Implementation of power inverter on grid connected photovoltaic generator system

Argo Prastyo$^{1,2}$, Cahyantarie Ekaputri$^{1,3}$, and Muhamad Reza$^{1,4}$
$^1$Telkom University, School of Electrical Engineering, Bandung, Indonesia

E-mail: $^2$argoprastyo@student.telkomuniversity.ac.id
$^3$cahyantarie@telkomuniversity.ac.id, $^4$muhamad.reza@gmail.com

Abstract. The issuance of ESDM (ministry of energy and mineral resources) regulation number 49 of 2018 concerning the use of a rooftop solar power generation system by consumers of PT PLN (Persero). It is encouraging to conduct research on one method of generating electricity using solar panels. The voltage generated in the generation process using solar panels is a direct voltage (DC) and requires an inverter as a voltage converter to be an alternating voltage (AC) which is the daily consumption of Indonesian people. This research aims to develop the use of renewable energy using an inverter. This inverter uses batteries as a source of voltage, Arduino as a source of SPWM waves, and MOSFETs are arranged in a full-bridge configuration to convert 12V DC electricity into 12VAC which will then be filtered using a low-pass filter to pass a 50 Hz frequency and then increase the voltage using a transformer to 220Vmax / 155 Vrms. The result of designing this research is that the inverter is able to produce a sinusoidal wave output 220 Vmax with a frequency of 50 Hz. With the output signal approaching the sinusoidal signal purely from the filter output, the power loss from the use of the transformer causes the power output from the inverter to be not optimal.

1. Introduction

Indonesia is the largest energy consumer of Southeast Asian countries has the world’s largest steam coal. Indonesia exports steam coal and liquid natural gas but import oil [1]. The world primary energy comes from non-renewable fossil fuel crude oil and Natural Gas (NG) finite natural resources. The new discoveries and technological advancements have also ensured increasing production from crude oil and NG resources. Presently, the biggest challenge faced by the oil and gas sector is how to increase production when existing fields are experiencing depletion [2]. In 2010, the world oil production from major oil-producing regions reached a maximum and is projected to decline steadily [3]. On the contrary, the future energy consumption from NG requires a change in energy sources that are currently satisfied by the liquid fuels and demands more infrastructures in the form of pipeline facilities. However, the increased demand for NG in gas exporting countries can contribute to NG shortage in the gas importing countries [4].

Moreover, according to International Energy Agency (IEA), the world oil production from currently producing fields reached to maximum and oil production rate is expected to decline steadily years after years, if the new crude oil fields were limited and NG liquids or unconventional oil production continues insufficiently [5]. With the regulations issued by the Minister of Energy and Mineral Resources number 49/2018 in Indonesia consumers can now sell electricity to PLN which has an impact on cutting...
electricity rates commensurate with electricity generation from consumers by 65%, but to combine PLN AC current, the output current from the power inverter must match with the form of a PLN AC current which is a form of pure sine signal or pure sinusoidal signal. Thus, the technicians try to find other alternatives to generate electricity even though in the area they do not have the potential for electricity generation, one of which is using new renewable energy from sunlight or often called photovoltaic. Photovoltaic is an alternative type of generator that uses photon energy from the sun which will produce DC voltage by disturbing electron bonds in solar cells. But the type of load that is widely used in household appliances is the type of load that requires AC voltage, to change the DC voltage produced by photovoltaic a DC to AC converter is called an inverter. An inverter is an application of an electronic circuit that functions to convert the type of DC voltage to AC voltage. Using an electric inverter generated by photovoltaic can be stored towards the battery for storage and can be converted into AC voltage. The inverter can convert 12 Volt DC voltage to 220 Volt AC voltage with a frequency of 50 Hz and can produce a pure sine signal output.

2. Literature Review

2.1. Power inverter
An inverter is a circuit that can change the type of Direct Current (DC) voltage to alternating current (AC). The inverter can be used on devices or electronic devices that need AC voltage but have a DC voltage source. In the inverter circuit system there are several circuit blocks that can be separated according to their functions, namely, PWM signal generator blocks, switching blocks consisting of Mosfet components as the main material, filter blocks as the desired frequency escape, and step-up voltage blocks by the transformer to raise filter output voltage to obtain the desired system output voltage.

2.2. PWM generator
The PWM is a method for manipulating signal width expressed in the form of pulses per period, to obtain a different voltage value. The type of PWM signal used in this research is a type of SPWM (sine pulse width modulation) which is the result of a comparison of the carrier signal in the form of a wedge gear signal and a reference signal in the form of a sinusoidal signal. The comparison between the carrier signal and the reference signal is shown in Figure 1.

![Figure 1. Comparison of carrier signals with reference signals](image)

But in this research, the SPWM signal is directly implemented on a microcontroller in the form of an Arduino Nano device programmed by activating the output pin in a time range from 0 to 2000ms or on a bit scale which can be assumed from 0 to 255 for 0-100% duty cycle.

