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Submission date: 21-Jun-2020 02:55PM (UTC+0700)
Submission ID: 1347302115
File name: IONAL_BOOST_INVERTER_FOR_1000_WP_PHOTOVOLTAIC_APPLICATION_1.docx (3.56M)
Word count: 3358
Character count: 17988

EXPERIMENTAL MODEL OF SINGLE PHASE DC – DC BOOST CONVERTER FOR 1000 WP PHOTOVOLTAIC APPLICATION

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Abstract – *The photovoltaic system is used and utilized as a source of electricity demand in many developed countries including Indonesia. Nowadays the photovoltaic system is an alternative source of electricity that is inexpensive reasonably priced and easily applied in public facilities until laboratory usage. Electrical Engineering Laboratory (EEL), Faculty of Engineering (FoE), Universitas Jenderal Achmad Yani (Unjani) available 1000 Watt peak (1kWp) photovoltaic application. The PV system is planned to be connected to the grid and produces 220VAC / 50Hz characteristics to meet the existing load capacity. The PV systems modeled include Pulse Width Modulation (PWM) controlled DC/DC boost converter, and DC/AC converter circuit. The experimental design in this study is proposed to meet the electrical load followed by the characteristics of the photovoltaic system. The three types of power electronic switching namely Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Insulated Gate Bipolar Transistor (IGBT), and Gate Turn-off Thyristor (GTO) are used to meet the highest efficiency. Based on the simulation results of a 1 kWp photovoltaic system that has been carried out from the three types of power electronic switching, it produces a minimum output voltage range of 210-230 VDC. DC/AC Converter simulation has been conducted and can be implemented on the grid-connected single-phase 220VAC / 50Hz with the best efficiency using MOSFET that is equal to 96.7%.*

Keywords: *Boost Converter; MOSFET; Pulse Wave Modulation; Photovoltaic System; Single-phase*

Received: May 2, 2019 *Revised: May 29, 2019* *Accepted: June 2, 2019*

INTRODUCTION

Inevitably, fossil fuels are immediately replaced by renewable energy. The Photovoltaic (PV) system is one of them. PV converts solar energy into electricity and is environmentally friendly energy. The basic element of a PV system is a PV cell. Cells can be grouped as arrays. The voltage and current available on PV directly power the load connected to the grid using an appropriate energy conversion device[1]. This advantage is used by public facilities to laboratories[2],[3].

This paper certainly cannot be separated from several existing studies, including about calculating energy losses in PV panels, calculation techniques and voltage drop to output power suitability by[4]. Electrical Engineering Laboratory (EEL), Faculty of Engineering (FoE), Universitas Jenderal Achmad Yani (UNJANI) available stand-alone PV system. Based on studies, PV systems are required to always operate at the MPP to get the energy benefits in the optimum state without shading and if shading is taken into account, this PV system has losses due to shading effect of around 20.8%, the maximum peak power will drop to 792 Wp[5]. The energy produced by PV panels is highly volatile and is greatly influenced by climatological conditions around the PV such as solar irradiation and ambient temperature so that the characteristics of the current and voltage generated by PV vary. Because of the unique characteristics of PV panels, PV panels are not directly connected to the load but use a DC/DC converter circuit to connect the PV panels and the existing load. PV panels have a maximum power point (MPP) that occurs when the current and voltage are at their maximum value. MPPT is a method used to maximize the acquisition of solar energy to the output performance of voltage, current and power that is typical of PV[6]. MPPT also acts as an electronic system operated by a PV panel so that the PV system can produce maximum power. Then in the PV system, it needs a grid connected inverter component so that the PV module can send power to the grid. The thing to do is to interconnect the direct current voltage to the alternating current voltage, one of which is the electronic power converter functions to convert it. Analysis and losses on the PV power rating are mapped by the influence of irradiance and varying temperatures, as well as the efficiency of the converter when in the existing condition of a grid-connected PV application system. The power generated from grid-connected PV systems is used to meet the local loads. If the local load is greater than the PV power, the network meets the remaining power requirements. Conversely, if the local load is less than the power generated by PV, then the PV power is sent to the grid. Systems that are connected to the grid must have good quality AC and the same as those provided by PLN. To ensure that the electricity, it is necessary to design an inverter that is suitable for the characteristics of the grid-connected PV application [7].

