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FULL BRIDGE TOPOLOGY SINGLE PHASE INVERTER IMPLEMENTATION WITH BOOTSTRAP CIRCUIT FOR SOLAR PANEL 540 WP

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Abstract

Currently, solar cells have been developed as a source of electrical energy and packaged in the form of solar panels. Solar panels convert incoming solar energy into electrical energy and generate direct current (DC) electricity. In its development, it is necessary to implement an inverter to convert DC voltage into alternating current (AC). A single phase full bridge inverter is implemented in this research. The inverter is equipped with a step-up transformer to increase the voltage to 220 VAC. In this study, testing was carried out by varying the frequency value from 40 Hz - 60 Hz and seeing the effect of the output voltage, output current, and efficiency. The test results show the average voltage on 12 watt LED lamps is 187.422 V and 100 watt incandescent lamps is 172.367 V. Tests with a 35 watt fan load variation have an average voltage value of 209.5 V. Based on the test, the average efficiency is obtained. Based on the test, the average efficiency is obtained. The percentage of the average frequency variation at the inverter output when loaded with 12 watt LED lamps is 77.41 and when loaded with 100 watt incandescent lamps is 55.31. The load variation test when loaded with a 35 watt fan has an average efficiency of 46.44.

Keywords: solar, inverter, energy, voltage, efficiency

1. Introduction

1.1 Introduce the Problem

From 2013 to 2018, Indonesia's population growth rate increased by 6.11% (Indonesian Central Statistical, 2019). Population growth is directly proportional to the electrical energy needs of the Indonesian people. National electricity consumption has increased by 20.7%, starting in 2013 at 0.84 per capita to 2018 at 1.06 per capita (ESDM and Ketenagalistrikan, 2019).

Power plants in Indonesia from 2017 to 2018 have increased by 4.38% and have a total capacity of 64,924.90 MW (ESDM and Ketenagalistrikan, 2019). Sources of electricity generation in Indonesia are still largely sourced from coal and natural gas, while for renewable energy sources it is only 3.22%. Therefore, a development in the field of renewable energy is needed. The government has planned an effort to develop 23% of electrical energy by the government (Perpres, 2020).

One source of renewable electrical energy is sunlight. Solar energy has many advantages, namely unlimited energy, does not cause pollution and does not require fuel. The use of solar

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energy can be done by installing solar panels on the roof of a house or building. The electrical energy produced by solar panels in order to be used requires an inverter device. This inverter produces AC voltage that can supply electrical equipment in a house or building.

The main component of the inverter is the MOSFET transistor. This type of transistor is used because the MOSFET has smaller switching losses and a longer delay-on time than IGBT (Philips Semiconductors, 1999).

The inverter functions to convert direct voltage (DC) into alternating voltage (AC) 220 VAC and a frequency of 50 Hz, thus meeting the standards for household electrical appliances. A full bridge inverter is implemented in this study to produce a pure sinusoidal waveform output voltage. The Inverter device is equipped with an Arduino Nano microcontroller. The microcontroller is used as a PWM signal generator in the MOSFET Driver IC IR2110 circuit.

1.2 Literature review

Inverter is an electrical device that can convert direct current (DC) into alternating current (AC). Inverters are widely used in the industrial world for example as a driver or motor speed controller (Akbar, Facta and Nugroho, 2015). In the implementation of solar power plants, inverters are usually used to run AC current equipment in the house or building. To perform its function, the inverter gets a direct current voltage source from solar panels, batteries, or other DC sources.

To ensure a smooth AC output waveform, it is necessary to control it by a control circuit. The control technique used is to control the amount of time and sequence used to turn the power valve on and off. One of the most widely used controls is pulse width sinusoidal modulation or commonly referred to as the abbreviation SPWM (W. Hart Danial, 2011).

In Figure 1 the full bridge inverter circuit has two switch legs where each leg has two switches. Each leg of the switch has two separate power controllers and has a diode connected to the load. Points a and b are the link between the inverter and the load. The inverter works by changing the conditions of each switch with a certain frequency. In the inverter circuit, the switches S1+ and S2+ or S1- and S2- cannot be turned on simultaneously because there will be a short circuit in the voltage source Vi.

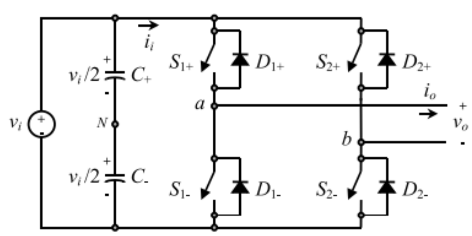

Figure 1. Single phase full bridge inverter circuit (W. Hart Danial, 2011)

Sinusoidal Pulse Width Modulation is a signal modulation that has a pulse active cycle width that can change with the amplitude of the carrier wave.

