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SPWM DC-AC Three-Phase Inverter Based On ATMega16 Microcontroller

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ABSTRACT: Industrial and household electricity generally uses AC electricity. While electricity generated from renewable energy sources is partly available in the form of DC electricity. DC electricity can be converted to AC electricity with a DC - AC inverter. The SPWM 3-phase inverter concept has been widely used to convert DC to AC for electrical systems that are not connected to the grid or connected to the grid, as well as for controlling 3-phase motors. A 50Hz sine frequency SPWM sine output is generated, a phase difference of 120˚ for each phase, and a carrier frequency of 43kHz. This design can be used as an Off Grid DC-AC inverter and 1 phase or 3 phase On grid DC AC Inverter, 1 phase to 3 phase inverter, as well as 3 phase motor control inverter. This design and prototype is expected to become the basis for things mention above.

KEY WORDS: AC, DC, Inverter, 3-Phase Inverter, SPWM.

I.INTRODUCTION

The utilization of electrical energy when carried out is generally in the form of alternating electricity or AC electricity, both 1 phase and 3 phase. Single phase electricity is widely used in households with little electricity consumption. While 3 phase electricity is widely used in industry, office buildings, and households with large electricity consumption as well as small industries that use a lot of electricity-based drives. [(PLN, 2020) Along with technological developments, the use of electricity sources from renewable energy is being developed. Electricity generated from renewable energy sources is partially available in the form of DC electricity. So that equipment is needed to change the form of DC electricity to AC form. (Supardi, 2018)

Equipment to convert DC electricity into AC electricity is called DC-AC inverter. At this time, various types of inverters are available, ranging from DC-AC inverter 1 phase off grid or stand alone, DC-AC inverter 3 phase off grid, DC-AC inverter 1 phase on grid, DC-AC inverter 3 phase on grid, and inverter for 3 phase motor controller. (Lee et al, 2007). Each inverter is usually available in a different device form, because there are differences in utilization and the method used. Each inverter also has a very basic equation, namely they both produce AC electricity with a certain frequency, phase and voltage.

Based on the basic concept similarities of each inverter, a hypothesis is obtained that the various functions of the inverter can actually be made in just one device but can be functioned differently according to its utilization. Because of this, research in this research will be carried out to design and manufacture a prototype DC-AC inverter that can adjust the frequency, wave phase, and output voltage.

II. SIGNIFICANCE OF THE SYSTEM

The paper mainly focuses on how SPWM inverter signal is generated from triangle signal and three-phase sine signal by external modulator and two programable device ATMega16. The study of literature survey is presented in section III,

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Methodology is explained in section IV, section V covers the experimental results of the study, and section VI discusses the future study and Conclusion.

III. LITERATURE SURVEY

Much research has been done on DC-AC inverters. The current development of inverter technology is using the SPWM (Sine Pulse Width Modulation) method. SPWM is a sine generation method from modulated pulses. Usually using a combination of pure sine signals modulated with a triangular wave as a carrier. (Papadopoulos et al, 1998)

Some of the research on 3 phase DC AC inverters was carried out at the simulation level and some others were carried out to prototypes with the main components of DSP (Digital Signal Processing) microprocessors. For the most part, the development of inverters is very specific to their utilization. The inverters that have been developed recently are single phase off grid DC-AC inverters, on grid DC-AC inverters, 1 to 3 phase inverters for 3 phase motor controllers, 3 phase to 3 phase inverters for 3 phase motor controllers. (Zang et al, 2008)

Several types of inverters have a basic equation, namely they both produce a sine wave voltage output. The off grid DC-AC inverter converts the DC voltage source into a sinusoidal AC voltage source, with a fixed AC frequency of 50/60Hz with a voltage between phase and neutral of 220VAC, phase free. (Rahman, 2016) The on-grid DC-AC inverter changes the DC voltage source to a sinusoidal AC voltage source, with a fixed AC frequency of 50/60Hz with a voltage between phase and neutral of 220VAC, the phase must follow the phase grid. (Leel et al, 2011) The fundamental difference between the two inverters is the phase setting.

