Design of A Single-Phase Pure Sine Wave Inverter Using Arduino as The Main Controller

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Abstract

Solar Power Plants (PLTS) have gained popularity in many countries as a clean, cost-effective, and sustainable source of electricity for communities. However, these plants face challenges in converting the electrical current produced by solar panels from direct current (DC) to alternating current (AC), which is widely used by most electrical equipment. In this regard, the role of inverters is crucial. This study aims to design and construct a single-phase pure sine wave inverter using Arduino as the primary controller. The inverter produces a pure sinusoidal output signal with adjustable width using the modulation index and is equipped with a safety system to prevent short circuits between MOSFETs by setting dead time in the Pulse Width Modulation (PWM) signal. The designed inverter output can generate a sinusoidal signal of up to 100 Watts without significant distortion under various loads, with an output voltage of 220VAC ±0.25% and a frequency of 50Hz ±0.10%. While the inverter efficiency reaches 70% across various loads, there is potential to enhance efficiency by incorporating a feedback voltage system and adjusting the carrier frequency. This study has successfully designed and implemented a single-phase inverter that generates a pure sine wave using Arduino as the main controller.

Keyword: *Inverter, Pure Sine Wave, Pulse Width Modulation, Arduino*

I. INTRODUCTION

In this modern era, technological advances have brought major changes in the way we use and manage energy resources, and electrical energy has become a basic human need in everyday life (Usman, 2018). Dependence on electricity as the main energy source has increased along with the increasing need for electricity in various sectors of life, including household, industrial, commercial, and transportation. However, the sustainability of using conventional energy resources such as fossil fuels is increasingly being questioned due to serious environmental impacts, including greenhouse gas emissions and global warming(Winarno & Soerawidjaja, 1998).

In response to this challenge, there has been a shift towards the use of renewable and environmentally friendly energy resources, such as solar energy, wind energy, and hydro energy. Solar PV systems are becoming one of the main solutions in providing renewable energy, especially in areas that have high sun exposure throughout the year (Nurjaman & Purnama, 2022). Solar power plants have become a popular choice in many countries to provide clean, cost-effective, and sustainable electrical energy for the community.

However, in its application, Solar Power Plant (PLTS) also faces several challenges, mainly related to the conversion of electric current generated by solar panels from direct current (DC) to alternating current (AC) which is generally used by most electrical appliances (Subandi, 2020). This is where the role of the inverter becomes very important. Inverters in Solar Electric Generating Systems (PLTS) are used to convert electrical energy generated from solar panels, so that it can be used to power electronic equipment, and as an alternative power supply replacement when there is a PLN power outage.

A perfect inverter can produce a pure sine wave with the same waveform as the household power grid waveform. This sinusoidal wave is needed to provide stable power with good quality, so that it can be used for electronic equipment that is sensitive to voltage fluctuations, such as computers, televisions, and industrial equipment that requires flexibility and high-power quality (Usman, 2018).

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Based on this, the author is interested in compiling this thesis with the title "Design of a single-phase pure sine wave inverter using arduino as the main controller". In the inverter circuit, arduino is used to control SPWM, dead time, and also the modulation index. The 12 volt DC input is taken from a battery or power supply voltage source by producing a 220 volt AC output.

II. THEORY

A. Inverter and Working Principle

An inverter is a voltage converter circuit from a DC source to an AC voltage. DC voltage sources that can be used by inverters are batteries, solar panels, dry batteries, and other DC voltage sources. With the output of the inverter in the form of AC voltage 220V or 120V, and an output frequency of 50Hz or 60Hz.

An inverter is basically a device that makes alternating voltage (AC) from direct voltage (DC) by means of wave formation. However, the waves generated by the inverter are square waves and not sinusoidal. The formation of this AC voltage is achieved through the use of two pairs of switches (Karyadi, 2019). The following is a picture of one of the inverter topologies, namely full-bridge which explains the working principle of the inverter for the formation of square voltage waves, can be seen in Figure 1.