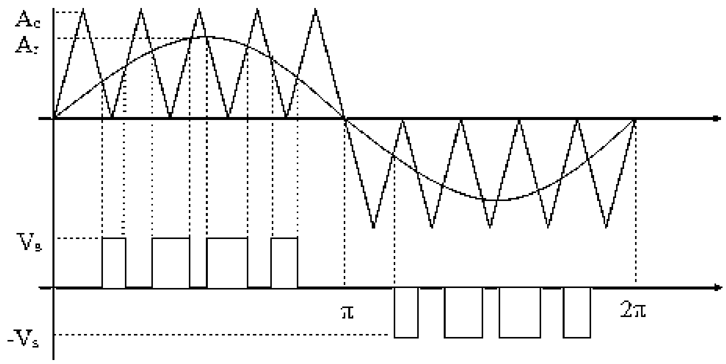

Figure 1. SPWM Signal Formation (W. Hart Danial, 2011)

Based on Figure 2 explains that the SPWM signal is a comparison of a sine wave signal (reference signal) with a triangular signal wave (carrier wave). This comparison will produce an SPWM wave with a modulation index (M) which will affect the value of Vs so that it can be adjusted from 0 to 1 by changing the amplitude value of the reference signal.

The driver circuit in general has a main function, namely as an amplifier of the SPWM signal from the output of the control circuit which later this signal will be used to control the switching that occurs in the MOSFET. Another function of this driver circuit is as a shield that is used to separate the control circuit and power circuit (Muttaqin, Setiawan and Facta, 2016).

The bootstrap circuit functions as a minimum system driver, so that the driver's performance can run well. Bootstrap is useful in high voltage gate drivers, allowing the circuit to work according to a full bridge type inverter topology. Here is a schematic of the bootstrap circuit (Suroso, Setiawan and Winardi, 2018).

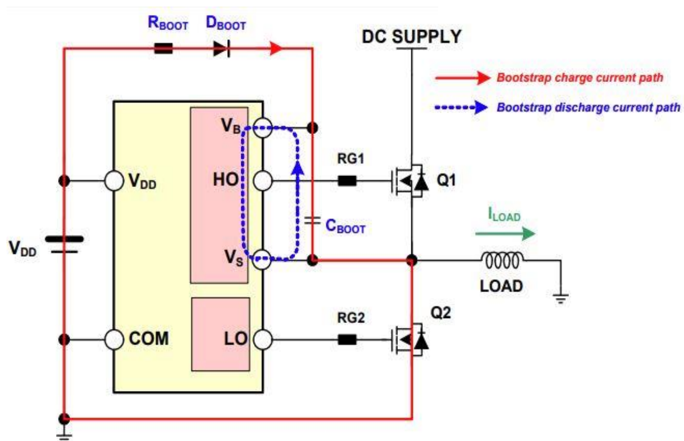

Figure 3. Bootstrap driver circuit schematic (Semiconductor Components Industries, 2017)

IC IR2110 is used as an integrated circuit (IC) used in the bootstrap driver. This component has features suitable for high speed power MOSFET control. This IC is designed to withstand a voltage of +500V or +600V (Baharom *et al.*, 2015).

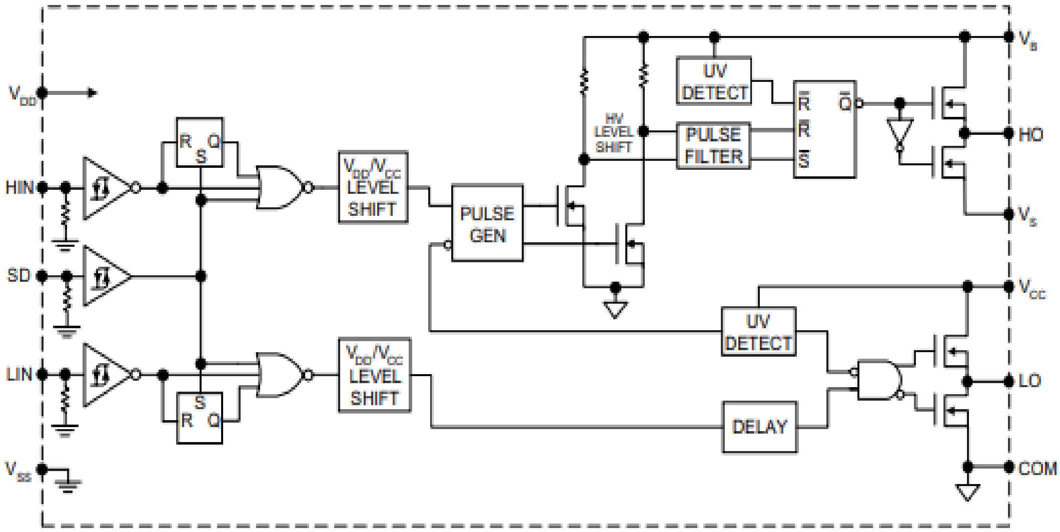

Figure 4. IC Schematic IR2110 (International Rectifier, no date)

Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is a transistor that has basic materials in the form of metals and semiconductors with a certain concentration of impurities. The advantage of MOSFETs over BJTs is their low power dissipation. Based on the type of channel, MOSFET consists of two types, namely n-channel (type N) and p-channel (type P) (Rashid, 2007).

1.3 Research design steps

The method used by the inverter is switching or switching performed by MOSFET or IGBT. The switch has a function to reverse the direct voltage into alternating voltage. At the inverter output, the resulting voltage depends on the switching frequency. The inverter is made of a power switch so that the AC output waveform consists of discrete values. This causes the AC output waveform not to be as expected because the fundamental component (the power switch) behaves that way.

