1]. One of the most popular energy sources today is renewable energy. Renewable energy is derived from natural sources that are sustainable and will not run out over a long period of time, such as sunlight, water, wind, biomass, and geothermal energy. On the other hand, fossil fuels such as oil, coal, and natural gas are still widely used to produce energy. However, the increasing use of fossil fuels by humans can lead to a rise in greenhouse gas emissions. This issue can be mitigated by increasing the use of renewable energy sources. One of the key technologies associated with the utilization of renewable energy is the inverter [2].

An inverter is a crucial device in electrical power generation systems, functioning to convert direct current (DC) voltage into alternating current (AC) voltage. It plays a vital role in renewable energy applications such as solar panels and wind turbines, which are increasingly utilized in both residential and industrial settings. Since the energy produced by these sources is typically in the form of DC, while most household appliances and electronic equipment operate on AC, the inverter ensures optimal performance and compatibility with everyday electrical loads [3]-[5].

Sinusoidal Pulse Width Modulation (SPWM) is a modulation technique that produces a sinusoidal waveform by periodically varying the pulse width of the switching signal. The selection of the appropriate switching technique plays a crucial role in optimizing the performance of the inverter. An efficient switching method can reduce switching losses, minimize electromagnetic interference (EMI), allow the use of smaller filters, and result in lower Total Harmonic Distortion (THD). MATLAB Simulink is utilized to analyze and visualize the output performance of the system. This study employs the unipolar SPWM method, which offers several advantages, including reduced total harmonic distortion (THD), lower switching power losses, and higher overall efficiency.

In this method, the inverter output voltage switches between two levels—positive and zero (unipolar) which reduces switching losses, generates fewer harmonics, and improves the overall system efficiency. The combination of unipolar SPWM with a single-phase inverter provides an effective solution for various renewable energy applications, such as solar panel systems, uninterruptible power supplies (UPS), electric motor drives, and power factor correction.

This study aims to simulate a single-phase full-bridge inverter using the unipolar Sinusoidal Pulse Width Modulation (SPWM) technique with MATLAB Simulink software. The objective of the simulation is to evaluate the output voltage waveform under two conditions: with and without the use of an LC filter. This research is also expected to contribute to improving the quality of the inverter's output voltage waveform.

2. METHOD

This research focuses on the simulation of a single-phase inverter employing the unipolar Sinusoidal Pulse Width Modulation (SPWM) technique. Sinusoidal Pulse Width Modulation (SPWM) functions to control the pulse width based on a sinusoidal waveform. The working principle of SPWM involves comparing a reference waveform with a carrier waveform using a comparator in order to generate an ideal sinusoidal output. The simulation model consists of a DC voltage source, a single-phase full-bridge inverter, a signal generator, and an LC filter as an additional component. Two simulation scenarios are carried out: the first involves analyzing the inverter output without an LC filter, and the second includes testing the inverter with an LC filter installed at the output. The evaluation results are used to verify that the LC filter can effectively reduce harmonic distortion and improve the quality of the output waveform. Figure 1 show the block diagram of proposed inverter.

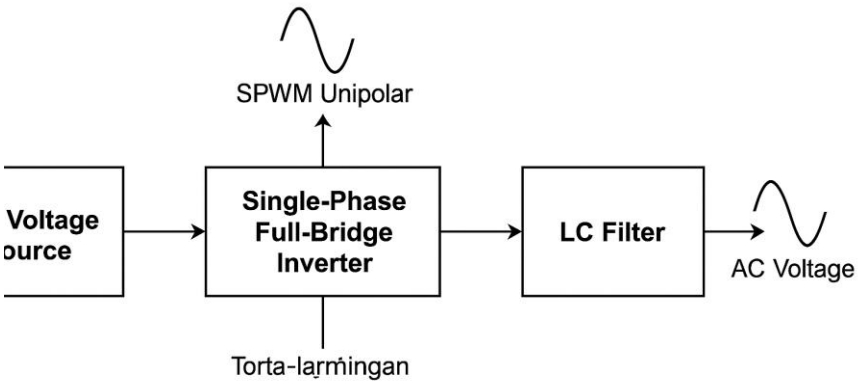


Figure 1. Block diagram

The block diagram of the system, as shown in Figure 1, represents the configuration of a single-phase full-bridge inverter using unipolar SPWM modulation. The system begins with a DC voltage source, which acts as the input power supply. This DC voltage is then fed into the full-bridge inverter circuit, which is controlled by a unipolar SPWM signal generated through a comparison between a sinusoidal reference and a triangular carrier signal Switching with this technique uses two sinusoidal signals with the same frequency and amplitude but with a phase difference of 180° [6]-[10]. The switching signals regulate the four switches of the inverter to produce a pulse-modulated AC voltage. An efficient switching method can reduce switching losses, minimize electromagnetic interference (EMI), allow the use of smaller filters, and result in lower Total Harmonic Distortion (THD) [11]-[14].