This paper will discuss a DC/DC Converter scheme and comparison of the performance of three types of power electronic switches to meet the 220VAC / 50Hz grid-connected PV criteria of a 1 kWp PV system EEL. The power electronic switches used are Metal Oxide Semiconductor Field Effect Transistors (MOSFETs), Insulated Gate Bipolar Transistors (IGBT), and Gate Turn-off Thyristors (GTO) on DC/AC converter. These three components are tested experimentally using models and simulations with supporting component values that approach the simulation results according to the standard.

METHOD

Parameter Design and Specification

The peak power is obtained by multiply the current with the voltage of PV panels. Table 1 shows the (Vmp) max. the voltage from one panel to load the 18 VDC voltage is configured in series, so from the 10 PV panels is 180 VDC multiplied by the nominal current on the PV [8],[9]. Follow by Equation (1) – Equation (3),

$$Vmp_{total\_series} = \sum_{n}^{i} = 1\,Vmp_n \tag{1}$$

$$Imp_{total\_series} = 1Vmp_n \tag{2}$$

$$Pmp = Vmp\,.Imp \tag{3}$$

Table 1. Technical Data of PV Parameters

No	Nameplate	Details
1	PV Cell Technology	Si-mono Crystalline
2	Max. Operation Voltage	V_{mp} 18 V
3	Max. Operation Current	I_{mp} 5.56 A
4	Short Circuit Current	I_{SC}6.02 A
5	Open Circuit Voltage	V_{OC} 22.36 V

Modeling of PV Characteristics

The parameters of the characteristics of a PV system can be determined by modeling the specifications of the existing PV panels based on Table 1. The Characteristics of PV panels are tested through the current to voltage (I-V) including open-circuit voltage (V_{OC}), short circuit current (I_{SC}), and PV output power (P-V). The equivalent circuit and the characteristic of the PV cell shown by Figure 1 and Eq. (4)[10][11].

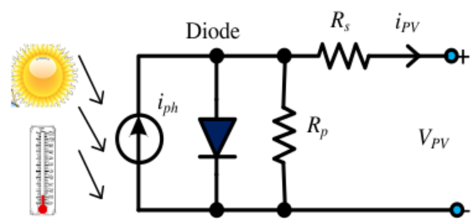

Figure 1. Equivalent Circuit of Single Cell

$$i_{pv} = i_{ph} - i_o\left[exp\left(\frac{v_{pv}+i_{pv}R_s}{nk_BT/q}\right)-1\right] - \frac{v_{pv}+i_{pv}R_s}{R_p} \tag{4}$$

Equation (4) shows I_{PV} and V_{PV} for the output voltage and current of the PV cell, Iph is the current resulting from the process of alluring photon force. Whereas, the diode saturation current is modeled, which shows the characteristics of the diode. q is the electron charge, and n is an ideal factor, k_B is the Boltzmann constant, then the temperature (T) of the solar cell (˚K), R_p is the shunt resistance with a leakage current that pass the path into the cell. Rs is a shunt resistance that shows a decrease from within a series [12]. All of this relates to the maximum amount of current and voltage that can be produced from solar cells.

Modeling and Simulation Concept

- **DC/DC Boost Converter**

Research related to the background and analysis as well as the relationship with previous research is the simulation of Power Point Tracking on PV panels using SIMULINK/MATLAB R2017a. PV panels using MPPT systems produce greater output power than PV panels without MPPT [13],[14]. To meet these criteria, the converter circuit is simulated using a DC voltage source (VS), MOSFET as Switch (S), inductor (L), diode (D), load resistance (RL) and capacitor (C). Where (IO) the output current, (VO) is the output voltage[15]. Circuit is tested and compared on each component of power electronics.