2. Method

The implementation of the inverter in this study is used to convert direct current voltage into alternating current voltage. The voltage coming from the DC bus is converted by the inverter so that the output voltage can be used for alternating current loads. The fully implemented bridge inverter has several parts which are:

1. MOSFET driver and microcontroller supply
2. Arduino Nano control circuit and IR 2110. driver IC
3. Full bridge inverter circuit
4. Step-up transformer
5. Alternating current electric load

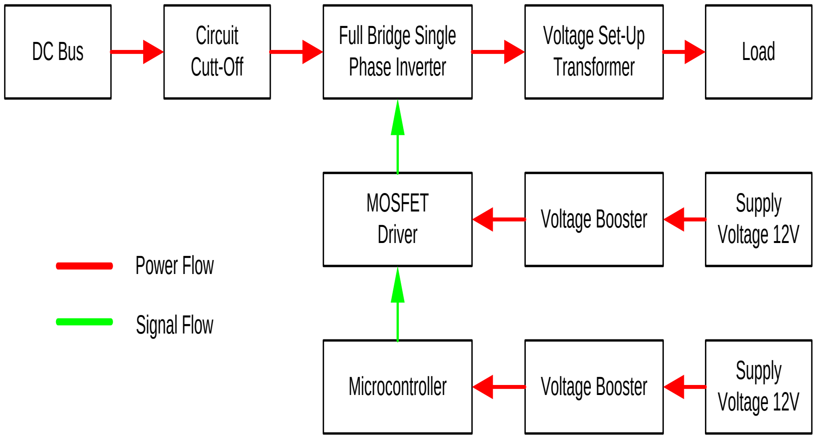

Figure 5. Block diagram of full bridge inverter system

2.1 Hardware Design

The inverter used is a single phase inverter with a Full Bridge topology to convert DC voltage to AC. The output waveform that will be generated from a full bridge inverter is a sinusoidal wave. The inverter design is shown in Figure 6.

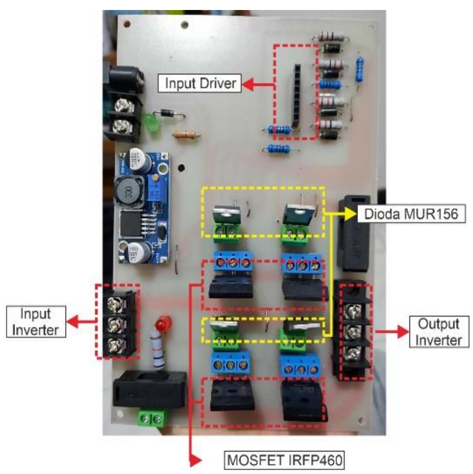

Figure 6. Bridge inverter design

2.2 MOSFET Driver Design

Based on Figure 7, there is a driver circuit that is installed with the IR2110 IC. The output of the Arduino Nano microcontroller is connected to the IC IR2110 on the HIN pin (high input) and the LIN pin (low input). The HO (high input) and LO (low input) pins are the output pins of the IR2110 IC. At the output of this pin, a UF2007 diode and 18 resistor are installed to overcome the capacitance effect of the MOSFET which will affect the triggering signal due to the delay time.

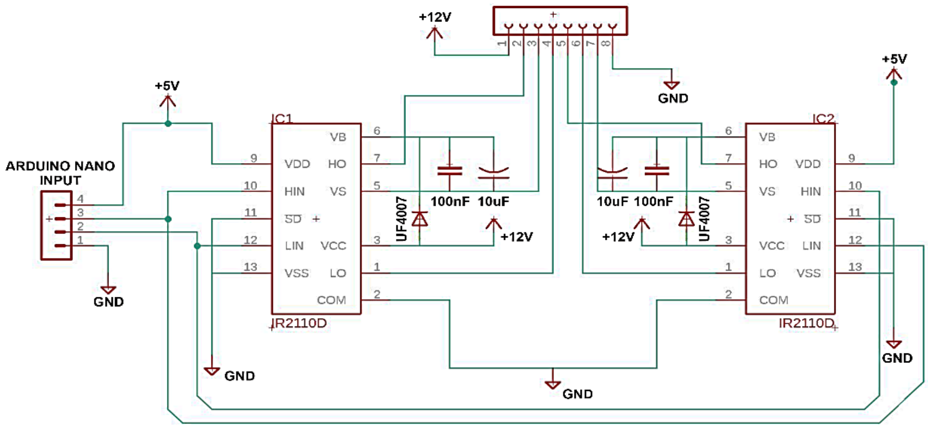

Figure 7. Rangkaian Driver MOSFET IC IR2110

2.3 Control Circuit Design

In this study using an Arduino Nano 8 bit microcontroller. The microcontroller is used to process the inverter modulation signal and the SPWM signal triggering generator. This microcontroller has 30 pins. The following is a schematic of the use of pins and the realization of the Arduino Nano microcontroller circuit.

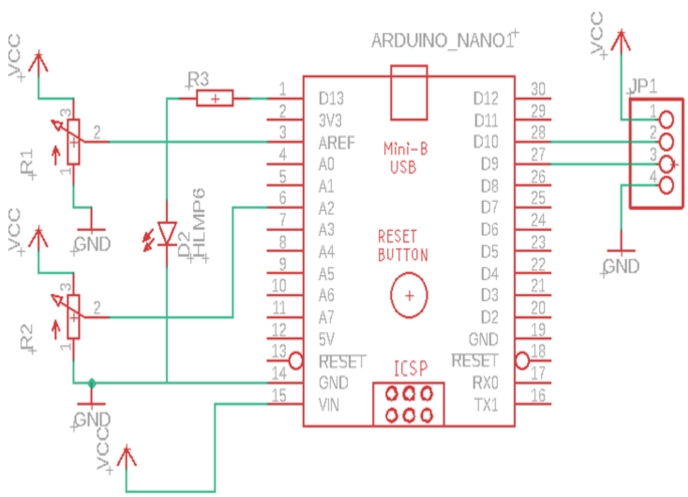

Figure 8. Rangkaian Driver MOSFET IC IR2110

3. Results

In this study using an Arduino Nano 8 bit microcontroller. The microcontroller is used to process the inverter modulation signal and the SPWM signal triggering generator. This microcontroller has 30 pins. The following is a schematic of the use of pins and the realization of the Arduino Nano microcontroller circuit.