The 3 phase off grid DC-AC inverter converts the DC voltage source into a sinusoidal AC voltage source, with a fixed AC frequency of 50/60Hz with an interphase voltage of 380VAC or a phase to neutral voltage of 220VAC, the difference between the phases is 120 degrees, and the initial phase is free. (Youssef et al, 2017) A 3 phase off grid DC-AC inverter converts a DC voltage source into a sinusoidal AC voltage source, with a fixed AC frequency of 50/60Hz with an interphase voltage of 380VAC or a phase to neutral voltage of 220VAC, the difference between phases is 120 degrees, and the initial phase must match the phase grid. The equation for 1 phase and 3 phase inverters, on grid and off grid lies in frequency, phase and voltage control.

Some 3 phase motor control inverters have 3 phase inputs and some have 1 phase input. The 3-phase motor control inverter must have an adjustable output frequency setting so that the rotational speed of the motor can be adjusted. (Lee et al, 2007) The similarity with other inverters is that they both produce a sine voltage with an adjustable frequency. (Sharkh et al, 2007)

From the equations of various types of inverters, it can be hypothesized that all types of inverters can be made with one basic design, namely an SPWM generator whose data is regulated by frequency, phase and output voltage. Setting the output voltage can use the concept of controlling the voltage on the buck converter, namely by adjusting the modulation pulse width. Meanwhile, the SPWM modulation settings must follow the pwm modulation pattern resulting from the enumeration of the sine function with the triangular function. In this study, we will try to adjust the voltage by adjusting the width of the lower side of the SPWM carrier triangular signal.

IV. METHODOLOGY

A. Sinusoidal Pulse Width Modulation

The 3-phase DC-AC inverter in this study uses the SPWM (Sinusoidal Pulse Width Modulation) 3-phase sine wave generation method, namely a sine wave formed from a modification of a sine wave to a triangular wave so as to produce a PWM (Pulse Width Modulation) wave whose pulse width is aligned with the level voltage on the sine wave.

An illustration of the formation of the SPWM signal is shown in Figure 1. The SPWM is formed by comparing the original sine wave that is desired or will be modulated with the triangular carrier signal. If the triangular signal voltage level Vtriangle(t) is higher than the sine Vsine(t) signal voltage level at time t, then the SPWM signal is 0 or OFF. If the

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voltage level of the triangular signal Vtriangle(t) is lower than the voltage level of the sine Vsine(t) signal at time t, then the SPWM signal has a value of 1 or ON.

The triangular carrier signal frequency must be greater than the sine signal to be modulated, in this study using a carrier frequency of 40 kHz. The triangle signal as a carrier will determine the PWM frequency of the generated SPWM signal, so that the SPWM components work in the carrier signal frequency area.

Generation of sine signals with the SPWM method has advantages in terms of efficiency, where the power dissipation of the switching components will be minimal because the SPWM switching only works ON-OFF. Another advantage of SPWM is that the form of a sine signal at the output that is filtered will be a complete sine signal, in contrast to the 3-position step voltage inverter which is generally applied to a UPS where the sine is a 3 step coarse step wave. SPWM allows the use of smaller components, especially for transformers if needed, because the required transformer works at a carrier frequency or in this study 40 kHz and generally at a frequency value of tens of kHz. Transformers for frequencies in the tens of kHz are made of ferrite cores and require much smaller dimensions than 50 Hz transformers.

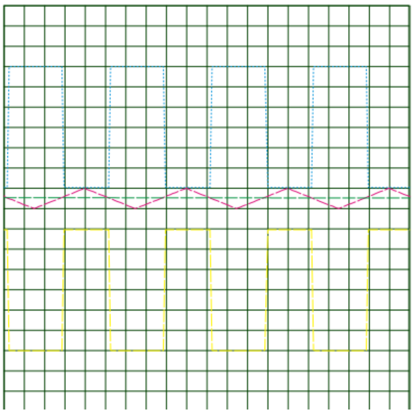

Figure 1. SPWM Signal Formation

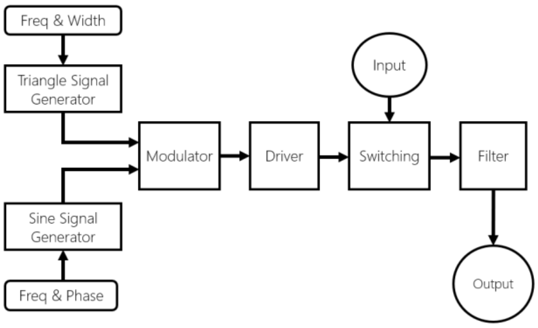

Figure 2. 3-Phase Inverter DC-AC Block Diagram

B. 3-Phase DC-AC Inventer Design

The design of the 3-phase DC-AC inverter in this study is shown in Figure 2. The 3-phase DC-AC inverter in this study uses the 3-phase SPWM wave generation method from a 3-phase sine wave and a triangular carrier wave, each of which is generated separately.

