Design of Unipolar Pure Sine Wave Inverter with Spwm Method Based On Esp32 Microcontroller As a Support of The Ebt System On Ship

Zindhu Maulana Ahmad Putra¹, a) Anggara Trisna Nugraha², b) Yuning Widiarti³, c) Wafiq Safaroz⁴, d) and Rama Arya Sobhita⁵, e)

¹, ², ³, ⁴, ⁵Departmen of Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Road Teknik Kimia, Keputih, Sukolilo, Surabaya, 60111, Indonesia

a) Corresponding author: zindhu@ppns.ac.id
b)anggaranugraha@ppns.ac.id
c)yuning.widiarti@ppns.ac.id
d)wafiqsafaroz@student.ppns.ac.id
e)ramasobhita@student.ppns.ac.id

Abstract. Along with developments in the maritime sector, especially on ships, the need for electric power on board will be very diverse. The use of diesel engines as power plants requires fuel to drive a diesel while the use of fuel in ships produced from petroleum processing is limited. Efforts to reduce the use of fuel is by implementing new renewable energy as independent electricity on ship. In EBT inverter technology plays an important role in converting DC voltage to AC voltage. In the inverter, the use of microcontrollers as drivers to generate PWM signals continues to develop. One of the developments of the microcontroller is ESP32. The problem that often occurs in inverters is that the output voltage is unstable. In addition to maximizing the performance of the inverter, it is necessary to add a protection system to reduce the risk of damage to the inverter or the load. Therefore, an inverter was made using the ESP32 microcontroller driver with the addition of protection and the fuzzy method as a voltage stabilizer. This inverter will change the 12 Vdc to 220 vac. In the Matlab simulation, the inverter can change the 12 vdc to 12 vpeak with a carrier signal of 20 khz and a reference signal of 50 hz. From the results of the inverter output will be changed to 220 vac using a step up transformer. The research overlay is being able to make a pure sine wave SPWM inverter using an ESP32 driver with a stable voltage.

1. Introduction

Inverters have an important role in the renewable energy sector, one of which is in the maritime sector. Inverter is an electronic device that converts direct current (DC) to alternating current (AC)[1]. Manufacture of inverters using a microcontroller as a PWM signal generator continues to grow. One of the developments is the use of the ESP32 microcontroller as a PWM signal generator for the inverter. The output wave-form generated from the inverter can generally be divided into 3 types, namely: rec-tangular (Square Wave),
modified sine signal (Modified Sine Wave), and pure sine signal (Pure Sine Wave)[2],[3]. This type of pure sine wave signal is an inverter output with a pure sine signal. An inverter’s output waveforms should ideally be sinusoidal [4]. Higher energy efficiency from pure sine wave inverters allows for more efficient use of power and less waste [5]. This type of inverter is needed, especially for the load on the ship so that it works more easily, smoothly and does not heat up quickly.

Ahmed et al designed a pure sine wave inverter using a microcontroller with output 220Vac 50Hz, pure sine waveform. The drawback is that when given a load of 60 watts the voltage drops to 203 V [6]. In a study entitled simulation and design of a single phase inverter with digital PWM issued by an arduino board with the conclusion that Arduino offers a simple and efficient program for PWM inverters [7]. On the other hand, Rafi et al have designed a pure sine wave inverter using an Arduino microcontroller using feedback with the output waveform from the inverter almost close to sine with a frequency of 50Hz [8]. Several studies with the title of developing a modified sine wave inverter using a microcontroller with four-level wave output results, the drawback of the modified sine wave is that it is not compatible with some electronic equipment [9] Andre et al. Research conducted by Muhammad et al used the Sinusoidal Pulse Width Modulation (SPWM) modulation technique with the output of the inverter circuit having a fixed frequency value [10].