3.1 Control Circuit Test

Testing the SPWM signal issued by the Arduino Nano microcontroller using two channels placed on pin D9 and pin D10. This microcontroller is designed with a carrier frequency of 31 kHz. The test circuit is shown in Figure 9.

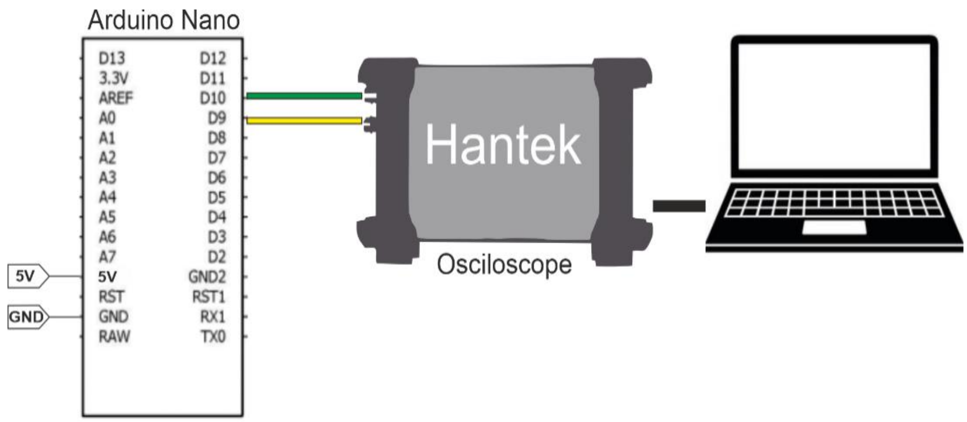

Figure 9. Arduino Nano microcontroller SPWM test circuit

SPWM signal test results on pins D9 and D10, respectively, are shown in Figure 10 and Figure 10. dAxis X indicates time (t) and Y axis indicates voltage (volts).

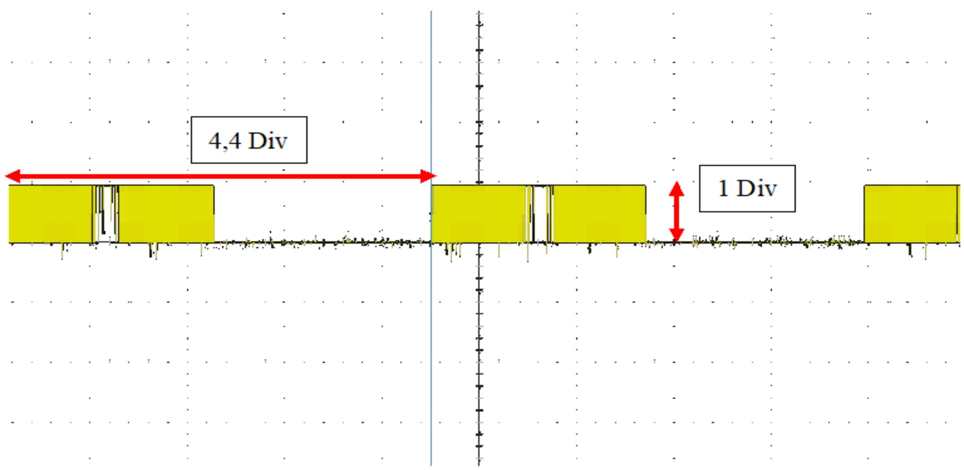

Figure 10. Arduino Nano pin 9 SPWM signal waveform

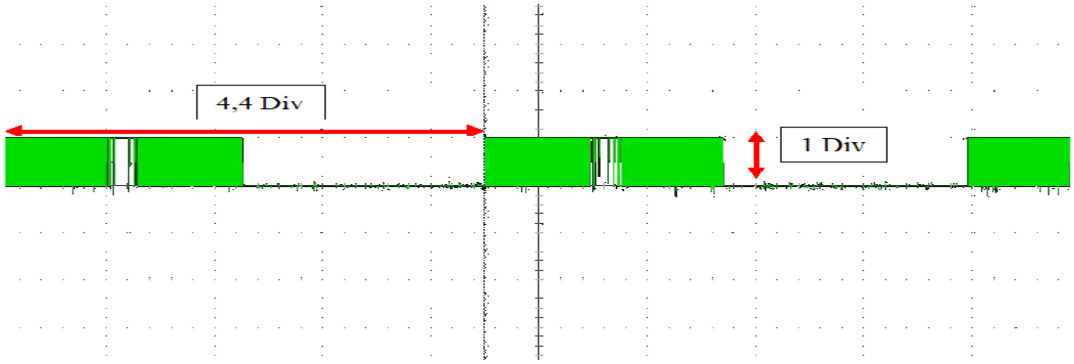

Figure 11. Arduino Nano pin 10 SPWM signal waveform

Figures 10 and 11 show that the high voltage is 1 div on a 5V/div scale, so the SPWM voltage can be calculated as 5V. The SPWM signal voltage in the test has met the voltage requirement. The value of the SPWM output frequency can also be known, with a period of 4.4 div and a t/div of 5 ms, 45 Hz is obtained.

