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Performance Improvement of Grid Tie Inverter on Microgrid of Solar Photovoltaic

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Abstract. Microgrid systems are supplied from solar photovoltaic (PV) as an input grid-tie inverter (GTI). In this research, GTI used is a grid-tie micro-inverter 1000 watt. GTI is a power converter direct current (DC) into alternating current (AC) and can operate when connected to electricity grid utility. GTI output connected to a local load such as incandescent lamps, CFL lamps, small refrigerators, TV and fans. The problem with the microgrid system with GTI is GTI unable to operate to generate power if it does not detect the reference voltage of grid utility (islanding condition). This research proposes the idea to replace electricity grid utility with a battery system from wind power generation when grid utility is interrupted or blackout. The research experiment conducted in a renewable energy laboratory of Faculty of Engineering, University of Mataram. The addition of controlled renewable energy sources such as small wind turbines can improve the performance of GTI to optimize power generated on the microgrid system, when electricity from power grid utility is interrupted or outages. The variables measured in GTI performance testing on the microgrid system are voltage, current, and THD. The value of voltage generated by GTI to 2 conditions of test carried out is still within the allowable standard limit of ± 10% of nominal voltage (220 Volts). Similarly, the THD value of the result is still below the specified standard (5%).

Keywords: Microgrid, grid tie inverter, renewable energy, solar photovoltaic, small wind turbines

1. Introduction

Indonesia has enormous solar energy potential; it is on the equator with global irradiance range 4.20 - 5.27 kWh/m^2.day [1]. This research is in accordance with Government Regulation No. 79/2014 on National Energy Policy that supports the utilization of solar PV technology as a sustainable energy source for electrical energy needs in Indonesia.

With good control systems, microgrid of solar PV can be used as a reliable power generation. The power generated by solar PV varies depending on the solar irradiance received at that time. This causes problems with power quality produced if connected to power grid utility, where solar PV will be seen as a negative load by the system because it has uncontrolled characteristics related to fluctuations in energy sources [5]. This problem can be solved by adding more controlled power generations, such as energy storage systems (batteries) or hybrid systems with diesel generators or micro turbines [7].

It has been known several publications to improve the performance of solar PV [2, 3], hybrid on microgrid systems [4, 6, 8], and serve as a reference in this research. The research aims to analyze the performance of the microgrid system from solar PV to ensure that GTI continues to operate, despite interruptions or outages of power grid utility. A backup power source is supplied from a small wind generator (battery-controlled system). GTI expected to continue to operate and resulted in improved performance for continuity of service to customers with power quality requirements met.

2. Methods

The method used is true experimental research to get an overview of the performance of GTI on microgrid from solar PV. The microgrid system is in Renewable Energy Laboratory, Faculty of Engineering, and University of Mataram. The equipment consists of solar PV, small wind turbines, GTI and load systems. The diagram line of an experimental test is shown in Figure 1.