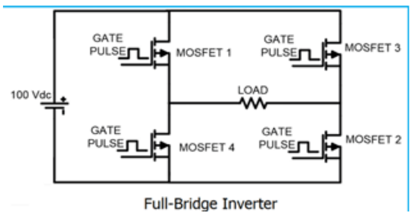

Figure 1. Inverter Working Principle
(Source : Karyadi, 2019)

In this research, the inverter designed uses a full-bridge inverter circuit. Full-bridge inverter is a topology in the inverter, namely a circuit. Full-bridge inverter has 4 switches paired between (S1,S2) and (S3,S4). AC output is obtained from DC input by opening and closing the specified switch. The output voltage Vo can be +Vdc, -Vdc, or zero, depending on which switch is closed.

As shown in Figure 1 above, four switches explain the working principle of the inverter. DC current will flow towards the load R from the left towards the right if switches S1 and S2 are on. If S3 and S4 are on, the DC current will flow to the load R from right to left. Pulse width modulation circuit is used to convert DC voltage into AC voltage in the inverter. The formation of the switch wave can be seen in Figure 2. as follows.

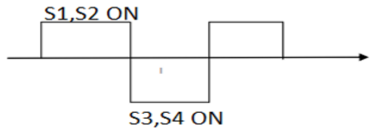

Figure 2: Voltage Waveform
(Source : Karyadi, 2019)

In the full-bridge inverter circuit there is a condition that needs to be considered that S1 and S4 must not close at the same time as S2 and S3, because this will cause a short circuit on the DC source (Karyadi, 2019). The output voltage results can be summarized as follows.

When switches S1 and S2 are closed, the output voltage Vo = +VDC.
When switches S3 and S4 are closed, the output voltage Vo = -VDC.
When switches S1 and S3 are closed, the output voltage Vo = 0.
When switches S2 and S4 are closed, the output voltage Vo = 0.

B. MOSFET IRF3205

MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a transistor with semiconductor material (silicon) that has a certain level of impurity concentration. This level of impurity can be divided into, N-type MOSFET transistor (NMOS) and P-type MOSFET transistor (PMOS). Silicon material is used as the foundation (substrate) of the drain, source, and gate. In this research, the type of MOSFET used is MOSFET IRF3205 which can be explained as follows. MOSFET IRF3205 is an N-Chanel MOSFET transistor designed for operation in a high voltage and current range, making it suitable for use in applications that require high power control (Chukwulozie, 2016). The enhancement mode MOSFET transistor consists of N-type and P-type. The symbol of this transistor can be seen in Figure 3. as follows.

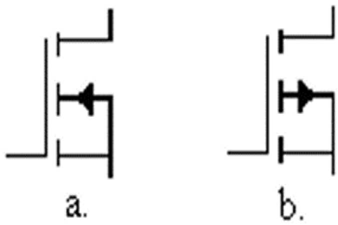

Figure 3. (a) N-Channel Depletion (b) P-Channel Depletion
(Source : A. Malik, 2018)

C. EGS002 Module

The EGS002 module is a device used to convert PWM (Pulse width modulation) signals into AC (Alternating Current) signals. So that EGS002 is commonly used as a DC to AC inverter, where DC signals from power sources such as batteries or solar panels are converted into AC signals that can be used by AC devices (Ramadhani et al., 2021). EGS002 is a specialized controller board for single-phase sine inverters, which is controlled by ASIC EG8010 as the controller chip and IR2110S as the driver chip.

D. Transformer

A transformer is a device used to transform voltage and current in an electrical system. The working principle of a transformer is based on electromagnetic induction, where a change in current in the primary winding creates a magnetic field in the transformer core. This magnetic field then induces current in the secondary windings, which allows the transformation of voltage and current according to the ratio of the number of turns in the primary and secondary windings. Transformers can be used to convert high voltage to low voltage (step-down) or convert low voltage to high voltage (step-up) (Siburian Jhonson, 2019). In this study, the transformer used is a 5A step-up UPS transformer where the primary side used is 12V and the secondary side is 220VAC. The transformer tool can be seen in Figure 4, as follows.

Figure 4. Transformer
(Source : R. Umar, 2019)

E. Arduino Microcontroller

Arduino Uno is an Interated Circuit (IC) based microcontroller, which can be programmed to produce outputs as needed. The Arduino microcontroller itself can generate pulses with periods that can be adjusted as needed to produce precise and accurate delay times, so that it can be used as a pure sine wave generator.