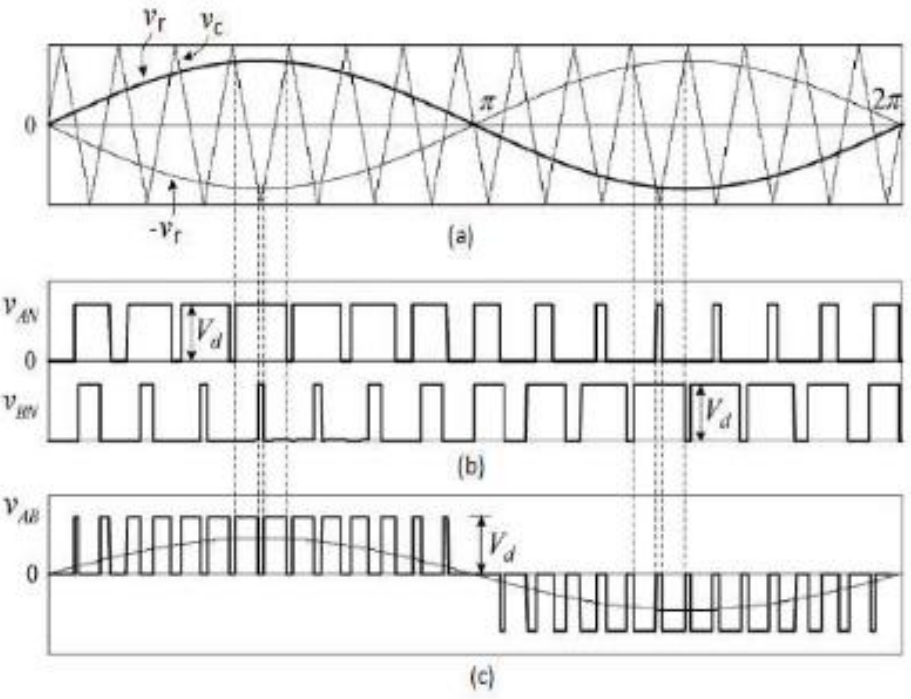


Figure 2. Unipolar Switching

At the output side, an LC filter is integrated to suppress high-frequency harmonics and smooth the waveform. The filtered output produces a near-sinusoidal AC voltage suitable for various applications such as renewable energy systems, uninterruptible power supplies (UPS), and motor drives. This configuration is designed to evaluate the effectiveness of the LC filter in improving output quality by comparing the inverter's performance with and without the filter.

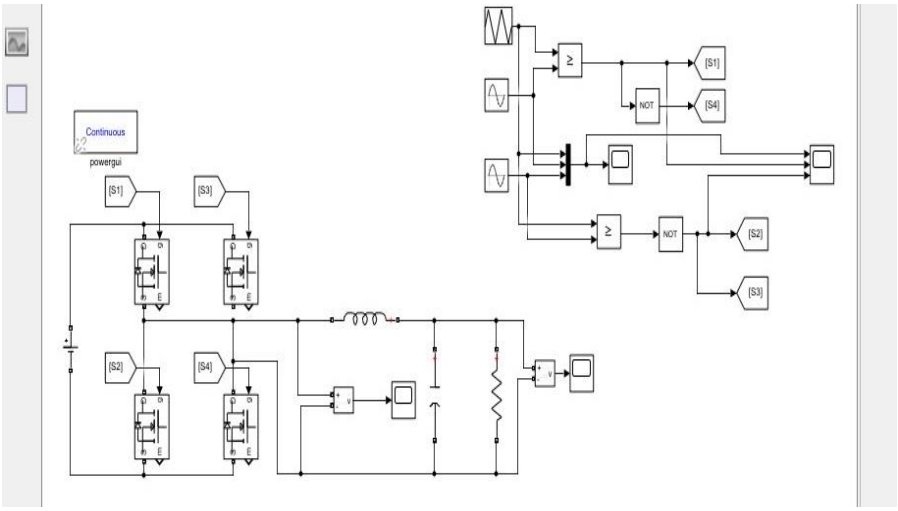


Figure 3. Simulation of single phase inverter spwm unipolar

The single-phase unipolar inverter using Sinusoidal Pulse Width Modulation (SPWM) was conducted under two conditions: without an LC filter and with an LC filter installed in a series-parallel configuration after the load. During the tests, several parameters were measured and observed, including the output voltage (VAC), Total Harmonic Distortion (THD), and the inverter's output waveform. These measurements aimed to evaluate the effect of the LC filter on the quality and stability of the inverter's output. hese are the results of the output waveform