The SPWM signal planning to be implemented in a full bridge inverter system is shown in Figure 12. The test results show that the SPWM signal is in accordance with what will be realized on the inverter.

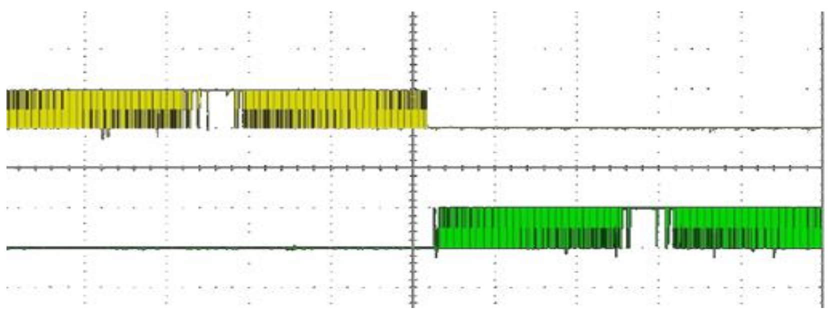

Figure 12. SPWM wave realization

3.2 IR2110 Bootstrap Circuit Output Testing

Testing the output of the IR2110 bootstrap circuit on the MOSFET driver is carried out in Figure 13.

Figure 13. MOSFET Driver test circuit

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Based on Figure 14, the MOSFET Driver output voltage has a height of 1.1 div with 10 V/div, so the bootstrap output voltage is 11 Volts. The MOSFET driver test was carried out at a frequency of 55 Hz with a width of 9 div and a t/div of 2 ms.

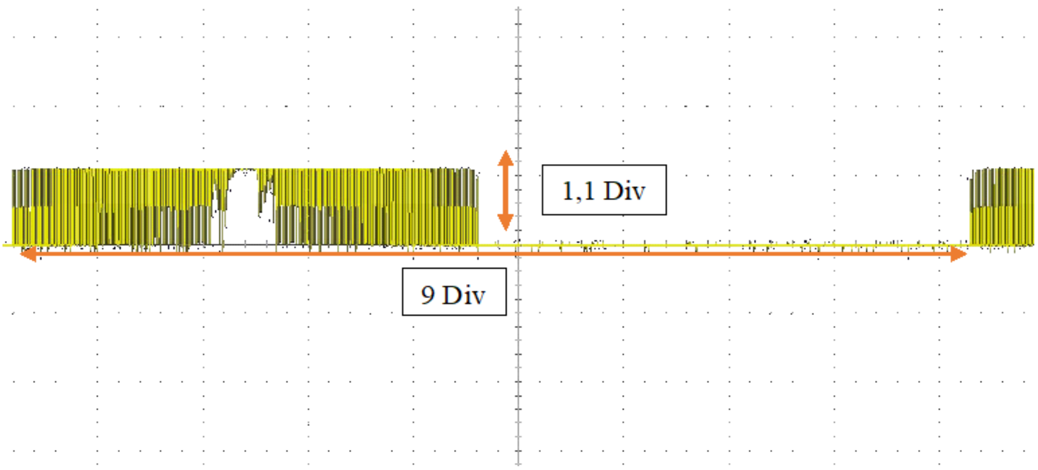

Figure 14. MOSFET Driver output signal with a frequency of 55 Hz

3.3 Power Circuit Test

The test is carried out when there is a load and no load at the inverter output. The following is a test result of a no-load inverter with the X-axis as time (t) and the Y-axis as voltage (volts).

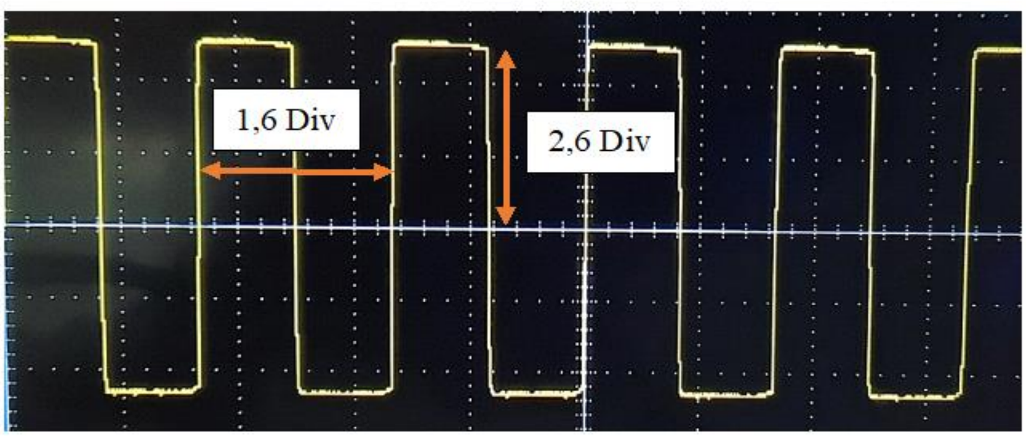

Figure 15. No-load inverter output voltage signal with frequency 60 Hz

3.3.1 Testing With 12 Watt LED Lamp

This test is carried out using 12 watt LED lamps to determine the output waveform, voltage, and current of a single phase full bridge inverter. The following is the output waveform of the inverter on the LED lamp load with the X axis as time (t) and the Y axis as voltage (volts).