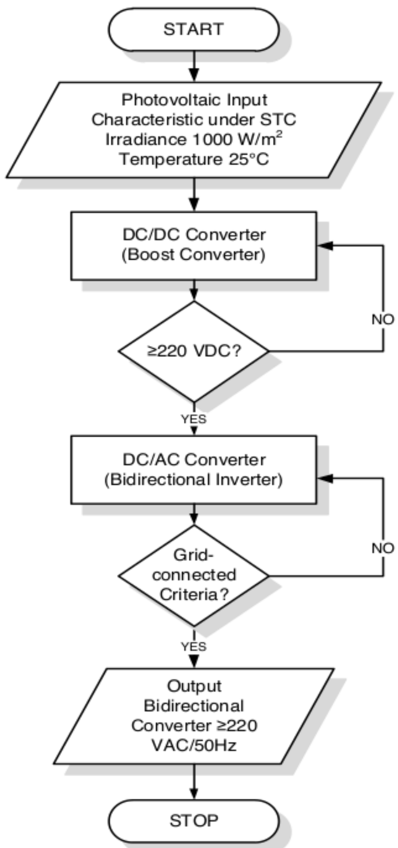

Figure 2. Flowchart Model and Simulation

- **DC/AC Converter (Inverter)**

Figure 2 Show the PV Input in Standard Test Condition (STC) at Irradiance 1000 W/m² and at temperature 25°C. Design a DC/DC Boost Converter with an output voltage of 220 VDC. Then model the DC/AC converter/inverter to change the DC voltage to AC and the grid connected to PLN 220VAC / 50Hz. Grid-connected inverters have a certain standards, because these inverters are connected to a large power system grid. The standard for grid-connected inverters is written in IEC61727 and IEEE1547 shows the voltage and frequency for grid-connected inverters listed in Table 2.

Table 2. Standard voltage and frequency range

No.	Normal Rating Condition	IEC61727	IEEE1547
1	Voltage	85% - 110%	88% - 110%
2	Frequency	50 +/- 1 Hz	59,3Hz – 60,5 Hz (Freq. rating 60 Hz

RESULTS AND DISCUSSION

PV Panel Characteristics Model

The results of the calculation of the system configuration using Eq. (1) – Eq. (3) produces a maximum power of 1000.8 Watt peak. In this simulation the PV panels are connected in series to produce large voltages while the current remains at its nominal value according to Table 1. The installation used on PV panels can be seen in Figure 3.

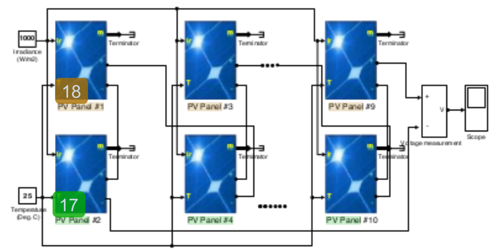

Figure 3. 1 kWp Array Configuration

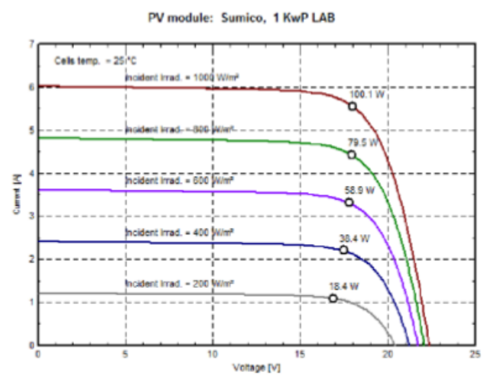

Figure 4. Characteristic curves of I-V

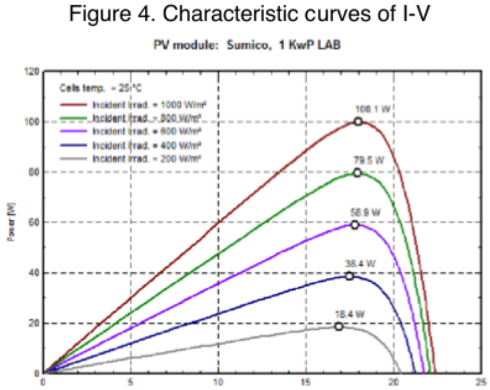

Figure 5. Characteristic curves of P-V

Figure 4 and Figure 5 shows the PV cells have a characteristic voltage source on the right of the I-V curve where the output voltage is almost fixed. In contrast, current source behavior is inspected

