Design and simulation of single phase inverter using SPWM unipolar technique

Nurul Farhana Abdul Hamid, Muhammad Alleef Abd Jalil, Nor Syafiqah Syahirah Mohamed
School of Electrical System Engineering, Universiti Malaysia Perlis, Arau, Perlis, Malaysia.
Email: nurulfarhana@unimap.edu.my

Abstract: This paper presents the design and simulation of single-phase inverter using sinusoidal pulse width modulation (SPWM) unipolar technique. The circuit has been designed and simulated using the Matlab/Simulink program. Metal Oxide Semiconductor Field Effect Transistor (MOSFET) has been used as a switch. The project aims to use the Matlab/Simulink program to design, analyze and control switching for inverter circuits. Single-phase inverter circuits are divided into three main divisions which are the inverter part that consists of the MOSFET switch, the control circuit which generates switching pulses generated through the microcontroller and filter parts that contain inductors, capacitors and resistors to reduce harmonic. The results of the experiment show the output of the sine wave with the output voltage of 230 V and 50 Hz.

1. Introduction

The semiconductor devices are used in the electrical field with an increase in time. Power semiconductor is the heart of the modern power electronics and mainly use to converts the power from one to another form [1].

Inverters are circuits that convert Direct Current (DC) to Alternating Current (AC). Since the main objective of the inverter is to use a DC voltage source to supply a load requiring AC, it is useful to describe the quality of AC output [2]. The input of the inverter is taken from various DC source like a battery, photovoltaic, fuel cell, alternator, etc. There are two types of circuit used in single-phase inverter circuit which are half-bridge and full bridge configurations. Inverters have been widely used for applications, from small switched power supplies for a computer to large electric utility applications to transport bulk power [4].

The Sinusoidal Pulse Width Modulation (SPWM) technique is the most common one and it is based on the principle of comparing a triangular carrier signal with a sinusoidal reference waveform according to [3]. The advantages of unipolar SPWM is this technique only need small filter to produce sine wave and reduce Total Harmonic Distortion (THD).

Thus, the purpose of this project is to compare and analyze the results of THD between the bipolar SPWM and unipolar SPWM switching technique. Furthermore, the hardware prototype of the inverter using unipolar SPWM was developed to confirm the simulation results are verified. Arduino Uno is used as a microcontroller.

2. Single phase inverter topology

There are two types of circuit used in single-phase inverter circuit which is half-bridge and full bridge configuration. Inverters have been widely used for applications, from small switched power supplies
for a computer to large electric utility applications to transport bulk power[4].

**Half-Bridge Inverter**

A single-phase half-bridge inverter circuit and its output waveform are shown in Figure 1(a). The inverter circuit consists of two power switches. The switches can be transistors, MOSFET, IGBT, etc. [1]. Two diodes are connected parallel to the power switch to block the reverse voltage. The switching operation is done in such that two switches are not ON at same time. If the two switch are ON at the same time, it is very harmful for power switches because of high flow of current. Table 1 shows the switching state and the output of the inverter.

**Full-Bridge Inverter**

A single phase full bridge inverter circuit and its output waveform are shown in Figure 1(b). It consists of four power switches and it is used in higher power rating application [1]. The four switches are S1, S2, S3 and S4. The operations can be divided into two cases which is, first, switches S1 and S4 are turned ON and kept ON for the one-half period and S2 and S3 are turned OFF and produced output voltage across the load is equal to Vdc. Second, when S2 and S3 are turned ON, the switches S1 and switches S4 are turned OFF. And the output voltage is equal to −Vdc. Table 2 shows the switching state and the output of the inverter.

| Table 1. Switching states of half bridge inverter [1] |
|-----------------------------------------------|
| S1 | S2 | V<sub>O</sub> |
|----|----|-------------|
| ON | OFF | V<sub>d</sub>c |
| OFF | ON | −V<sub>d</sub>c/2 |

| Table 2. Switching states of full bridge inverter [1] |
|-----------------------------------------------|
| S1 | S2 | S3 | S4 | V<sub>P</sub> | V<sub>o</sub> | V<sub>ao</sub> |
|----|----|----|----|-------------|-------------|-------------|
| ON | OFF | OFF | ON | V<sub>d</sub>c/2 | −V<sub>d</sub>c/2 | V<sub>d</sub>c |
| OFF | ON | ON | OFF | −V<sub>d</sub>c/2 | V<sub>d</sub>c/2 | −V<sub>d</sub>c |
| ON | OFF | ON | OFF | V<sub>d</sub>c/2 | V<sub>d</sub>c/2 | 0 |
| OFF | ON | OFF | ON | −V<sub>d</sub>c/2 | −V<sub>d</sub>c/2 | 0 |