In previous studies the microcontroller used was Arduino. In this study, the further development of previous research is the use of the ESP 32 microcontroller as a PWM signal generator. In addition, the advantages of the ESP32 microcontroller are that it has the advantage of more pinouts, more analog pins, larger memory, low energy, bluetooth and already available wifi module [11]. The benefits of using this environment are its simple configuration and good community support [12]. If the product of the 16 PWM channels on the ESP32 is less than the clock speed, they can be independently tuned for a different frequency and duty cycle resolution. [13].

The advantages of the ESP32 microcontroller have encouraged researchers to conduct special studies related to the manufacture of ESP 32 as a generator of PWM signals at the driver input so that they can control switching mosfets with unipolar SPWM outputs.

2. Materials and Method

2.1. Materials

The materials used in this study are the following components:

<table>
<thead>
<tr>
<th>No</th>
<th>Component</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power supply 12 vdc</td>
<td>As a 12v voltage supply on the inverter</td>
</tr>
<tr>
<td>2</td>
<td>MOSFET IRF1404</td>
<td>As a switch to change the dc voltage to ac voltage</td>
</tr>
<tr>
<td>3</td>
<td>ESP32</td>
<td>As a PWM signal generator on the inverter</td>
</tr>
<tr>
<td>4</td>
<td>PZEMT004T</td>
<td>To read voltage, frequency and current</td>
</tr>
<tr>
<td>5</td>
<td>DC voltage sensor</td>
<td>To read the dc voltage on the battery</td>
</tr>
<tr>
<td>6</td>
<td>Fan</td>
<td>To cool the mosfet</td>
</tr>
<tr>
<td>7</td>
<td>Inductor</td>
<td>As a LPF filter</td>
</tr>
<tr>
<td>8</td>
<td>Capacitor</td>
<td>As a LPF filter</td>
</tr>
<tr>
<td>9</td>
<td>LCD i2c 20x4</td>
<td>To display the results of microcontroller readings</td>
</tr>
</tbody>
</table>
2.2. Method

The preparation of this study was carried out in a planned manner presented in the form of a flowchart. The following is a flowchart of research conducted systematically.

![Research flowchart]

**Figure 1. Research flowchart**

Fig. 1 shows that the manufacture and design of tools for research requires a structured research flow. The first process is problem identification. After the problem has been identified, the next stage is literature study. Literature study serves to find solutions and understand deeper problems on the research topic. After understanding how to solve the problem the next step is design and system planning. At this stage the determination of the components needed and the application of the appropriate method.

2.2.1 System Block Diagram

Please The system block diagram is a diagram that represents an overview of the system to be made. So that the block diagram becomes a reference and guideline for writers to complete their research. Fig. 2 is a block diagram that will be implemented directly so that the manufacture of tools can be achieved.

<table>
<thead>
<tr>
<th></th>
<th>Voltage regulators</th>
<th></th>
<th>To lower the voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Toroid transformer</td>
<td></td>
<td>To raise the voltage</td>
</tr>
</tbody>
</table>
Fig. 2 shows the input is 12 vdc power supply then read by the voltage sensor to find out the voltage value of the power supply besides that the 12 vdc power supply voltage will flow towards the voltage regulator. The output of the voltage regulator will supply the ESP32. The output from ESP32 is in the form of a PWM signal then goes to the driver so it can turn the MOSFET on and off. The output of the MOSFET is a voltage of 7.8 vrms which will then be filtered using a low pass filter so that the wave output becomes more stable. The wave output from the low pass filter will be increased to ac 220 v using a Step Up toroid transformer. After being raised, it will be filtered again with a series of capacitors after which the output will be read by the voltage and current sensors. On ESP32 the results of sensor readings will be displayed on the LCD.