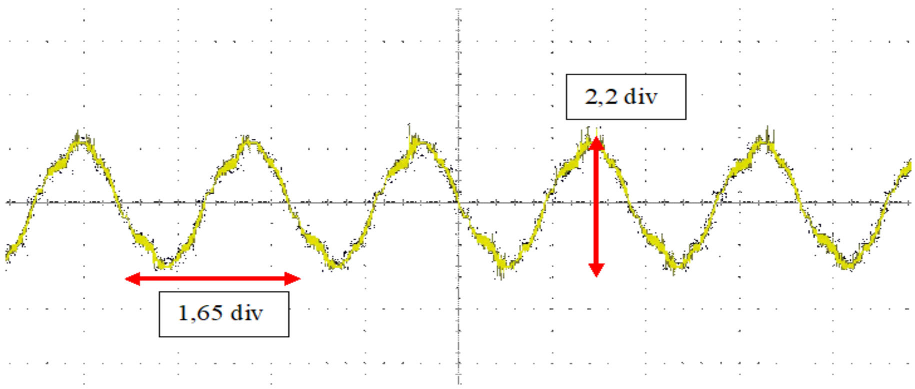

Figure 16. The output voltage waveform of the LED lamp load when the frequency is 60 Hz

To determine the effect of frequency changes on the output voltage and current of a single-phase full-bridge inverter with a step-up transformer. Circuit testing is done by varying the output frequency in the range of 40 Hz – 60 Hz. The load used for 12 Watt LED lamps, as shown in Tables 1 and 2.

Table 1 Output test results with 12 Watt LED lamp load

Frequency (Hz)	V_{in} (V_{DC})	I_{in} (A)	V_{out} (V_{AC})	I_{out} (A)
40	66.6	1.1	183.7	0.45
43	66.5	1.1	184.6	0.45
45	66.5	1.1	185.9	0.45
48	66.5	1.1	186.5	0.45
50	66.6	1.1	188.7	0.44
53	66.6	1.1	188.8	0.44
55	66.6	1.1	189.5	0.44
58	66.6	1.1	189.6	0.44
60	66.6	1.1	189.5	0.44

Table 2 Power efficiency test results with 12 Watt LED lamp load

Frequency (Hz)	Input Power (W)	Output Power (W)	Efficiency (%)
40	73.26	57.87	78.99
43	73.15	57.32	78.36
45	73.15	57.72	78.91
48	73.15	57.07	78.02
50	73.26	56.46	77.07
53	73.26	56.49	77.11
55	73.26	55.86	76.26
58	73.26	55.89	76.30
60	73.26	55.86	76.26

3.3.1 Testing With 100 Watt Incandescent Lamp

This test is carried out using incandescent lamps to determine the output waveform, voltage, and current of a single-phase full-bridge inverter. The following is the output waveform of the inverter on the incandescent lamp load.

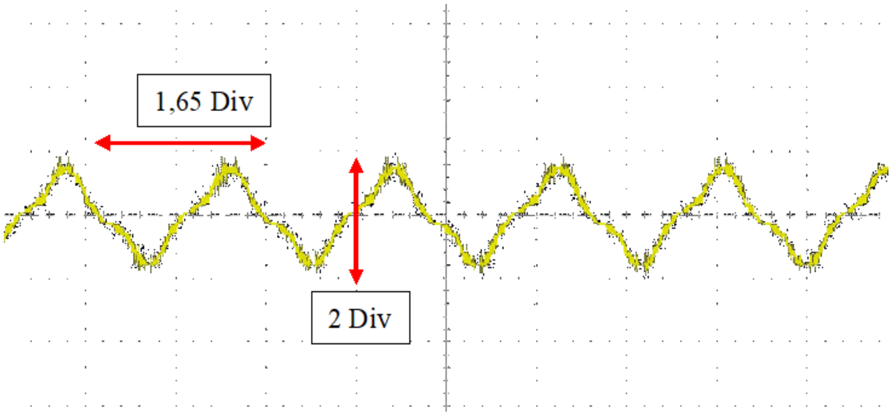

Figure 17. Incandescent lamp load output voltage waveform at a frequency of 60 Hz

To determine the effect of frequency changes on the output voltage and current of a single-phase full-bridge inverter with a step-up transformer. Circuit testing is done by varying the output frequency in the range of 40 Hz – 60 Hz. The load used is a 100 Watt incandescent lamp, as shown in Tables 3 and 4.