2.3. Transformer
The transformer is a passive component that serves to change the value of the alternating voltage on the primary coil to be larger or smaller in the secondary coil. A transformer cannot work if it is connected to a DC voltage source. Comparison of voltage and current in the primary and secondary coils using Equation 1.
\[
\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}
\]  \hspace{1cm} (1)

The transformer can increase or decrease the voltage or current level according to the ratio. In addition, the impedance connected to one side of the transformer can be larger or smaller (step-up, step-down) on one side, depending on the ratio [6].

2.4. Filter

Frequency filters are divided into two, namely active filters and passive filters. The active filter is a filter circuit that uses passive electronic components such as operational amplifiers (OP-AMP), transistors and others. A passive filter is a filter circuit that uses passive electronic components in the form of resistors, capacitors, and inductors. The difference from the use of active and passive components is that the use of active components requires a source to work as in OP-AMP and transistors, while the use of passive filters does not require a source to be used. In the design, this time the author uses a low-pass filter as a filter option on systems where this type of filter will pass low frequencies as desired. Figure 2 shows the low-pass filter circuit.

![Low pass filter RC](image)

**Figure 2. Low pass filter RC**

2.5. Enhancement Mosfet

The physical enhancement doesn’t have a channel between drain and source because the bulk layer extends with the SiO₂ layer at the gate terminal. MOSFET transistor enhancement consists of N-type and P-type which will be displayed in Figure 3.

![MOSFET](image)

**Figure 3. (a) N-channel enhancement MOSFET (b) P-channel enhancement MOSFET**

Next, Characteristics of MOSFETs have ID flows as a function of VDS with VGS parameters. on MOSFET there are three operating conditions, namely cut-off, linear and saturation. In the condition of the cut-off area, the gate voltage is smaller than the drain pressure, so the source is not voltage and the current cannot flow (ID = 0). In linear areas when the gate is given a voltage, the electrons will flow from the source to the drain or the current flows from the drain to the source. Next, the drain will act as resistance so that the drain current (ID) will be proportional to the drain voltage using Equation 2.

\[
I_D(LIN) = k_n \left[ (V_{GS} - V_T)V_{DS} - \frac{V^2}{2} \right]
\]  \hspace{1cm} (2)
When the drain voltage is increased until the voltage at the gate becomes neutral, the channel inversion layer on the drain side will disappear and will reach a point called the pinch-off point. This condition is the beginning of the saturation work area. If it exceeds these conditions, the increase in voltage at the drain will not change the drain current, so the drain current remains, using Equation 3.

\[
I_d(SAT) = \frac{k_n}{2} (V_{GS} - V_{TN})^2
\]

The p-MOSFET channel has similarities like the n-MOSFET channel when it’s the same in saturation condition.

\[
cutoff = V_{GS,p} \leq -V_{TP}
\]

\[
I_D(off) = 0
\]

\[
saturate = V_{SG,p} \geq -V_{TP}, \text{and } V_{SD,p} \geq V_{SG,p} + V_{TP}
\]

\[
I_D(SAT) = \frac{k_p}{2} (V_{SG,p} - V_p)^2
\]

3. Experiment
In general, PLN electricity sources distributed in the household have a frequency range from 50-60 Hz. Therefore, we need a wave source that has a frequency of 50Hz and has a cycle of 50% and produces waves with sinusoidal waveforms. Arduino output waveform can be seen in Figure 4 and Figure 5.
Furthermore, the above Arduino output behind the phase uses IC 4047 to form a phase difference SPWM waveform. The goal is because the MOSFET used works at +5V and -5V voltages. This arrangement is done directly on Arduino so that it will form 2 different phase SPWM waves as shown in Figure 6.

To get a large MOSFET output, the output of Arduino grew up using a driver with a unit of 12V from the battery so to produce waves that have a voltage of V (p-p) of 24V. The voltage signal from the SPWM results will be used to activate the gate of the N-channel and P-channel MOSFETs so that the signal changes to AC voltage with a voltage of V (p-p) of 24V. The output of the MOSFET before entering the low-pass filter circuit can be seen in Figure 7.
For the results of the output, the low-pass filter can be seen in Figure 8.

![Figure 8. The results of a low-pass filter](image)

The output voltage, the low-pass filter can be explained in Equation 7

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2}$$  \hspace{1cm} (7)

Where $R_{total}$ is the total resistance in the series explained in Equation 8

$$R_{total} = R_1 + R_2$$  \hspace{1cm} (8)

While the value of the reactance of a capacitor in an AC circuit equal to Equation 9

$$X_c = \frac{1}{2\pi f C}$$  \hspace{1cm} (9)

From this formula, it can be seen the resistance value of the capacitor is inversely proportional to frequency. The smaller the frequency, the value of the resistance of a capacitor will be even greater, while the greater the value of the frequency will result in the value of the resistance of the capacitor is small. The resistance of the AC circuit to the component produces an impedance whose value depends on the value of the capacitor and the frequency of the AC voltage source. The impedance of a series circuit in an AC circuit can be calculated by the formula explained in Equation 10

$$Z = \sqrt{X_c^2 + R^2}$$  \hspace{1cm} (10)

Then by combining equation (7) into equation (10) formula will be obtained:

$$V_{out} = V_{in} \times \frac{X_c}{\sqrt{X_c^2 + R^2}}$$  \hspace{1cm} (11)