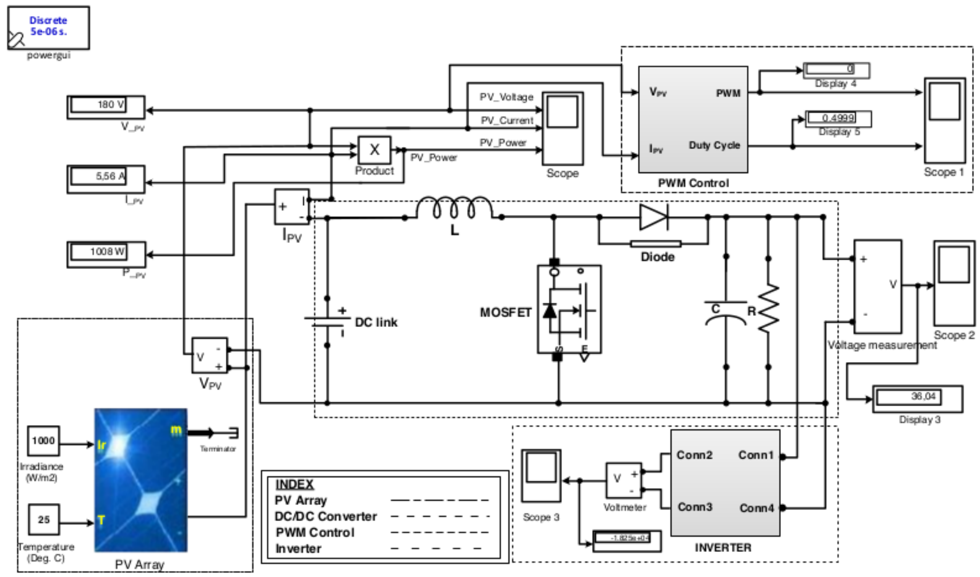

Figure 6. Scheme of Simulation using SIMULINK/MATLAB R2017a

on the left of the I-V curve. Indicates a utilized spot where the output power will be able to optimize. This operating point is well known with Maximum Power Point (MPP).

Figure 6 shows the proposed simulation block which is done through a library that already exists on Simulink. The PV system scheme is modeled as a whole and each block consists of 4 stages, ranging from PV panel blocks, boost converter blocks, PWM control blocks and DC/AC converter inverter blocks. Each has functions and sub-programs. The output waveform is displayed through the block function of the scope and easily displays the current and voltage of each block. The controller is designed to generate the amount of output produced. The results of this test are based on varying amounts of solar irradiance.

Modeling of DC/DC Converter

As shown in the simulation in Figure 6. Fig. 7 is the switching process occurs when the switch gate (S) opens, the diode polarization will occur simultaneously. The Inductor voltage (L) then advances to the main source voltage (V_S), giving an output voltage (V_O) greater than (V_S) the main source and experiencing reinforcement with the same polarity. Thus, the load (R_L) is fed by the inductor (L) and the source voltage (V_S). PWM and MPPT controllers generally use the series-type or shunt controller feature. After the process from the Boost Converter is then forwarded to the inverter block then converted to AC voltage. PWM type controllers utilize power electronic components in DC/DC conversion circuits for tracking the MPP of the PV module or curve I-V PV array. The controller measures the charging conditions and adjusts the pulse.