In an inverter with a full-bridge topology, two pulse sequences with different conditions are required, so that Arduino can be programmed by creating a program that produces two different pinout conditions, by working one pinout OFF first then ON according to the period that has been set, for the other pin ON first then OFF with the period that has been set. From this it can be concluded that when the first pin is ON, the second pin is OFF and vice versa periodically (Dinda Triatno, 2017).

F. METHODS

The stages carried out in order to make the Design of One-Phase Pure Sine Wave Inverter Using Arduino as the Main Controller, so that the results are in accordance with the objectives and can be carried out properly are made in the form of flow charts and block diagrams in Figure 5. and Figure 6.

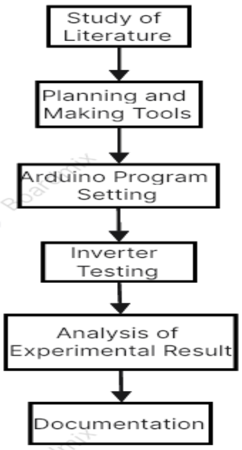

Figure 5. Flowchart of the Working Stage

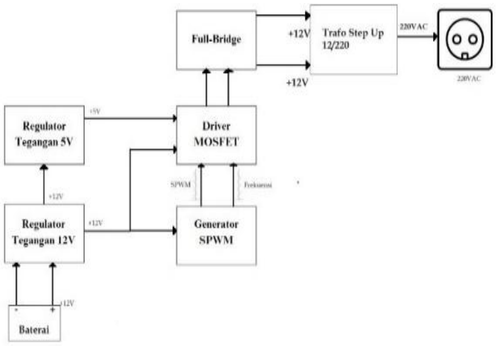

Figure 6. System Block Diagram

G. Inverter Circuit Schematic

At this stage involves several important steps, namely, designing and creating circuit schematics and PCB (Printed circuit board) layouts. The first thing to do at this stage is to create an Arduino circuit scheme to be connected to the EGS002 module, which can be explained as follows.

In this study, the EG8010 IC contained in the EGS002 module was not used and replaced with Arduino. By removing the EG8010 IC, the functions of the EG8010 IC must be replaced with Arduino, such as the operating voltage for EGS002 of 5V, the GND (Ground) line, and the SPWM generator. The output pins on the Arduino which are used as full-bridge MOSFET controllers in the inverter include:

1. Pins 9 and 10, used as SPWM generators. Pin 9 is connected to R30 and pin 10 is connected to R32.
2. Pins 11 and 12, used as a 50Hz signal generator. Pin 9 is connected to R34 and pin 10 is connected to R36.

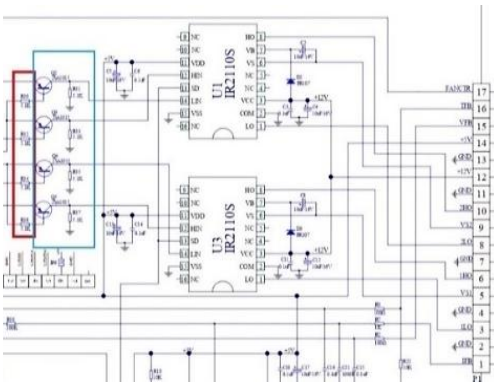

Figure 7. EGS002 Module Schematic

In Figure 7, above is connected pin out from Arduino uno to 4 resistors marked red. After connecting the Arduino uno with the EGS002 module, the next step is to design a 100Watt inverter schematic, the designed inverter circuit can be seen in Figure 8, as follows.

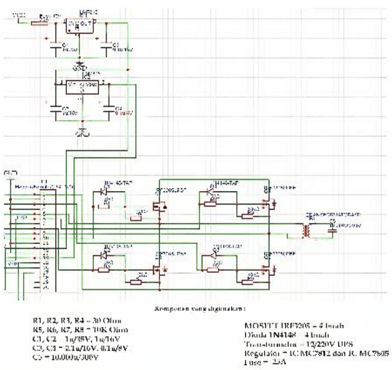

Figure 8. Inverter Schematic

The schematic drawing in Figure 8, is an inverter circuit, with the following information:

1. 4 pins of EGS002 are used to trigger the gate MOSFET, namely pin 3 (1LO), pin 6 (1HO), pin 8 (2LO), pin 10 (3HO).
2. 2 pins that go to the transformer, namely pin 5 (VS1), and pin 9 (VS2).
3. Pin 1 (IFB)
4. Pins 2, 4, 7, 11, and 13 are connected to ground.
5. 12V voltage regulator on pin 12
6. 5V voltage regulator on pin 14.