If at a frequency of 0 Hz, using equation (9) the capacitor resistance is:

$$X_c = \frac{1}{2\pi f C} = \frac{1}{0} = \infty$$
\[ V_{\text{out}} = V_{\text{in}} x \frac{X_c}{\sqrt{X_c^2 + R^2}} \]  \hspace{1cm} (12)

\[ V_{\text{out}} = V_{\text{in}} x \frac{\infty}{\sqrt{\infty + R^2}} \]  \hspace{1cm} (13)

\[ V_{\text{out}} = V_{\text{in}} \]  \hspace{1cm} (14)

If at the frequency \( \infty \) then the resistance of the capacitor can be obtained using equation (9):

\[ X_c = \frac{1}{2\pi f C} = \frac{1}{\infty} = 0 \]  \hspace{1cm} (15)

\[ V_{\text{out}} = V_{\text{in}} x \frac{X_c}{\sqrt{X_c^2 + R^2}} \]  \hspace{1cm} (16)

\[ V_{\text{out}} = V_{\text{in}} x \frac{0}{\sqrt{0 + R^2}} \]  \hspace{1cm} (17)

\[ V_{\text{out}} = 0 \]  \hspace{1cm} (18)

From the results of the above calculation, it can be concluded that when the frequency is low the entire voltage will fall on the capacitor, and at the high frequency, the capacitor voltage will be equal to zero (0). The cut-off frequency in the circuit is obtained when the value \( X_c = R \), from here we can find the cut-off equation using the formula:

\[ X_c = R \]
\[ \frac{1}{2\pi f C} = R \]
\[ f_{\text{cut-off}} = \frac{1}{2\pi R C} \]  \hspace{1cm} (19) \hspace{1cm} (20) \hspace{1cm} (21)

From the filter design that will be used on the inverter, the author will enter a value of 50 Hz for the cut-off frequency value and will use a capacitor value of 100uF 25V so that the resistance value obtained using equation (21) is:

\[ f_{\text{cut-off}} = \frac{1}{2\pi R C} \]
\[ 50 = \frac{1}{2\pi R \times 100uF} \]
\[ R = 33\Omega \]

**Figure 9.** Voltage and waveform of transformer output without load
For testing a no-load transformer, the resulting voltage is quite high and relatively stable. With a voltage source from a 12V battery, the inverter able to produce a voltage of 220V max without being connected to the load. The results of the Voltage and waveform of transformer output without load can be seen in Figure 9 and Testing with 5-watt load as shown in Table 1.

| No. | Input voltage (v) | Output without load (vmax) | output Inverter (vrms) | current Inverter (mA) |
|-----|------------------|---------------------------|-----------------------|----------------------|
| 1   | 12.5             | 228                       | 157                   | 72.6                 |
| 2   | 12.6             | 224                       | 158                   | 72                   |
| 3   | 12.7             | 236                       | 164                   | 73                   |
| 4   | 12.8             | 228                       | 160                   | 74.4                 |
| 5   | 12.9             | 228                       | 157                   | 74.9                 |
| 6   | 13               | 224                       | 153                   | 75                   |
| 7   | 13.1             | 224                       | 154                   | 75.1                 |
| 8   | 13.2             | 224                       | 155                   | 75.4                 |
| 9   | 13.3             | 233                       | 160                   | 75                   |
| 10  | 13.5             | 228                       | 160                   | 77.1                 |
| average | 12.96         | 227.7                     | 157.8                 | 74.45                |

4. Conclusion
From several experiments and tests that have been done, it can be concluded that. The design of this inverter is capable of producing an output voltage of Vmax 220 or equal to 155 Vrms with an input range of batteries that varies between 12-13VDC. The design of this inverter is capable of producing an output voltage of Vmax 220 or equal to 155 Vrms. The inverter able to work on the load even though there is a decrease in voltage which tends to be drastic, namely at a 12-Watt load there is a decrease in voltage up to + - 130 Vrms. The amount of load installed affects the voltage drop that occurs in the inverter. Simulation and testing results are not much different, both from the voltage produced and the waveform produced. There are only a few factors that influence implementation errors including the ideal nature of the simulation.

References
[1] A. Zahedi, (2018), “Large scale solar PV generation for Southeast Asian countries,” 2017 Australas. Univ. Power Eng. Conf. AUPEC 2017, vol. 2017-Novem, pp. 1–5.
[2] IEA, (2010), "World Energy Outlook 2010," International Energy Agency, Paris 2010.
[3] L. Hughes and J. Rudolph, (2011), "Future world oil production: growth, plateau, or peak? “Current Opinion in Environmental Sustainability, vol. 3, pp. 225-234.
[4] M. Bilgin, (2009), "Geopolitics of European natural gas demand: Supplies from Russia, Caspian, and the Middle East," Energy Policy, vol. 37, pp. 4482-4492.
[5] IEA, (2011), "World Energy Outlook 2011," International Energy Agency, Peris, France 2011
[6] BP, (2012), "BP Statistical Review of World Energy June 2012," London, UK