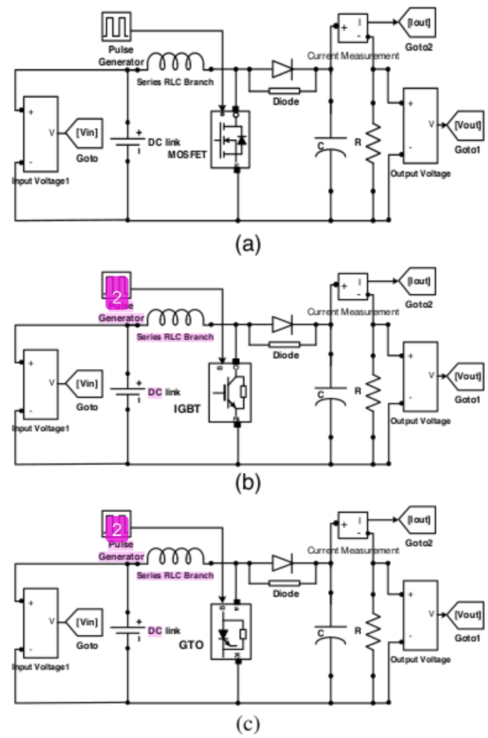

Figure 7. DC/DC Boost Converter Model;
a) MOSFET, b) IGBT, c) GTO

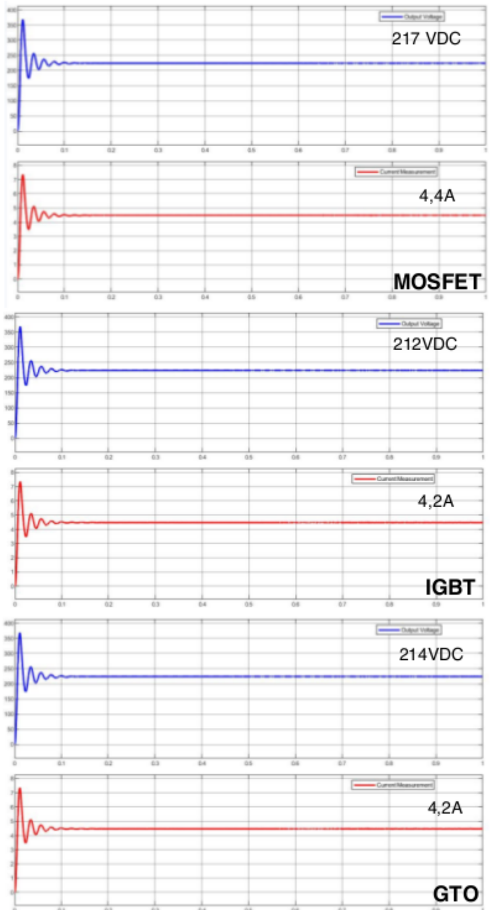

Figure 8. DC/DC Boost Converter Simulation

The voltage regulation can be done outside or inside the converter. Voltage regulation outside the converter is done by adjusting the input voltage variant of the converter. The voltage regulation in the converter is known as Pulse Width Modulation (PWM). Boost converter simulation using MOSFET results in the expected voltage and current with an increase in voltage of 18%, with the voltage is 224 VDC and the current with a value of 4.4 A compared to other components. See Fig. 8 and Fig. 9 for the DC/DC Boost Converter Diagram simulation result using table 3. After the process from the Boost Converter is then forwarded to the inverter block then converted to AC voltage. PWM type controllers utilize power electronic components in DC/DC conversion circuits using for tracking the MPP of the PV module or the curve of the I-V array. The controller measures the charging conditions and adapts the pulse.

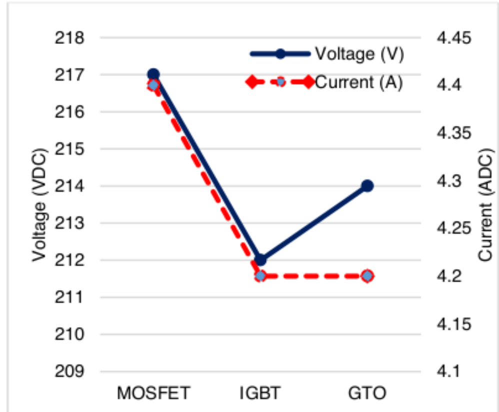

Figure 9. Testing Simulation Result

Table 3. Switching Component Parameters

No.	Components	MOSFET	IGBT	GTO
1	Inductance	3 μH	266 μH	2 μH
2	Capacitance	2.5 mF	2 mF	2.7 mF
3	Resistance	50 Ohm	50 Ohm	50 Ohm