Table 3 Test results with a 100 watt incandescent lamp load

Frequency (Hz)	V_{in} (V_{DC})	I_{in} (A)	V_{out} (V_{AC})	I_{out} (A)
40	66.6	1.8	172.5	0.57
43	66.5	1.8	173.4	0.57
45	66.5	1.8	173.4	0.57
48	66.5	1.8	172.6	0.57
50	66.6	1.8	172.5	0.56
53	66.6	1.8	172.2	0.56
55	66.6	1.8	172.1	0.56
58	66.6	1.8	172.3	0.56
60	66.6	1.8	170.3	0.56

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Table 4 Inverter power efficiency with 100 watt incandescent lamp load

Frequency (Hz)	Input Power (W)	Output Power (W)	Efficiency (%)
40	119.88	68.83	57.41
43	119.7	68.20	56.97
45	119.7	68.20	56.97
48	119.7	66.90	55.89
50	119.88	65.69	54.79
53	119.88	65.57	54.70
55	119.88	64.57	53.86
58	119.88	64.65	53.93
60	119.88	64.35	53.30

4. Discussion

Based on Figure 18, testing with frequency variations affects the change in the output voltage of the single-phase full-bridge inverter. The smallest voltage at a frequency of 40 Hz is 183.7 and the largest voltage is 189.5 at a frequency of 60 Hz. The value of the LED output voltage between the frequency of 40 Hz - 60 Hz tends to increase this is due to the capacitive nature of the components that make up the 12 Watt LED lamp.

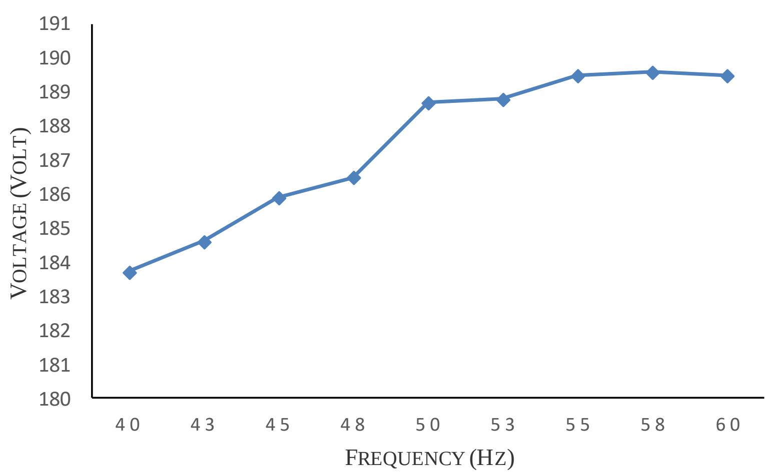

Figure 18. Frequency relationship to output voltage on LED lamp load

Figure 18 shows that the efficiency at a frequency of 40 Hz is 78.99% and for a frequency of 60 Hz the efficiency is 76.26%. The efficiency value does not change significantly with changes in frequency. The difference in efficiency values is due to losses when the inverter is loaded with 12 Watt LED lamps.

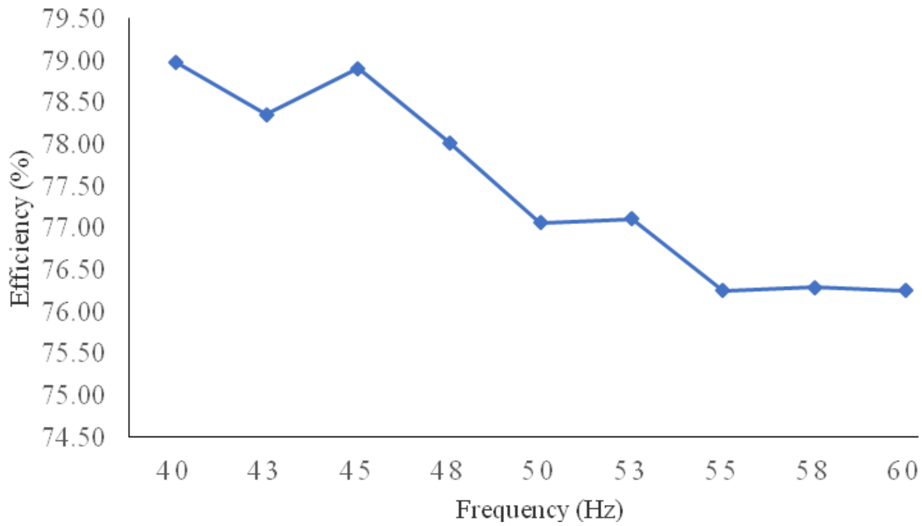

Figure 19. Frequency relationship to efficiency in LED lamp

Tests with a 100 Watt incandescent lamp load are shown in Figure 20. The frequency variation does not affect the change in the output voltage of the single-phase full-bridge inverter. The output voltage at a frequency of 40 Hz is 172.5 and the output voltage at a frequency of 60 Hz is 170,3. The change in voltage in this test is due to the large inductance reactance on the transformer is influenced by the magnitude of the frequency, the greater the frequency, the greater the inductance reactance value of the transformer.

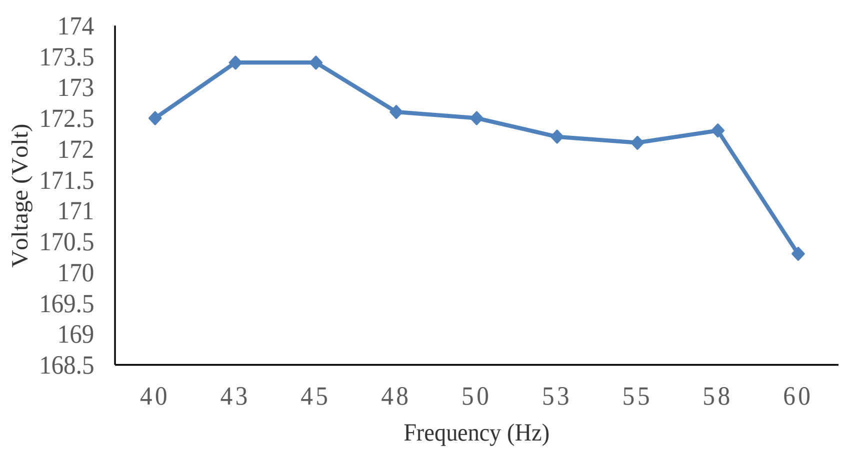

Figure 20. Frequency relationship to output voltage on 100 Watt incandescent lamp load

The efficiency value does not change significantly with changes in frequency, as shown in Figure 21. It can be seen that at a frequency of 40 Hz, the efficiency is 57.41% and for a frequency of 60 Hz, the efficiency is obtained.