A 3-phase sine wave is generated by a sine signal generator with a program on an ATMega16 microcontroller. The output of the sine signal generator is a 3-phase sine signal with a frequency of 50 Hz each and a difference between phases of 120˚. The triangular wave as a carrier is generated by the triangular signal generator with a program on an ATMega16 microcontroller. The output of the triangular signal generator is a signal in the form of an isosceles triangle with a frequency determined by the program. The frequency of the signal triangle automatically determines the width or period of the signal.

The outputs of the triangular signal generator and the sine signal generator are fed to the modulator. This modulator is a circuit consisting of 3 comparator groups. Each comparator group to process one sine phase into 1 SPWM phase. The output of the modulator circuit is a 3 phase SPWM with the same level as the signal generator output level. This 3 phase SWPM is included in the IR2110 driver circuit, where each phase requires 1 IR2110 driver. The IR2110 driver is a circuit with the main components of the IR2110 series IC (Integrated Circuit) made specifically for mosfet or IGBT drivers. IR2110 input is a TTL level voltage signal and outputs a gate level Mosfet or IGBT.

The output of the driver circuit is used to control the switching MOSFET array which forms the SPWM voltage from the DC input voltage. The output of the switching circuit is SPWM with a peak-to-peak voltage level of Vpp according

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to the input DC voltage. The output of the switching SPWM is connected to the filter circuit to obtain a 3 phase 50 Hz pure sine wave.

1) 3-Phase Sinus Signal Generator

The 3-phase sine signal which functions as a reference signal in this study is generated using the ATMega16 microcontroller with the scheme shown in Figure 3. The microcontroller circuit is made using a working frequency according to the microcontroller clock crystal 11.0592 Mhz.

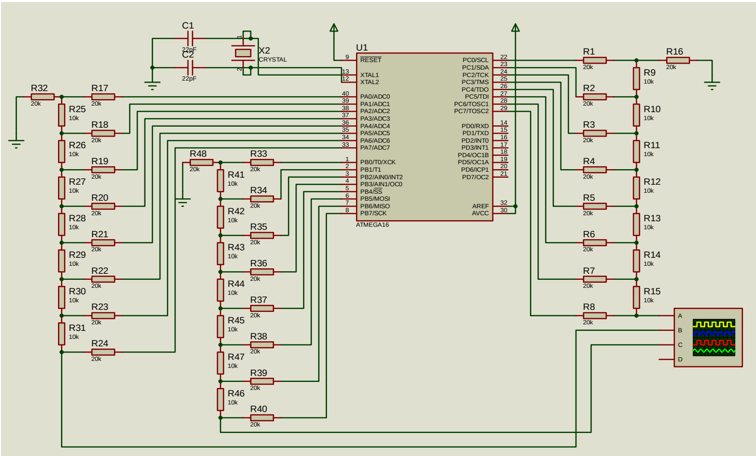

Figure 3. Schematic of 3 Phase Sine Signal Generator

The microcontroller output is a binary digital signal. Each phase of the sine signal uses 1 microcontroller port which consists of 8 binary data pins. So, for the generation of 3-phase sine requires 3 ports, each port has 8 binary data pins. The 8-bit binary data output from each port is converted to an analog signal using a DAC (Digital to Analog Converter). In this design the DAC used is a DAC made from an array of resistors with the R-2R equation or also called the R-2R Resistor Ladder Network DAC. The DAC in this design is shown in Figure 3 in section R1-R16 as DAC phase T, R17-R32 as DAC phase R, R33-R48 as DAC phase S, with R values of 10kΩ and 2R 20kΩ.

The sine signal in each phase is formed by outputting the sine signal voltage value at time t to the microcontroller port then this binary value is converted to an analog value. Binary data values from sine signals are made in the form of look-up table programs for each value, with 360 sampling for one sine wave period. The flowchart of this sine signal formation program is shown in Figure 4.

2) Triangle Signal Generator

The triangular signal which functions as the SPWM Carrier signal is generated using the ATMega16 microcontroller. The crystal clock used by the triangular signal generator ATMega circuit is 11.0592 MHz. The triangular wave generator circuit scheme in this study is shown in Figure 5. In the 3-phase DC-AC inverter design, this study only uses 1 triangular signal for the carrier of 3 sine signals.