2.2.2 SPWM (Sinusoidal Pulse Wide Modulation)

The SPWM (Sinusoidal PWM) method is also called the Triangulation, Sub harmonic, or Suboscillation method [14]. The Pulse Width Modulation (PWM) is a technique which is characterized by the generation of constant amplitude pulses by modulating the pulse duration by modulating the duty cycle [15]. One effective method used to convert analog circuits to digital outputs based on microprocessors is pulse width modulation, or PWM [16]. This SPWM is obtained by comparing a sinusoidal wave with a carrier wave in the form of a triangular wave [17]. SPWM gives superior performance than bipolar SPWM switching[18]. There are two basic forms of SPWM inverter output waves, namely bipolar and unipolar SPWM [19][20]. The output voltage of the inverter circuit under bipolar SPWM technology has positive and negative levels(c). SPWM with unipolar switching voltage requires two comparators to compare triangular signals and two reference signals consisting of positive and negative signals [21]. The steps for generating spwm using esp32 are as follows.

- Determine the desired frequency and period of the reference wave (sine) with the following equation:

\[ T = \frac{1}{f} \]
Where, \( T \) = Period and \( f \) = sine wave frequency.

- Determine the period for each SPWM pulse. The period of each SPWM pulse is closely related to the carrier frequency, therefore it is necessary to determine the carrier frequency used. In this final project, the carrier frequency used is 20 kHz.
- Determine the number of generated SPWM pulses by comparing the period of the reference signal and the carrier signal.
- Determine the duty cycle per PWM pulse. This can be done using the following formula:

\[
y = A \sin (\theta) = \text{wide duty cycle divided by PWM pulses} \\
A = \text{pulse wave amplitude}
\]

### 3. Result

#### 3.1 Materials

The aims of testing the pwm output on ESP32 is to determine the frequency of the ESP32 output waveform. In this research, the output on ESP32 is set at 50 hz reference signal and 20 khz carrier signal. Fig. 3 is the result of the output on the ESP32 measured using an oscilloscope.

![PWM signal 50Hz and 20kHz](image)

**Figure 3.** PWM signal 50Hz and 20kHz

**Table 2.** ESP32 pin output results

<table>
<thead>
<tr>
<th>Pin ESP32</th>
<th>VRMS</th>
<th>VPP</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pin 12 &amp; 13</td>
<td>3.15 VAC</td>
<td>6.60 VAC</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Pin 14 &amp; 27</td>
<td>2.84 VAC</td>
<td>6.36 VAC</td>
<td>20.83 Khz</td>
</tr>
</tbody>
</table>

The output results above are as expected. the output is 50 hz on the reference signal and 20 khz on the carrier frequency signal but the VRMS output on the ESP32 pin is sometimes less than 3.3 VRMS.

#### 3.2 PWM Signal Driver IR2110

The IR2110 driver circuit produces a 20khz output on the 1HO and 1LO pins. Below is a picture of the 20 khz signal of the IR2110 driver.
Fig. 4 shows the waveform output is in accordance with the plan, a carrier signal with a frequency of 20khz. The voltage value per box is the volts per dive, the volts per dive here is used to view or read the resulting voltage value, so each box on the oscilloscope monitor screen reads 5V for each box. The voltage generated by the SPWM signal above is 11.25 Vp-p at 1LO and 23.35 Vp-p at 1HO for peak to peak.

Fig. 5 shows the wave output is in accordance with the plan, the amplified 50 hz frequency. The voltage value per box is the volts per dive, the volts per dive here is used to see or read the resulting voltage value, so each box on the oscilloscope monitor screen reads 5V for each box. So that the voltage generated by the SPWM signal above is 11.25 Vp-p at 1LO and 23.35 Vp-p at 2LO for peak to peak. The resulting frequency is 50 Hz.

Table 3. Voltage measurement results on IC IR2110N Channel

<table>
<thead>
<tr>
<th>No.</th>
<th>IC Driver</th>
<th>Voutput</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>IR 2110 ( 1 )</td>
<td>4.9 VAC</td>
<td>20Khz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.6VAC</td>
<td>20Khz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.9VAC</td>
<td>50Hz</td>
</tr>
<tr>
<td>2.</td>
<td>IR 2110 ( 2 )</td>
<td>11.45VAC</td>
<td>50Hz</td>
</tr>
</tbody>
</table>

Table 3 is the result of measuring the SPWM signal voltage generated by the Mosfet Driver IC (IR2110) as the PWM input on the mosfet for switching in the inverter circuit.