(a) Half-bridge single-phase inverter  
(b) Full-bridge single-phase inverter

**Figure 1.** Single Phase Inverter and Its Output [1]

### 3. Simulation model of single phase unipolar SPWM inverter

The block diagram of the single phase unipolar SPWM is shown in Figure 2. The system consists of control circuit which is microcontroller circuit that use to generate SPWM pulse. Next, the inverter circuit or full bridge circuit to provide the output. LC filter was used to reduce harmonic, so it will produce the sine wave signal [5]. Lastly, the step-up transformer to increase the voltage to 230V. The simulation model of unipolar SPWM inverter shown in Figure 6 is divide into three parts which are control circuit, an inverter circuit and low pass filter circuit.
Single phase full bridge inverter shown in Figure 3 consist of DC voltage source and four switching elements. The switching element use in this development is power MOSFET because it needs to be force-commutated devices with high-frequency switching [5].

A low pass filter is functioning to reduce harmonics generated by pulsating modulation waveform [6]. Figure 4 shows the circuit of low pass LC filter that required at the output terminal of full bridge inverter. The value used in the prototype for inductor is 880 µH and the capacitor is 30 µF.

Two sinusoidal waves are used as reference signal and triangular wave as carrier signal are used in PWM technique. The pulses obtained depend on two parameter modulation index and modulation frequency [7]. Figure 5 shows the simulation model of a control circuit which consists of two sinusoidal waves, triangular wave and relational operation.
4. Simulation Results

The simulation Total Harmonic Distortion (THD) and fundamental voltage with and without filter for unipolar SPWM with amplitude modulation ratio, \( m_a = 1.0 \) with \( f_{carrier} = 5 \text{ kHz} \) is presented. Figure 7 shows the simulated THD for unipolar SPWM without filter. It shows that the \( V_{\text{fundamental}} = 11.87 \text{ V} \) and THD = 53.97%.

Figure 8 shows that the simulated fundamental voltage, \( V_{\text{fundamental}} = 11.89 \text{ V} \) and THD = 2.95% for unipolar SPWM with filter. Compare to Figure 4.10, THD for unipolar SPWM with filter is lower than without filter. Furthermore, unipolar SPWM with filter is the best technique for inverter.
Figure 7. Simulated fundamental voltage and THD for $m_a = 1.0$ for unipolar SPWM without filter

Figure 8. Simulated fundamental voltage and THD for $m_a = 1.0$ for unipolar SPWM with filter

The control circuit of SPWM unipolar inverter requires two sinusoidal modulating waves $V_m$ and $V_m^{-}$ as shown in Figure 9. The modulating wave common triangular carrier wave $V_{cr}$ are compared as shown in Figure 9(a) and generating switching pulse as shown in Figure 9(b) and Figure 9(c). SPWM 1 represent switch 1 and switch 2, while SPWM 2 represent switch 3 and switch 4.

Figure 9. The control circuit of unipolar SPWM inverter: (a) Modulation and carrier waves, (b) switching pulse for SPWM 1, (c) switching pulse for SPWM 2
The output waveform of the inverter waveform is shown in Figure 10 which produces the output of 12 V. The LC filter circuit function is to reduce harmonic which produced the sine wave output as shown in Figure 11.

The output voltage of LC filter is step-up to 230 V as shown in Figure 12 using a step-up transformer. Based on the result obtained, the output of SPWM unipolar inverter is successfully design and simulate by using Matlab/Simulink.

5. Experimental Results

Figure 13 shows the complete hardware prototype of single phase inverter that have been developed. The switching strategy that has been used is SPWM unipolar with one as amplitude modulation ratio is selected based on the simulation result. The switching pulse period is collected from the Matlab
workspace.