Triangular signal generation is carried out through a program where the triangular signal analog value at the time t is in-state and output directly to the microcontroller port in the form of binary digital data then converted into an analog signal by the DAC R-2R. The triangular signal generation program flowchart is shown in Figure 6.

The triangular signal generator program does not make a look-up table and also does not take the form of a function but directly states its value in each line of the program code to speed up the execution time for each line so that the resulting triangular wave frequency can reach 40 kHz. The output binary value is a value with a range of 0-255 or 8 binary bits with step 5 so that there are 52 binary value changes in the microcontroller port for each half wave period. One wave period consists of the values 0-255 and 255-0.

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3) Modulator, Driver, and Switching

The modulator, driver, and switching circuit scheme is shown in Figure 7. The modulator in this inverter uses an LM393 comparator to compare the sine signal voltage value with the triangle carrier signal voltage value. Each phase of the sine signal requires 2 comparators. On one LM 393 IC there are 2 comparators, so that one phase sine signal requires 1 LM 393 IC. The results of the comparison of the sine signal voltage and the carrier signal voltage produce a direct SPWM.

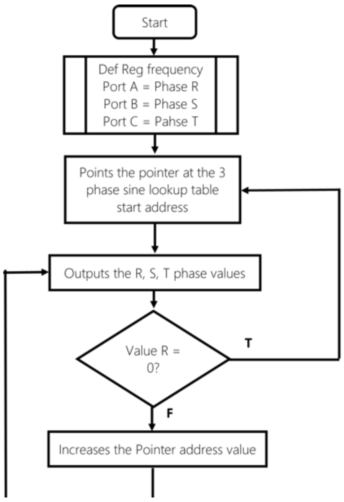

Figure 4. 3-Phase Sine Generator Microcontroller. Program Flowchart

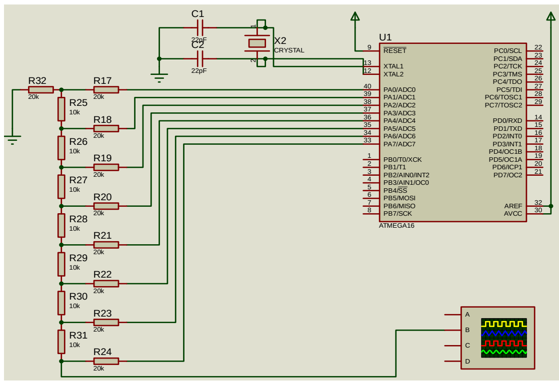

Figure 5. Triangular Signal Generator Design Scheme

SPWM modulator results are inserted into the driver to activate switching when the signal is 1 or ON or High. When one side of the switching is ON, the switching on the opposite side must be OFF, so the opposite switching controller is needed where the value is always the opposite or NOT of the other switching. Therefore another comparator is installed with the opposite input from the other comparator so that the output value is NOT from the other as well as the driver output and the switching conditions are NOT as well.

V. EXPERIMENTAL RESULTS

The DC-AC 3 Phase SPWM Inverter circuit as a result of the implementation of this research design is shown in Figure 8. The wave generator circuit is made in 1 circuit block. The modulator and driver circuits are made in 1 block, and the switching circuit is made in one block. Separation of circuit blocks aims to facilitate grouping of circuits and signal levels so that they are safer and easier in troubleshooting. The wave generator circuit has a digital voltage level of 5V TTL. The modulator and driver circuit has a TTL voltage level of 5V and a driver output voltage level of 12V. The switching circuit has a higher voltage level, in this study it was tested at a voltage of 50V, 100, 220 and 310 V.

A. Simulation and Testing of 3 Phase Sine Generating Circuits

A simulation of a 3-phase sine generator circuit is shown in Figure 9. The simulation results show that the 3-phase sine signal generator program and the DAC that has been made can produce a 50Hz 3-phase sine signal with a phase difference of 120˚ each.

The circuit that has been made has also been tested and measured using an oscilloscope with the measurement results shown in Figure 10. The results of measurements with an oscilloscope on the signal generated by the 3-phase sine wave generator circuit show that the signal produced is the same as the signal generated in the simulation, namely 3 sine

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signals. 50 Hz with a phase difference of 120˚ each. The sine signal voltage level resulting from the generation of this circuit is the 5V TTL voltage level.