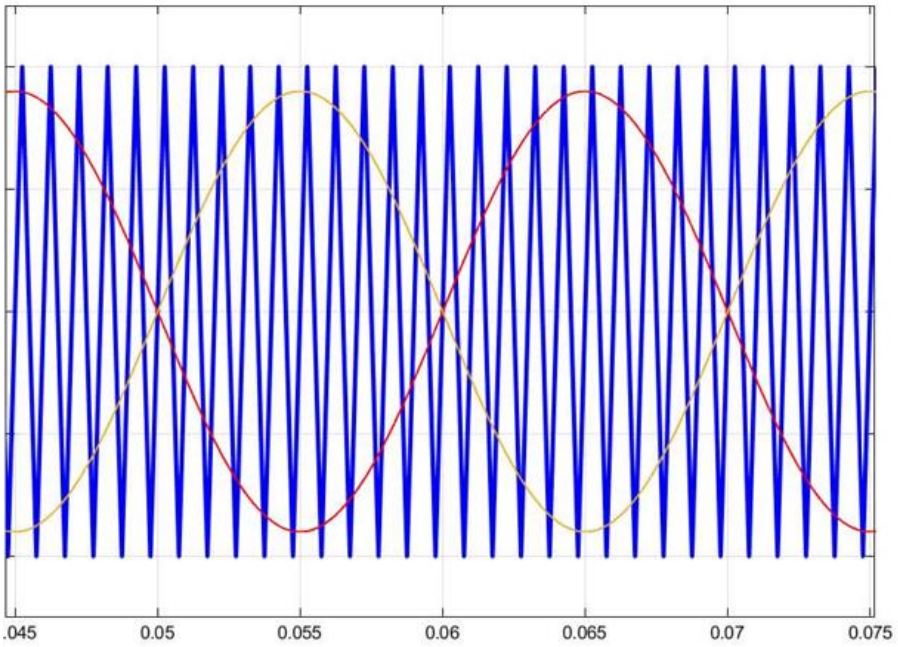


Figure 4. Effects of selecting different switching under dynamic condition

One of the parameters used is Total Harmonic Distortion (THD). THD is the comparison between the harmonic components and the fundamental frequency. The purpose of THD is to measure the deviation of the waveform caused by harmonics within one period [15],[16]. Calculation of Total Harmonic Distortion (THD):

$$THD = \frac{\sqrt{\sum_{n=2}^{50} V_n^2}}{V_1} = \frac{\sqrt{V_1^2 + V_2^2 + V_3^2 + ... + V_n^2}}{V_1} \quad (1)$$

V1 represents the RMS voltage of the fundamental frequency. The amplitude modulation index (ma) is the ratio between the amplitude of the input signal and the amplitude of the carrier signal. The amplitude modulation index (ma) is defined as the ratio between the amplitude of the reference (input) signal and the amplitude of the carrier signal. This index is essential for determining the output voltage amplitude of the inverter. In a single-phase inverter employing unipolar Sinusoidal Pulse Width Modulation (SPWM), the modulation index (ma) plays a critical role in shaping the output waveform. It directly affects the output voltage magnitude and overall power quality, making it a key parameter in inverter performance optimization. The modulation index (ma) can be calculated using the following formula:

$$Ma = \frac{Vref}{Vcarrier} \quad (2)$$

- If **ma < 1**, the SPWM operates in the normal modulation range.
- If **ma = 1**, the output voltage reaches its maximum value without distortion.
- If **ma > 1**, distortion occurs in the output waveform.

3. RESULTS AND DISCUSSION

The discussion can be made in several sub-sections. The performance testing of a single-phase unipolar inverter employing Sinusoidal Pulse Width Modulation (SPWM) was carried out under two conditions: without an LC filter and with an LC filter connected in a series-parallel configuration after the load. The measured and observed parameters include output voltage (VAC), Total Harmonic Distortion (THD), and the output waveform of the inverter.