Model of DC/AC Converter Simulation Result

DC/AC Converter circuit is modeled, using MOSFET, IGBT, and GTO switching. Figure 7 - Figure 9 is an inverter simulation circuit. The concept of the circuit is the line or direction of the current in the converter circuit branch. Some possibilities between the voltage and current source terminals will occur. A condition of relationship where current (I) flows from switch 1 to switch 4, then-current (I) flows from switch 2 to switch 3 and conditions where current and voltage are not connected. Conditions between switches 1, 2 and switches 3, 4 closing together may not occur. If this condition occurs it will result in a short circuit. This controller is modeled and used to run electronic loads that require 110 or 230V AC. In this case, the PV system has the power maximum characteristics of a 100 W PV module arranged in series in 10 panels, so the value of Pout is 100W multiplied by 10 panels producing 1000 Watt peak. These results are divided by the results of the multiplication of the efficiency of the inverter. In general, inverters must be designed >93% (0.93) or we take the highest efficiency, which is $\eta = 0.98$. Each inverter charging is given a value for each component as shown in Table 4, where the parameters of each component are proposed to produce a near-perfect output. This circuit is simulated using several different values of Impedance and capacitor parameters for each switching.

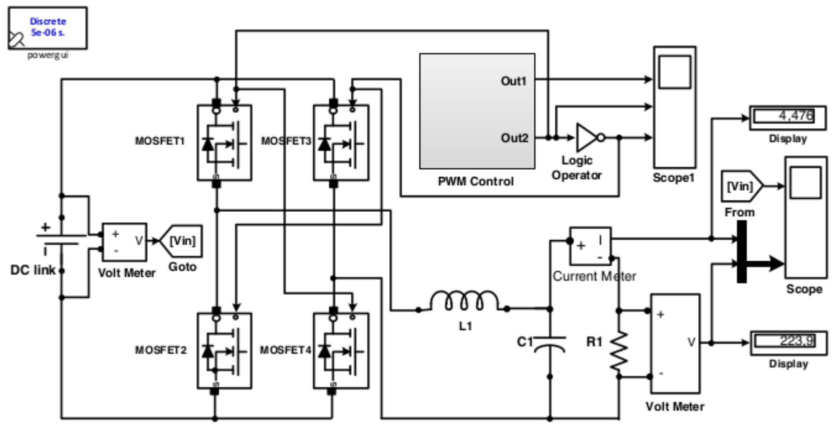

Figure 10. DC/AC Converter Model using MOSFET

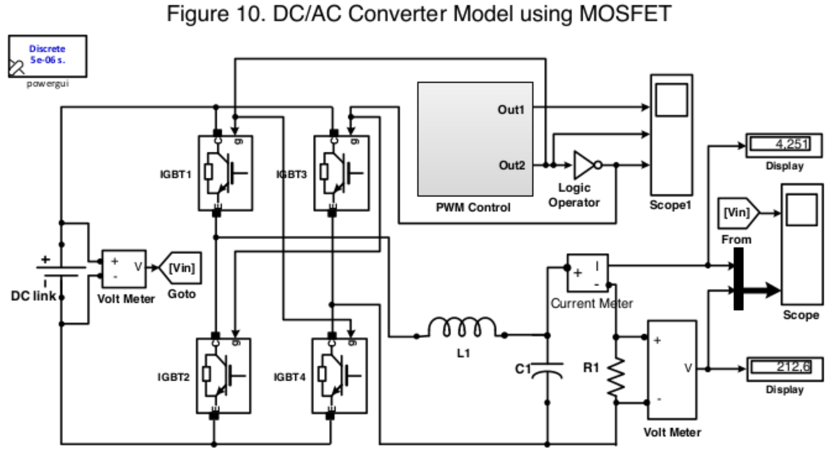

Figure11. DC/AC Converter Model using IGBT

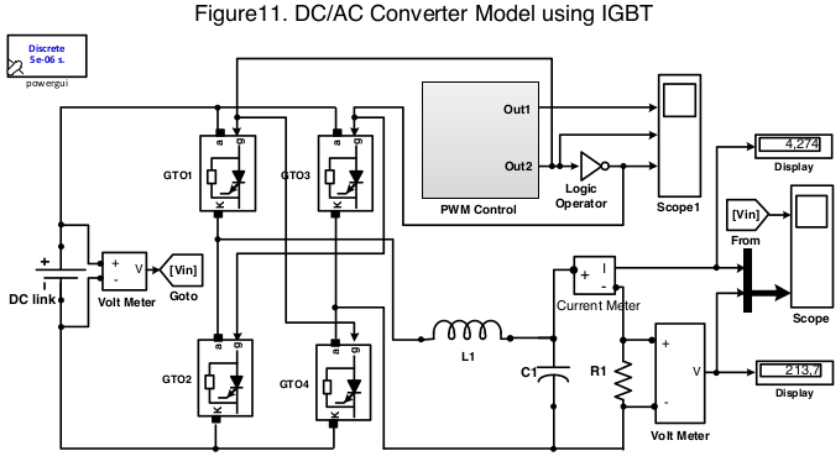

Figure12. DC/AC Converter Model using GTO

Figure13. Inverter Simulation Output

By using the components discussed in the previous section, the structure of the converter is expected to be obtained following the input process of the characteristics of the current source and voltage source, voltage polarity, and current direction. There is a reversal of current at the current source or voltage source under conditions S1 and S3 close and at conditions where S2 and S4 open or reverse conditions where S1 and S3 