H. Program Arduino

In this study, Arduino is used as a generator of SPWM signals and 50Hz fundamental signals. So to produce pure sinus waves or pulse rows with a minimum output voltage of 0 Volt and a maximum of 5 Volt periodically can be done by setting the program on the arduino uno to produce outputs in LOW and HIGH conditions periodically, as well as frequencies that are set by entering the desired time values. Since on the Arduine uno cannot enter frequency values directly, then to produce a Frequency value used the equation as follows.

$$F = \frac{1}{T} \quad (1)$$

This SPWM signal generation generally uses a sine lookup table technique that contains data-values of the sinusoid wave amplitude in a single cycle. These amplitude values are used as the PWM duty cycle, so that changes in the synusoid pattern affect the change in the pWM cycle duty. (Turahyo, 2017). In this study, a 10kHz carrier frequency was programmed to produce a single 50Hz sinus wave, requiring 200 PWM cycles, with the calculations as follows:

$$\text{PWM pulse} = \frac{F\ carrier}{F\ sinus} \quad (2)$$

$$\text{PWM pulsation} = \frac{10KHz}{50Hz} = 200$$

This SPWM signal generation generally uses the sine lookup table technique which contains data on the amplitude values of sinusoidal waves in one cycle. These amplitude values are used as the PWM duty cycle. So that changes in sinusoidal patterns affect changes in the PWM duty cycle (Turahyo, 2017). In this study, a carrier frequency of 10kHz is programmed to produce one 50Hz sine wave, so 200 PWM cycles are required, with the following calculation:

LookUpTable[0] = 0 (sinus value at 0 microsseconds),
LookUpTable[1] = 0,03125 (sinus value at 100 microsseconds),
LookUpTable[2] = 0,0625 (sinus value at 200 microsseconds)

Dead-time values and modulation indices are also programmed on Arduino to generate sinusoidal pulse width modulation. On an arduino the clock frequency is 16Mhz (16 million cycles per second), so the duration of one clock cycle can be calculated as follows:

The duration of one clock cycle = $\frac{1}{16000000}$ seconds (2.3)
The length of one cycle clock = 62,5 nanosecond
The dead time value is 312 nanosecond (5x62,5 Ns = 312,5Ns)
The modulation index value is set at 0,7

The arduino program to run PWM signals, dead time and modulation indexes, is implemented on the Interrupt Service Routine (ISR) function. Whenever there is overflow on the timer1, the Arduino will execute the ISR function which has the primary task of regulating the generation of SPWM (PWM) signals and controlling the dead time on the device to obtain efficient result.

I. Data Collection

The data in this study were taken from tests carried out using 2 measuring instruments, namely: a digital multimeter, and an oscilloscope. With testing divided into 3 tests as follows.

1. **Test and Measurements of Inverter Output Voltage.**
   Tests and measurements of the inverter voltage are carried out to evaluate the output voltage on the inverter. This test is divided into two types, namely:

   a) Testing and measuring with varying loads and also giving a certain time interval to each load to see the stability of the inversor device
   b) As well as testing the inverter's resistance to peak current (surge), by giving a load with maximum power to the inverter.
2. **Frequency Testing and Measurement**
   This test is done to find out the frequency generated by the inverter. Based on planning, the expected frequency is 50Hz. This test aims to ensure that the frequencies generated are in line with the planned.
3. **Testing and Measurement of Output Waves**
   This test is aimed at evaluating the performance of the network that has been designed, in producing pure sinus waves. In this test, the evaluation of the waveform is divided into two parts:
   a) Waveform of the Arduino uno microcontroller output
   b) Waveform of the inverter output

III. RESULTS AND DISSCUSION

A. System Design Results

Figure 9. Inverter Realisation Image

The results of the research conducted are in the form of success in making an inverter device using Arduino as the main controller.