B. Triangular Signal Generator Circuit Testing

Testing the triangular signal generator circuit is shown in Figure 11. The test results of this circuit show that the triangular signal generator circuit can produce an isosceles triangle signal with identical up and down slopes.

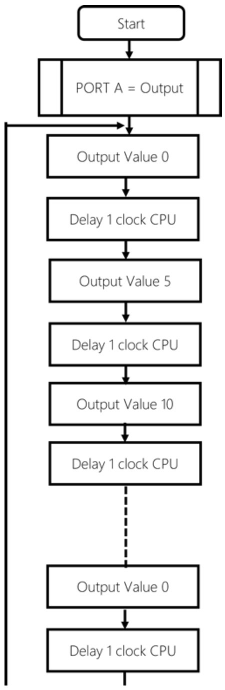

Figure 6. Triangle Signal Generator Program Flowchart

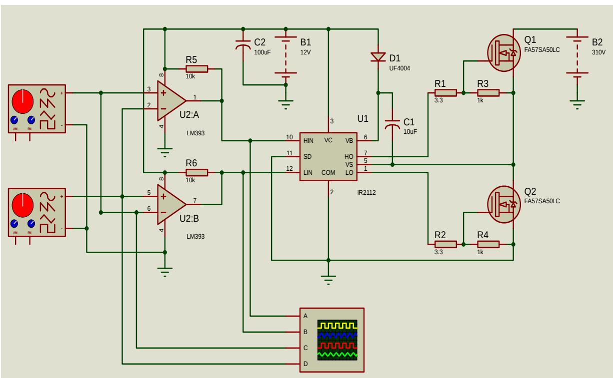

Figure 7. Modulator, Driver and Switching Circuit Schemes

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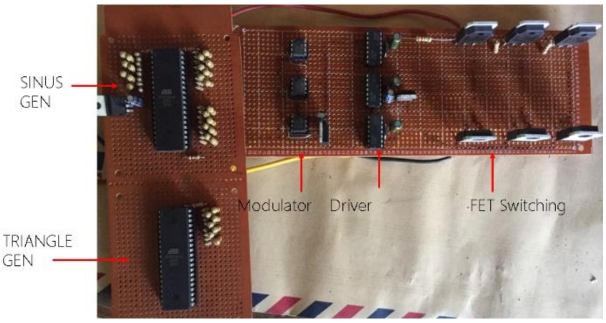
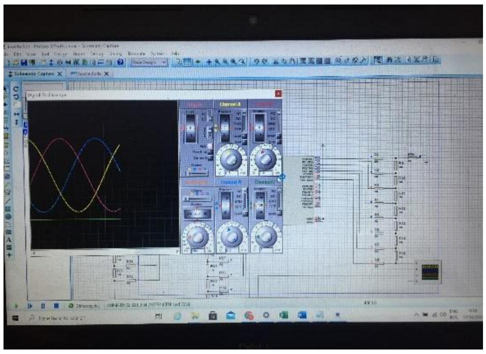


Figure 8. 3-Phase DC-AC Inverter Circuit Figure



9. 3-Phase Sine Generator Simulation

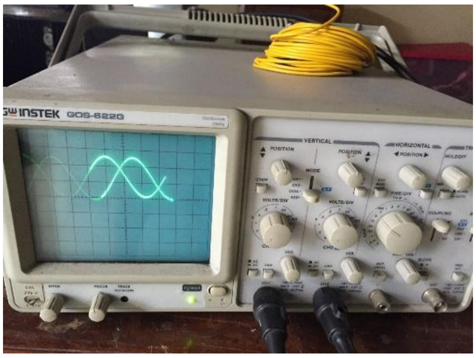


Figure 10. Measurement of Sine Signal Generating Results of 3-Phase Sine Signal Generator

The last algorithm applied to generate this triangular signal is the direct state value in the listing program so that it can produce a variable frequency of 53kHz, 43kHz and 33kHz. While the previous algorithm that has been used is the look-up table algorithm which can only produce the highest frequency of 3kHz. The last algorithm used can be used on a 3 phase DC-AC inverter in this study with the selected frequency being 43kHz.