The switching element used in this development is power MOSFET because it needs to be force-commutated devices with high-frequency switching [5]. The IRFZ44N MOSFET had been used in this experiment for the switching element. The specification of IRFZ44N are shown in Table 3.

| Description | Value |
|-------------|-------|
| V_{DSS} (V) | 55    |
| I_D (A)     | 49    |
| R_{DS(on)} (Ω) | 0.032 |
| P_D (W)     | 94    |

Arduino Uno is selected as the control circuit. The switching pulse coding has been written in Arduino Uno to trigger the gate driver and MOSFETs. The SPWM signal from the Arduino cannot be connected directly to the MOSFETs. The power MOSFET needs to be in the range of 10 V to 20 V to ensure that the MOSFET will trigger. The MOSFET gate driver from ZN2 Technology are used to overcome this problem.

For LC filter circuit, the value for inductor is 880 μH and the capacitor is 30 μF. Step-up transformer was used to boost the voltage to another voltage level. After the filter, the voltage needs to be step-up to 230 Vrms as required voltage. The specification of the transformer used in the experimental is shown in Table 4.

| Description                  | Value    |
|------------------------------|----------|
| Frequency                    | 50 Hz    |
| Input Voltage                | 12 Vrms  |
| Output Voltage               | 230 Vrms |
| Turns Ratio                  | 1:19     |
| Primary Rms Current          | 38.33 A  |
| Secondary Rms Current        | 2 A      |

Figure 14 shows the results from the experimental for the switching pulse that is produced by Arduino Uno and Figure 15 shows the output of MOSFET gate driver. Gate driver needs to increase the voltage to trigger the power MOSFET.
Figure 14. Switching pulse produce by Arduino Uno

Figure 15. Switching pulse produce by MOSFET gate driver

The output waveform of the inverter is shown in Figure 16 which produce the output of 12 V and Figure 17 shows the output voltage of experimental for SPWM inverter without filter. The experimental output waveform for LC filter is shown in Figure 18.

Figure 16. Output waveform of SPWM inverter

Figure 17. Output voltage of the experimental without filter

Figure 18. Output waveform of the LC filter

The results of total harmonic distortion of the experimental is shown in Figure 19. It shows that THD is 25.6% larger than simulation which is under 3%. This because the filter is not smoothing as the simulation and the losses of switching voltage. The filter needs to solder directly to the board and not using terminal block in order to overcome this problem.
6. Conclusion

This project has achieved the objectives of the project which is design complete switching strategy for inverter application. There are several circuit of SPWM unipolar inverter such as control circuit, an inverter circuit and low pass filter circuit. All the circuit are successfully design. The total harmonic distortion, fundamental voltage, output waveform of the control circuit, an inverter circuit and low pass filter circuit are formed and analysed. The inverter had been developed and produces the THD of 25.6%. The inverter prototype also had been analyse and used an application such as light bulb as the output as well to prove that there is a current flow on it.

Acknowledgments
The author would like to acknowledge School of Electrical System Engineering, Universiti Malaysia Perlis for the funding of this work.

References

[1] P. Dushyantsinh, S. Ashish, P. Dharam, and U. Ketul, “Single Phase Inverter Controlled Using SPWM Technique,” Gujarat Technological University, Ahmadabad, 2014.

[2] N. S. MAN, “Modeling And Analysis Performance Simulation Performance Of Multilevel Inverter Using Bipolar And Unipolar Switching Schemes,” 2015.

[3] M. N. Lakka, “Design of a high switching frequency FPGA-based SPWM generator for DC/AC inverters,” Chania, Greece, 2012.

[4] Azuan, “Modeling and simulation of single phase inverter with PWM using MATLAB/Simulink,” pp. 1–38, 2007.

[5] B. Ismail et al., “Design and Development of a SPWM Single Phase Inverter,” 2009.

[6] B. Majhi and Under, “Analysis of Single-Phase SPWM Inverter,” 2015.

[7] N. Jadhav, “Use of Advanced Unipolar SPWM Technique for Higher Efficiency High Power Applications,” vol. III, no. I.