B. Inverter Efficiency Results

This test aims to determine the performance of the inverter when using a load with a power of 20 watts to 100 watts, which is the full load on the inverter.

Figure 10. Efficiency Testing

The results of the voltage and current testing using a digital multimeter fixer are presented in the form of a table, which can be seen in Table I and II as follows.

Table I
Inverter Input Voltage and Current

	Beban	*Input* Inverter (Tegangan)	*Input* Inverter (Arus)
1	Lampu 20 Watt	12,8 VDC	5,13 A
2	Lampu 60 Watt	12,78 VDC	6,22 A
3	Lampu 100 Watt	12,75 VDC	9,10 A
		12,77	6,81

Table II
Inverter Ouput Voltage and Current

	Beban	*Output* Inverter (Voltage)	*Output* Inverter (Current)
1	Lampu 20 Watt	205 VDC	0,278 A
2	Lampu 60 Watt	190 VDC	0,322 A
3	Lampu 100 Watt	174 VDC	0,442 A
		189,6	0,347

Calculate the magnitude of input and output power so that the performance and efficiency of the inverter can be known. Can be calculated using equations (2.18), (2.19), and (2.20) obtained as follows.

Table III
Inverter Input Power

	Beban	Daya *Input* Inverter (Watt)	Daya *Input* Inverter (Watt)
1	Lampu 20 Watt	12,8 x 5,13	65,66 Watt
2	Lampu 60 Watt	12,78 x 6,22	79,55 Watt
3	Lampu 100 Watt	12,75 x 9,10	116 Watt

Inverter, the efficiency of an inverter can be calculated using the equation (2.17) as follows.

η=Pout/Pin×100%

From the equation then results efficiency on the inverter, which can be seen in Table V below.

Table IV
Inverter Input Power

	Beban	Daya *Output* Inverter (Watt)	Daya *Output* Inverter (Watt)
1	Lampu 20 Watt	205 x 0,278	56,99 Watt
2	Lampu 60 Watt	190 x 0,322	61,18 Watt
3	Lampu 100 Watt	174 x 0,44	76,91 Watt

From the input and output outputs of the

Table V
Efficiency Table

	Beban	$\frac{Pout}{Pin} \times 100\%$	Efisiensi (η)
1	Lampu 20 Watt	$\frac{56,99\ Watt}{65,664\ Watt} \times 100\%$	86,8%
2	Lampu 60 Watt	$\frac{61,18\ Watt}{79,55\ Watt} \times 100\%$	76,9%
3	Lampu 100 Watt	$\frac{76,91\ Watt}{116,02\ Watt} \times 100\%$	66,3%

From the results of this analysis, it can be concluded that inverter efficiency tends to decrease with increasing loads, with the highest efficiency recorded at 20 watts and the lowest at 100 watts, suggesting that inverters are more efficient at lower loads. This decrease in efficiency is mainly due to the drop voltage that occurs because the inverter is not equipped with a voltage feedback system. In order to improve inverter efficiency, it is recommended to add a voltagen feedback system that can automatically adjust the output voltage according to the change in load, so that the voltage output remains stable and the overall efficiency of the invertor increases.

C. SPWM Signal Test Results

The data collected included testing the results of the arduino program and the SPWM signal of the inverter output. Inverter tests included signal wave output and inverter voltage in both load-free conditions and with loads up to 100 Watt. Wave tests used an analogue oscilloscope measurement device with a reference scale on the osiloscopic probe x10, a voltage scale per division (Volt/Div) x10, and a time scale for division (Time/DIV) x10.

D. Dead Time Test Results

As a security measure to avoid both MOSFETs being simultaneously active and causing short circuits, the Arduino-controlled SPWM signals should be given dead time, where both Mosfets are dead. The use of dead time should be carefully calculated, as it can cause instability and potentially destroy. Then from that the calculation of dead time on the Arduino program uses the equation (2.3) as follows.

Duration of one clock cycle = $\frac{1}{16000000}$ second
Duration of one clock cycle = 62,5 nanoseconds
Dead time value of 312 nanoseconds (5x62,5 Ns = 312,5Ns)

From the above calculations, the dead time result is in the form of a signal on the oscilloscope as follows.