open and at conditions where S2 and S4 close. The selection of switch S is determined from the current direction if S is closed (ON) and the voltage polarity at S is opened (OFF). Switching on the MOSFET, IGBT and GTO inverter circuit shown in Figure 10 - Figure 12 produces several voltage waves and the output current approaches the Grid Connected criteria. Fig. 13 shows the results of inverter output in the form of AC currents and voltages that are close to sinusoidal with currents and voltages of 4.4 amperes and 224 VAC, respectively.

To get the current and voltage waves approaching the sine, the sinusoidal pulse width modulation control technique is used and each inverter is given a value for each component, and output shown by Table 4. Tests using IGBT power electronic switching obtained output voltage and current with a value of 212 Volts AC and 4.2 Amperes. The circuit that uses GTO switching component values is almost the same as the MOSFET and IGBT circuits. The circuit simulation shows a sine wave with the frequency results of 50 Hz for MOSFETs, 52.6 Hz for IGBT, and 55.5 Hz for GTO.

Table 4. Simulation Output of DC/AC Converter

No.	Components	Voltage (VAC)	Current (A)	Freq. (Hz)
1	MOSFET	227	4,4	50
2	IGBT	212	4,2	52.6
3	GTO	213,7	4,2	55.5

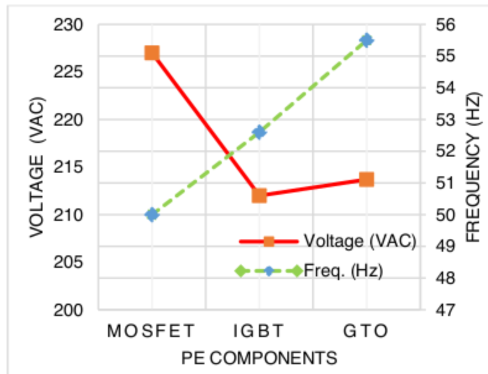

Figure 13. Output Voltage with Frequency of each component

CONCLUSION

Based on the results of simulations and tests that have been carried out on the three types of power electronic components in a grid connected single phase converter the conclusions that can be drawn are the simulation of the PV panels tested under STC is appropriate and meets the system characteristic requirements. Modeling of DC-DC Boost Converter has been carried out and according to the desired initial design i.e. the output voltage is 224 VDC for grid-connected 220V / 50 Hz PLN grids with a minimum voltage of 210-230VDC which is converted to 220VAC voltage using a grid-connected inverter. A circuit model that meets the Grid-connected criteria by using MOSFET switching and can be implemented to Grid-connected with an efficiency of 96.7%.

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