3.2.1 Unipolar Signal SPWM MOSFET

The inverter output in this study produces an output in the form of a unipolar SPWM signal where this signal is better than bipolar or using the pwm method.
Figure 6. Unipolar SPWM signal

Fig. 6 is a unipolar SPWM signal where the output voltage in the calculation is 10.8Vrms

Table 4. The result of the full vridge circuit output

<table>
<thead>
<tr>
<th>Vp-p</th>
<th>Voutput</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.05Vp-p</td>
<td>7.85VAC</td>
<td>50Hz</td>
</tr>
</tbody>
</table>

3.2.2 Pure Sine Wave Signal

The formation of a pure sine wave signal is by providing a low pass filter so that the inverter output becomes pure sine and remains stable at a frequency of 50 Hz. The LPF filter used is an LC filter. Determination of the filter value is based on the calculation below.

The value of the cut-off frequency is searched using the formula

\[ f_{\text{cut-off}} = \frac{1}{2\pi \sqrt{LC}} \]

Where:
- \( \pi \) is a constant with a value of 3.14,
- \( L \) is the inductor value in Henry (H), and
- \( C \) is the value of the capacitor in Farads (F).

Determination of the value of inductance using the calculation method by determining the value of the cut-OFF frequency. The value of the cut-OFF frequency is determined by the value of the inductor and capacitor. Then the formula for finding the value of the inductor:

\[ L = \frac{1}{4\pi^2 F C^2} \]

If the capacitor value is set at 2.2\( \mu \)F

Where the cut off frequency value is set = 1/2 carrier frequency

\[ F_{\text{cut off}} = \frac{20000}{2} = 10000 \text{ Hz} \]

Then the value of the inductor is

\[ L = \frac{1}{4(3.14)^2 \times 10000^2 \times 2.2 \times 10^{-6}} = 0.000152 \text{ H} = 152 \mu \text{H} \]

Below is the result of the inverter output after being given an LC filter.
The picture shows that the inverter wave output after going through the LC filter will be in the form of a pure sine wave. The pure sine wave output will then be connected to a toroid transformer so that it can become a 220 V Ac voltage. The following table shows the results of testing the inverter output using an LC filter.

Table 5. LC filter output results

<table>
<thead>
<tr>
<th>No</th>
<th>V max (v)</th>
<th>Vp-p (v)</th>
<th>Vrms (v)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.45</td>
<td>20.50</td>
<td>7.25</td>
<td>50</td>
</tr>
</tbody>
</table>

From the table above the resulting output is 7.25 Vrms with a frequency of 50 hz. Where the expected vrms output is 8.5 vrms.

3.2.3 Output Inverter Voltage

The inverter output voltage expected by researchers is 220 V. Below is the result of the inverter output voltage.

In Fig. 8, the output of the inverter after being stepped up using a toroid transformer of 220 V is in accordance with what is expected.
4. Discussion

The inverter output voltage is affected by several factors, including the carrier frequency signal and the current flowing in the system. Besides that, the lack of input voltage in the IR2110 driver can also affect the output of the full bridge circuit. In this study, the output voltage of the inverter is in the form of a unipolar spwm with a vp value of 12 V. From the calculation of the inverter output vrms, it produces a value of 8.5 Vrms, while the real result is 7.25 Vrms. This means that the output of the inverter has decreased by 1.25 V.

5. Conclusion

1. Pure sine wave unipolar inverter with SPWM method can be realized using ESP32 where ESP32 has many advantages over Arduino microcontroller.
2. Making the ESP32 driver as a pwm signal generator produces a pwm output of less than 3.3 v. This can affect the performance of the IR2110 driver because the minimum input voltage of the IR2110 is 3.3 V.
3. After adding the LPF filter, the inverter output becomes pure sine with a frequency of 50 Hz.

References