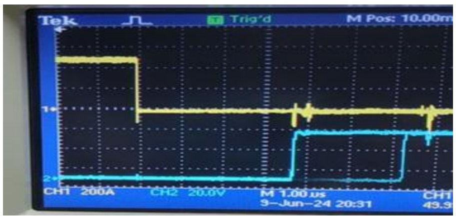

Figure 12. DeadTime Output Arduino

The test results in Figure 12 can be calculated using the equation (2.15) as follows.

T = kotak horizontal x *Time*/Div
T = 3,3 x 0.1 = 0,33 Mikrodetik
T = 3,3 X 10 = 330 Nanodetik

E. Inverter Output Signal Testing

Signal testing using an oscilloscope in this study to look at the output wave shape on an inverter and to measure the wave output on an osciloscope. Maximum voltage (Vm) with the following equation. Vm = 3,1 kotak vertikal x 10Volt/Div x 10(pengali probe), Vpp = 6,2 kotak vertikal x 10Volt/Div x 10(pengali probe), Vrms = Vp/√2, T = 4 kotak horizontal x 5 mili*second,* T = 4 kotak horizontal x 5 mili*second*, F = 1/20 mili*second.*

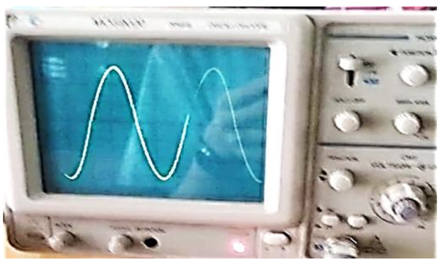

Figure 13. Inverter Output Signal without a Load

Figure 13 shows an inverter output signal without a load, from a signal on the oscilloscope obtained the following measurement results: Vm = 310, Vrms = 219,2 Vpp = 620, T = 20 mili*second*, F = 50Hz.

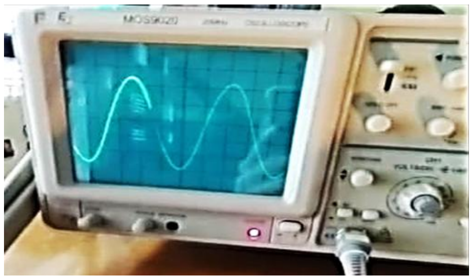

Figure 14. Inverter Output Signal with 20 Watt Load

Figure 14 shows an inverter output signal using a 20 Watt light load. From the signal on the oscilloscope, the measurements are as follows, Vm = 300, Vrms = 212,1, Vpp = 600, T = 20 mili*second*, F = 50Hz

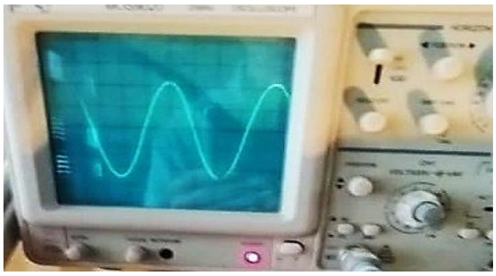

Figure 15. Inverter Output Signal with 60 Watt Load

Figure 15 shows the output signal of the inverter using a load of 60 Watt lamp. From the signal on the oscilloscope, the measurements are as follows, Vm = 270, Vrms = 190,9, Vpp = 540, T = 20 mili*second*, F = 50Hz

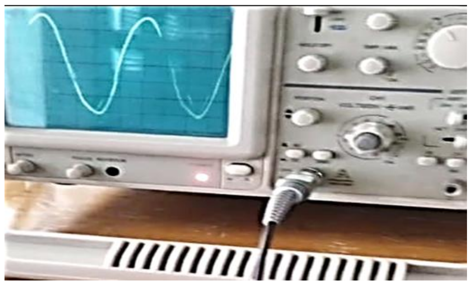

Figure 16. Inverter Output Signal with 100 Watt Load

Figure 16 shows the output signal of the inverter using a load of 100 Watt lamp. From the signal on the oscilloscope, the measurements are as follows, Vm = 250, Vrms = 176,7, Vpp = 500, T = 20 mili*second*, F = 50Hz.

