Single Phase Inverter with Power Monitoring using Arduino

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Abstract. The inverter is an electronic device which able to convert DC electricity into AC electricity. In the development of renewable energy resources, for example, solar power plants, inverters are needed. In this research, an inverter is made by real-time power monitoring. The inverter is made using unipolar PWM modulation and a full H bridge topology. PWM signals are generated from Arduino microcontrollers that will control MOSFET switching. Power monitoring is done by installing a DC voltage sensor and INA219 DC current sensor while on the output side using the PZEM 004t (v3) sensor and results will be displayed on the OLED. The experiment was successfully carried out by producing an approaching sine wave signal with a frequency of 50 Hz and 220 V AC voltage. The efficiency of the inverter is low because of loss from the transformer which has a no-load efficiency of 68.7%. When the 15W load has installed the efficiency of the inverter is 31.83% and when the 20W load has installed the efficiency of the inverter is 34.72%. Finally, when the smartphone’s charger is installed the total efficiency was 49.96%.

1. Introduction

The development of the industrial world which increasing in various fields is certainly able to make human life easier. In line with the rapid development of industry, the need for electricity as an energy source in industrial operations also increases. Electrical energy can be obtained through a power plant. At present fossil resources are still widely used in power generation. For example, a power plant that uses coal fuel is still the main power plant in Indonesia with a total capacity of 21 thousand GW, equivalent to 40% of the total installed capacity of the plant [1]. While for renewable energy, based on its geographical location, Indonesia actually has the potential to develop solar power plants with an average power of 4 kWh/ m\(^2\), namely in the western region of Indonesia, the irradiation distribution is around 4.5 kWh/ m\(^2\)/ day with a monthly variation of 10% and in the eastern region of Indonesia irradiation of about 5.1 kWh/ m\(^2\)/ day with a monthly variation of 9% [2].

In a solar power plant, a solar panel device is used to convert sunlight into electricity. Solar panels do not emit harmful greenhouse gas emissions such as fossil fuels, so the use of solar panels does not contribute to the effects of climate change. By using solar panels, clean energy from solar sources can be generated. The energy output from the solar panels is DC electricity. Because most of the load uses AC power, so that a tool to convert DC voltage into AC, known as an inverter, is needed. Therefore, the inverter is one of the tools developed in power electronics.

The inverter also has an important role as a provider of backup electricity in vehicles and at home. Batteries used as energy storage media certainly require an inverter to convert direct current into alternating current so that it can be used. On the other hand, inverter technology is increasingly popular to be used in a variety of electronic equipment such as motor control, electric vehicles, air conditioners, electric trains, and even airplanes. Inverters can be said to be ideal if the quality of the waveforms produced has small distortion and has high efficiency so that it will be effectively used.
Inverter both single-phase and three phases are already in the market. A lot of researchers also have to do this topic as in [3] [4]. In this research, inverter technology with Full H-Bridge topology which can monitor the power will develop. Arduino Uno is used to controlling the inverter to get output specifications of 220 V with a frequency of 50 Hz. Real-time power monitoring makes it possible to monitor the real-time efficiency of the system.

2. System Design
The block diagram of the developed inverter system is shown in Figure 1. DC source 12V is used for power input. In the DC power sensor, voltage divider and INA219 are used to monitor the input power. Full H-Bridge inverter topology is used in this research which has an advantage in output voltage over the other topology [5]. PZEM 004t (v3) is mounted on an AC power sensor that can measure the output power of the inverter. Arduino Uno R3 is installed for the PWM wave generator and controls the power monitoring which will be displayed on the OLED 1.3 screen.

Figure 1  Block Diagram

Unipolar PWM modulation is generated from Arduino to control the MOSFET switching. Unipolar PWM modulation is chosen because it has an advantage in output voltage compared to bipolar modulation, which is lower switching losses [6]. Figure 2 illustrate the unipolar PWM waveform which has three levels of voltage, V+, 0, and V-. The full H-Bridge inverter scheme is shown in Figure 3. It is containing 4 pieces of IRF3205 MOSFET. It also used 2 MOSFET driver IR2110 which one of its control a pair of MOSFET that in High-side and Low-side.

Figure 2  Unipolar PWM modulation [7]
3. Result and Discussion

3.1. Simulation

No-load simulation of the system is carried out in Proteus software. PWM signal generated from Arduino in the simulation shown in Figure 4 (a). The yellow one is output at pin 9 Arduino and the blue one is output at pin 10. Every PWM signal has a 5V peak voltage and a 10ms period. The output signal in IR2110 is shown in Figure 4 (b). The peak voltage of the PWM signal is rise to 12V depending on the IR2110 power input. The output waveform of the inverter in proteus simulation is shown in Figure 4 (c). The waveform is sinusoidal with a 50Hz frequency and Vrms 220V.