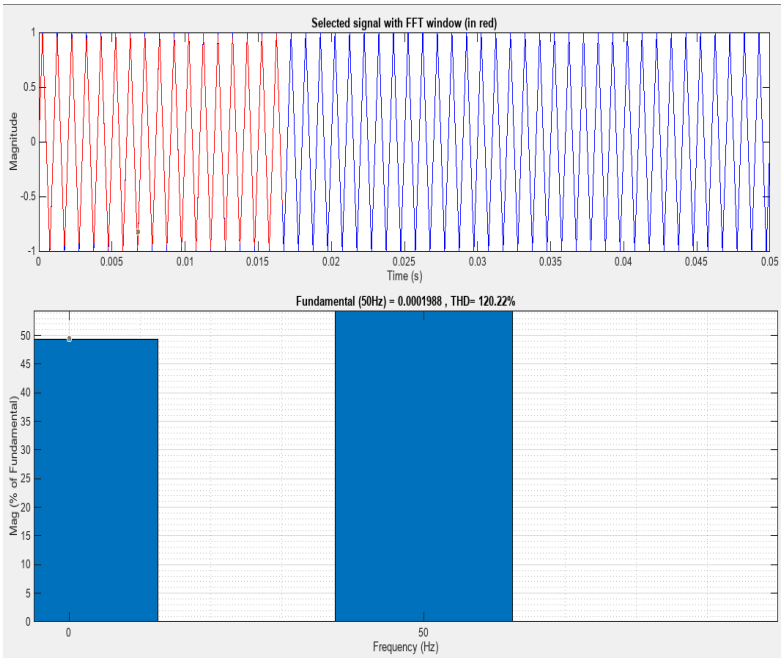


Figure 5. SPWM Single Phase Unipolar Without Filterring

The results obtained from the simulation of a single-phase inverter using unipolar SPWM with an input voltage of 100 V_{DC} were measured in MATLAB without applying an LC filter. As shown in Figure 5, the Total Harmonic Distortion (THD) is 120.27% at a frequency of 50 Hz when the filter is not applied.

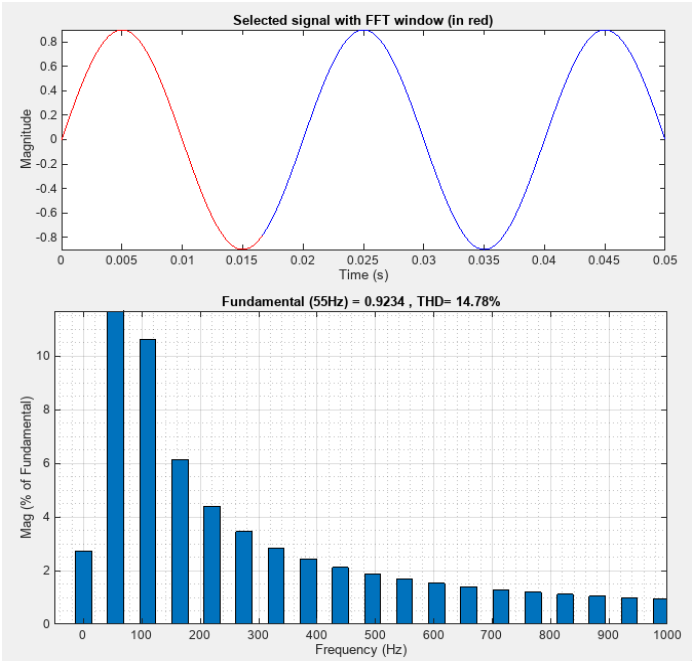


Figure 6. SPWM Single Phase Unipolar Using Filterring

However, with the application of an LC filter, the Total Harmonic Distortion (THD) was reduced to 14.78% at a frequency of 55 Hz when the filter was configured in a series-parallel connection. It can also be observed that the inverter output waveform has taken the shape of a sinusoidal wave. This indicates that the use of an LC filter is effective in attenuating high-frequency harmonic components generated by the inverter switching process, thereby significantly improving the quality of the output power.

4. CONCLUSION

Based on the simulation results of a single-phase inverter using the Unipolar Sinusoidal Pulse Width Modulation (SPWM) method, it was found that this switching technique is capable of producing an output waveform that closely resembles a sinusoidal wave. Without the use of an LC filter, the Total Harmonic Distortion (THD) was relatively high, reaching 120.27% at a frequency of 50 Hz. However, after applying an LC filter in a series-parallel configuration, the THD was successfully reduced to 14.78% at a frequency of 55 Hz. This demonstrates that the combination of the unipolar SPWM method and an LC filter is effective in improving the quality of the inverter output power and significantly reducing harmonic distortion.

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