Based on the test results, it is known that the inverter device tested using an oscilloscope shows variations in peak-to-peak voltage (Vpp) depending on the given load. Without a load, Vpp is recorded at 620V, with a 20 watt load dropping to 600V, a 60 watt charge dropping further to 540V, and with load 100 watt is 500V Vpp. To calculate the effective voltage (Vrms) of Vpp, the formula on the equation (2.14) is used as follows.

$$\text{Vrms} = \frac{Vpp}{2\sqrt{2}}$$

Thus, for the Vpp 620V, the Vrms is about 219V, for Vpp 600V, Vrms about 212V, to Vpp 540V, VRMS about 191V, and for VPP 500V, vrms about 177V. Measurements using an oscilloscope show no significant difference when compared to measurements using a digital multimeter, with the results of the measurement performed using digital multimeters on an inverter output at a load of 12 Watt of 205 VAC, at a charge of 60 Watt to 190 VAC and at a full load of 100 Watt obtained an invertor output of 174 VAC.

From this result, it can be concluded that the larger the load applied to the inverter, the lower the value of the peak-to-peak voltage (Vpp) and the effective voltage(Vrms) generated. This decrease in voltage performance is caused by the absence of voltage feedback on the inverter network, so the output has a significant voltage decreases.

IV. CONCLUSION

This research results in the successful design and implementation of a single-phase inverter that produces pure sine waves using Arduino as the main control. Tests show that the inverter can generate sinusoidal signals up to 100 Watts without significant distortion at various loads, with an output voltage of 220VAC ±1.88% and 50Hz Frequency ±0.10%. Although the inverter efficiency reached an average of 70% at various loads, there is potential to improve the efficiency by adding a voltage feedback system and adjusting the carrier frequency.

In this research, there are suggestions that are useful for the development of future inverter tools. In this study, the inverter has not been equipped with a voltage feedback system, so it experiences a significant voltage drop when the load changes. For future research, it is recommended that the circuit be equipped with voltage feedback from the transformer output to the load. In addition, the power generated by the current inverter is about 100 Watts. So in future research, it is recommended that the output power can be increased by improving the specifications of MOSFETs, transformers, and power supplies.

REFERENCE

Chukwulozie, O. P. (2016). Optimisation Techniques For Thermal Management In An Irf 3205 Mosfet Switches, Department Of Mechanical Engineering. May.

Dinda Triatno. (2017). Dan Pengujian Power Inverter Push-Pull Satu Fasa Pure Shine Wave 15 Watt. Teknik, Jurusan Energi, Konversi Bandung, Politeknik Negeri.

Karyadi. (2019). Rancang Bangun Inverter Satu Fasa Menggunakan Ic Sg 3525. Edu Elektrika Journal, 10(1), 57.

Nurjaman, H. B., & Purnama, T. (2022). Pembangkit Listrik Tenaga Surya (Plts) Sebagai Solusi Energi Terbarukan Rumah Tangga. Jurnal Edukasi Elektro, 6(2), 136–142.

Ramadhani, F. N., Luqman, M., & Siswoko, S. (2021). Modul Inverter Satu Fasa Menggunakan Mosfet Dengan Driver Egs002 Pure Sin Wave. Jurnal Elektronika Dan Otomasi Industri, 8(2), 39.

Siburian Jhonson. (2019). Karakteristik Transformator. Jurnal Teknologi Energi Uda, Viii(1), 21–28.

Subandi. (2020). Pemasangan Solar Cell Untuk Setrika Listrik Pada Usaha Sonic Loundry Condong Catur. Lppm Stmik El Rahma Yogyakarta, 4, No 2.

Turahyo, N. (2017). Implementasi Sinusoidal Pulse Width Modulation Pada Inverter Satu Fase Berbasis Lookup Table Menggunakan Mikrokontroler 16-Bit. Semnastek, November, 1–2.

Usman, M. S. (2018). Analisa Gelombang Inverter 20 Watt Pada Beban Listrik Rumah Tangga (Tugas Akhir). 77.

Winarno, O. T., & Soerawidjaja, T. H. (1998). Pengurangan Emisi Gas Rumah Kaca Sektor Energi Di Indonesia: Ulasan Hasil-Hasil Studi Asian Least-Cost Greenhouse Gas Abatement Strategy Project. In Jurnal Agromet (Vol. 13, Issue 2, Pp. 1–13).