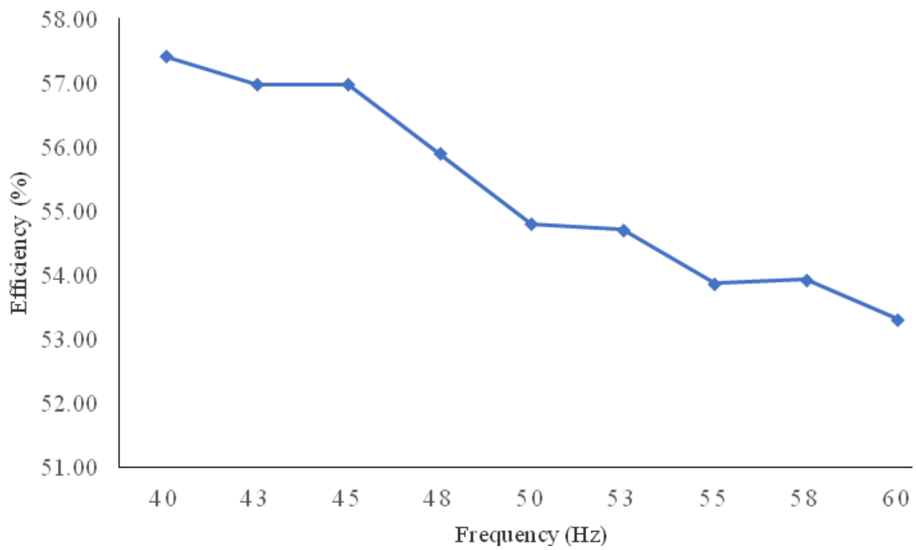

Figure 21. Frequency relationship to efficiency in 100 Watt incandescent lamp

Referring to Figures 15, 16 and 17 shows that the inverter can be set at a frequency of 60 Hz and can be set between a frequency of 40 Hz – 60 Hz. In general, the inverter implementation can be applied to the 540 WP solar panel system. Single phase full bridge inverter can be applied and adjusted to the load.

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References

Akbar, A. A., Facta, M. and Nugroho, A. (2015) ‘KECEPATAN PUTAR MOTOR PENGGERAK ROTARY SPARK GAP’, Transient, 4(4), p. 896.

Baharom, R. et al. (2015) 'Development of a gate drive with overcurrent protection circuit using IR2110 for fast switching half bridge converter', ARPN Journal of Engineering and Applied Sciences, 10(23), pp. 17463–17467.

ESDM, K. and Ketenagalistrikan, D. (2019) ‘Statistik Ketenaga Listrikan Tahun 2018’, Journal of Chemical Information and Modeling, 53(9), pp. 1689–1699.

Indonesian Central Statistical (2019) ‘Statistik Indonesia 2019’, Statistik Indonesia 2019 (Indonesian statistics), p. Jakarta: Badan Pusat Statistik.

International Rectifier (no date) ‘IR2110 (-1-2)(S) PbF / IR2113 (-1-2)(S) PbF Absolute Maximum Ratings’, Data Sheet No. PD60147, 2110, pp. 1–18.

Vol. 6, No. 05; 2021

ISSN: 2456-3676

Muttaqin, S., Setiawan, I. and Facta, M. (2016) 'Desain Dan Implementasi Voltage-Source Inverter (Vsi) Tiga Fase Uniform Pulse-Width Modulation (Upwm) Dengan Dspic30F4011', Transmisi, 18(4), p. 153.

Perpres (2020) 'LAMPIRAN II PERATURAN PRESIDEN NOMOR 18 TAHUN 2020 TENTANG RENCANA PEMBANGUNAN JANGKA MENENGAH NASIONAL TAHUN 2020-2024'.

Philips Semiconductors (1999) 'PowerMOS transistors Avalanche energy rated QUICK REFERENCE DATA PowerMOS transistors Avalanche energy rated', (September), pp. 1–7.

Rashid, M. H. (2007) Power Electronics Handbook: Circuits, Devices, and Application, Second. San Diego, California: Elsevier Inc.

Semiconductor Components Industries (2017) 'AN-6076 Design and Application Guide of Bootstrap Circuit for High Voltage MOSFETs', ON Semiconductors, pp. 1–15.

Suroso, S. M., Setiawan, I. and Winardi, B. (2018) 'PERANCANGAN INVERTER SATU FASA OFF-GRID MENGGUNAKAN DSPIC30F4011 DENGAN KONTROL ARUS METODE PROPORTIONAL RESONANT', TRANSIENT, 7(3), p. 754.

W. Hart Danial (2011) Power Electronics. New York: McGraw-Hill Book Company.