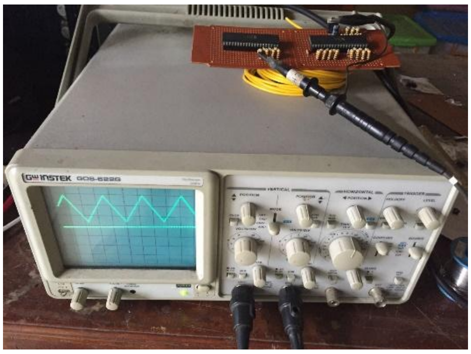


Figure 11. Measurement of Triangular Signal Generating Results of Triangular Signal Generator

C. Testing of Modulator, Driver and Switching Circuits

Testing the modulator circuit is carried out through simulation and direct measurement with an oscilloscope. The results of the modulator simulation test are shown in Figure 12. The modulator circuit produces a PWM signal with a voltage level of 12V. In the inphase section, the PWM signal is high when the sine signal voltage level is greater than the triangular signal voltage level. Whereas in the NOT part of the inphase, the PWM signal is low when the sine signal voltage level is greater than the triangular signal voltage level.

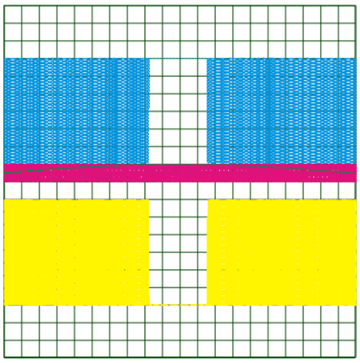


Figure 12. Modulator circuit testing

Testing the modulator, driver and switching circuits directly with an oscilloscope is carried out in one unit, that is, the modulator output is measured and the filtered switching output is measured so that the sine signal output of the inverter shows that it forms an SPWM which will become a sine when filtered. The results of this direct test are shown in Figure 13. The results of direct tests with an oscilloscope show that the data modulator circuit produces SPWM and can be processed properly by the driver and switching so that the filtered output of the switching is displayed by the oscilloscope in the form of a sine signal. The final result of a 3 phase DC-AC inverter is measured with an oscilloscope with the results shown in Figure 14 where the sine frequency value remains 50 Hz, the phase difference between phases is 120˚.

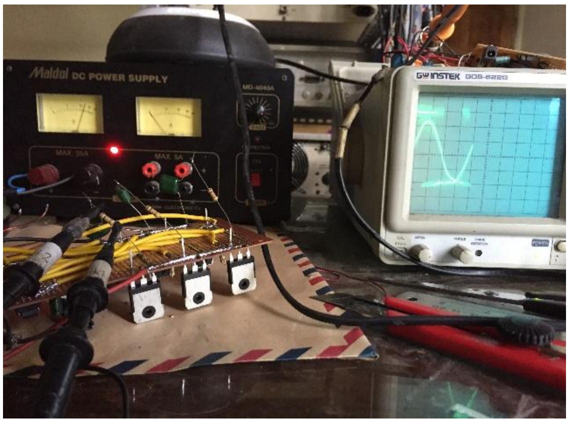


Figure 13. Testing the modulator, driver and switching circuits

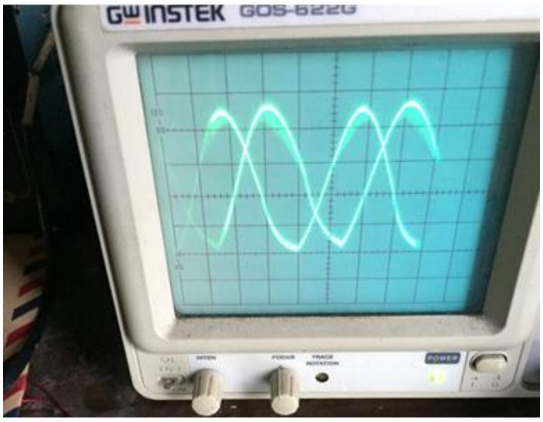


Figure 14. Test Results for 3 Phase DC-AC Inverter Output

VI. CONCLUSION AND FUTURE WORK

This research has succeeded in producing a design and prototype of a three-phase DC-AC inverter with:

1. Frequency setting is done by program on a 3-phase sine wave generator microcontroller with an output frequency of 50Hz
2. Setting the phase so that it becomes 3 phases that are balanced with a phase difference of 120 degrees is done by the program on the 3-phase sine wave generator microcontroller
3. Setting the triangular wave carrier frequency is done by programing the triangular wave generator microcontroller with an output frequency of 43kHz
4. Setting the output voltage is done by adjusting the DC input switching voltage.

This research can be developed and equipped with an output voltage regulator in the form of a DC-DC Converter so that the output voltage on this inverter can be stable at 220 VAC or 380 VAC.

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