3.2. Hardware Implementation

The inverter hardware is made after proteus simulation works well. The inverter hardware implementation is shown in Figure 5. The PWM signal generated from Arduino is shown in Figure 6(a). The yellow one is output at pin 9 Arduino and the blue one is output at pin 10 one. Every PWM signal has a 5V peak voltage and 10ms period. This result is the same as the simulation result.

The output signal in IR2110 is shown in Figure 6(b). The peak voltage of the PWM signal rises to 12V. The noise found on IR2110 signals can occur due to the effects of high-frequency signals and poor solder lines on the PCB. The output waveform of inverter hardware is shown in Figure 6(c). The waveform is nearly sinusoidal with a 50Hz frequency. The peak to peak voltage is shown at 600V it means the RMS voltage of the inverter without load is 212.1 V.

A no-load experiment is done to find inverter efficiency before connected to the load. In this inverter system, the transformer is added to step up the voltage output from the inverter which is around 8.48V to 220V. The transformer becomes an important part of the inverter circuit because it affects the output power of the inverter. The efficiency of the transformer will also affect the efficiency of the inverter. The efficiency of the no-load system is 68.7%. This low efficiency can be caused by the quality of copper for winding and the presence of eddy currents in the transformer iron core.
3.2.1 Sensor Validation

The voltage sensor on the DC side uses the voltage divider concept that compares the analog read voltage and the max bit in Arduino’s pin. The average error of sensor readings compared to multimeters is 0.50 which has an error percentage of 7.87\% as shown in Table 1. INA219 is used to measure the DC current. The average error of sensor readings compared to multi-meters is 0.0058 which has an error percentage of 1.27\%, detail in Table 2.

**Figure 4** Simulation results

**Figure 5** Hardware implementation
Figure 6  Hardware implementation results

Table 1  DC Voltage Sensor

| Voltage (V) | Multimeter (V) | Sensor (V) | Error (V) | % Error |
|------------|----------------|------------|-----------|---------|
| 1.0        | 0.88           | 0.96       | 0.08      | 9.1     |
| 2.0        | 1.91           | 2.10       | 0.19      | 9.9     |
| 3.0        | 2.93           | 3.10       | 0.17      | 5.8     |
| 4.0        | 3.89           | 4.17       | 0.28      | 7.2     |
| 5.0        | 4.93           | 5.30       | 0.37      | 7.5     |
| 6.0        | 5.87           | 6.27       | 0.4       | 6.8     |
| 7.0        | 6.93           | 7.47       | 0.54      | 7.8     |
| 8.0        | 7.90           | 8.52       | 0.62      | 7.8     |
| 9.0        | 8.90           | 9.57       | 0.67      | 7.5     |
| 10.0       | 9.94           | 10.77      | 0.83      | 8.4     |
| 11.0       | 10.89          | 11.79      | 0.9       | 8.3     |
| 12.0       | 11.86          | 12.84      | 0.98      | 8.3     |

Average 0.50 7.87

PZEM 004t(v3) is a sensor module that able to measure voltage, current, and power in the alternate current [8]. The voltage read of PZEM compared to a multi-meter is shown in Table 3. The average error of PZEM voltage readings is 0.42 which has an error percentage of 0.22%. The current read of PZEM compared to a multi-meter is shown in Table 4. The average error of PZEM current readings is 0.014 which has an error percentage of 3.9%.
Table 2  DC Current Sensor

| Current (A) | Multimeter (A) | Sensor (mA) | Error | % Error |
|------------|----------------|-------------|-------|---------|
| 0.1        | 0.09           | 93.3        | 0.0033| 3.67    |
| 0.2        | 0.19           | 191.1       | 0.0011| 0.58    |
| 0.3        | 0.30           | 301.2       | 0.0012| 0.40    |
| 0.4        | 0.39           | 399.5       | 0.0095| 2.44    |
| 0.5        | 0.50           | 503.2       | 0.0032| 0.64    |
| 0.6        | 0.60           | 604.6       | 0.0046| 0.77    |
| 0.7        | 0.69           | 702.3       | 0.0123| 1.78    |
| 0.8        | 0.86           | 805.7       | 0.0057| 0.66    |
| 0.9        | 0.90           | 905.8       | 0.0058| 0.64    |
| 1.0        | 1.00           | 1011.3      | 0.0113| 1.13    |

Average 0.0058 1.27

Table 3  PZEM Voltage Sensor

| No | Multimeter (V) | Sensor (V) | Error | % Error |
|----|----------------|------------|-------|---------|
| 1  | 188            | 188.50     | 0.5   | 0.27    |
| 2  | 190            | 190.40     | 0.4   | 0.21    |
| 3  | 191            | 191.40     | 0.4   | 0.21    |
| 4  | 193            | 193.70     | 0.7   | 0.36    |
| 5  | 194            | 194.10     | 0.1   | 0.05    |

Average 0.42 0.22

Table 4  PZEM Current Sensor

| No | Multimeter (A) | Sensor (A) | Error | % Error |
|----|----------------|------------|-------|---------|
| 1  | 0.178          | 0.17       | 0.008 | 4.49    |
| 2  | 0.231          | 0.23       | 0.001 | 0.43    |
| 3  | 0.264          | 0.27       | 0.006 | 2.27    |
| 4  | 0.432          | 0.46       | 0.028 | 6.48    |
| 5  | 0.463          | 0.49       | 0.027 | 5.83    |

Average 0.014 3.90

3.2.2 Load Test

In the load test, there are three loads used, which are 15W bulb, 20W bulb, and smartphone charger. The first experiment is using a 15W bulb as a load. The results are shown in Table 5. The average input power is 22.1 W and output power is 6.93W. The efficiency of the inverter is 31.83%. The output waveform with a 15W bulb load is shown in Figure 7. The waveform looks like a triangle wave. The testing condition is shown in Figure 8.
Second testing using 20W bulb. The average input power is 24.8 W and output power is 8.50 W. The efficiency of the inverter is 34.72%. The results are shown in Table 6. The output waveform with a 20W bulb load is shown in Figure 9. The waveform looks like a triangle wave. The third experiment is using a smartphone charger as a load. The results are shown in Table 7. The average input power is 14.3 W and output power is 7.14 W. The efficiency of the inverter is 49.96%. The output waveform with a smartphone charger load is shown in Figure 10. The waveform is sinusoidal.

### Table 5 15W Load

| No. | Vin (V) | Iin (A) | Pin (W) | Vo (V) | Io (A) | Po (W) | η (%) |
|-----|---------|---------|---------|--------|--------|--------|-------|
| 1   | 10.55   | 1.92    | 20.2    | 147.8  | 0.05   | 6.95   | 34.41 |
| 2   | 10.74   | 1.82    | 19.5    | 147.9  | 0.05   | 6.95   | 35.57 |
| 3   | 10.9    | 1.84    | 20.1    | 147.9  | 0.05   | 6.95   | 34.58 |
| 4   | 11.48   | 2.28    | 26.2    | 147.7  | 0.05   | 6.94   | 26.51 |
| 5   | 11.64   | 2.1     | 24.4    | 147.6  | 0.05   | 6.86   | 28.08 |
| Avg | 11.06   | 1.99    | 22.1    | 147.78 | 0.05   | 6.93   | 31.83 |

![Figure 7 15W LoadSignal](image1)

![Figure 8 15W LoadSignal](image2)

### Table 6 20W Load

| No. | Vin (V) | Iin (A) | Pin (W) | Vo (V) | Io (A) | Po (W) | η (%) |
|-----|---------|---------|---------|--------|--------|--------|-------|
| 1   | 11.01   | 2.61    | 28.7    | 94     | 0.09   | 8.48   | 29.54 |
| 2   | 10.45   | 1.94    | 20.3    | 93.9   | 0.09   | 8.47   | 41.70 |
| 3   | 10.64   | 2.17    | 23.1    | 93.9   | 0.09   | 8.47   | 36.70 |
| 4   | 10.94   | 2.42    | 26.5    | 93.6   | 0.09   | 8.53   | 32.20 |
| 5   | 11.5    | 2.22    | 25.5    | 93.6   | 0.09   | 8.53   | 33.44 |
| Avg | 10.91   | 2.27    | 24.8    | 93.80  | 0.09   | 8.50   | 34.72 |
4. Conclusion

The inverter has been successfully made accompanied by real-time power monitoring. The inverter is made to produce an output signal close to sinusoidal with a frequency of 50 Hz and a voltage of 220 V AC. The no-load efficiency of the inverter is 68.7% and decreases when the load is attached. This low efficiency can be caused by the quality of copper for winding and the presence of eddy currents in the transformer iron core. When a 15W load is installed the total efficiency is 31.83% while the 20W load when a total efficiency is 34.72% and when the smartphone’s charger is installed the total efficiency is 49.96%. The efficiency can be improved by eliminating switching losses with good wiring and soldering and by using high-frequency transformer which has higher efficiency.

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