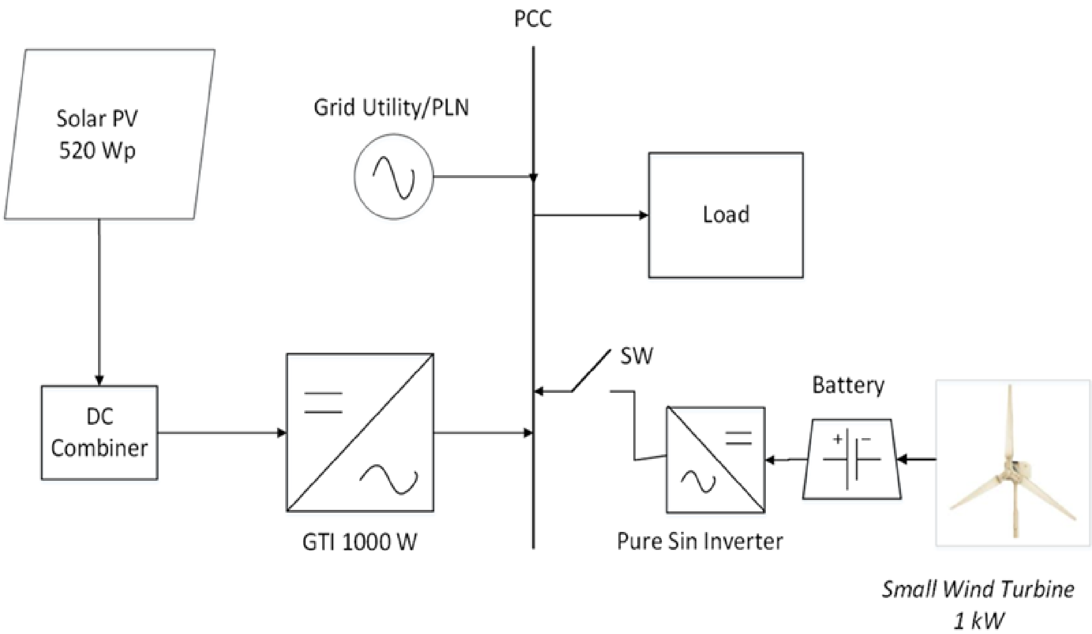


Figure 1. The diagram line of an experimental testing

2.1. Microgrid

The microgrid is a group of small distributed generation and integrated on a power grid utility. The power plant supplies electrical energy needs for small load communities such as housing, schools, campuses, offices, shops (markets) and small industries in urban or rural areas. The microgrid is essentially an active distribution network because it is a distributed generation system that is independent and has a varying load on the distribution system level [11].

The Microgrid is one example of a distributed generation scheme that covers a variety of energy sources, both fossil energy and renewable energy (wind, solar, biogas, etc.). Microgrid systems can operate in parallel with large interconnected systems or systems that operate independently, so they can work at the level of medium voltage and low voltage distribution network.

2.2. *Grid tie inverter*

GTI is a special type of inverter that can convert DC voltages into AC voltages and operate parallel with the utility power grid. GTI is known as a synchronous inverter or interactive grid inverter, which distinguishes it from other types of inverters. Some of the requirements that GTI must meet when connected to a power grid utility, ie the voltage, phase, and frequency of GTI output must be the same with voltage, phase, and frequency of power grid utility [9]. The circuit of a GTI shown in figure 2.

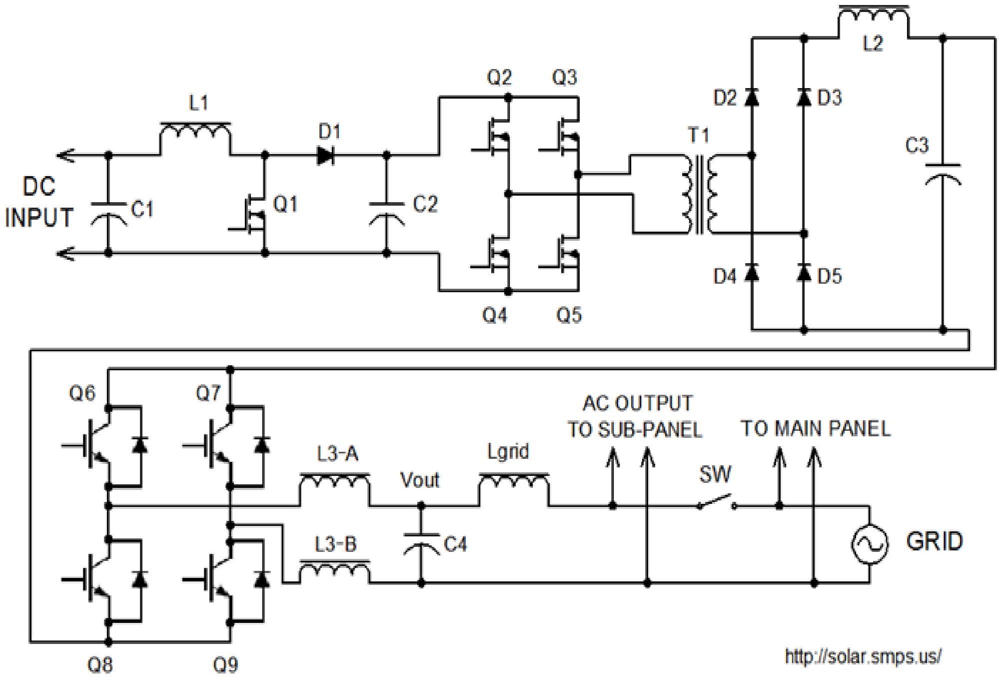


Figure 2. The circuit of a GTI [10]

DC input voltage will be increased by boost converter formed by inductor L1, n-MOSFET Q1, a diode D1, and C2. DC voltage will be converted to AC voltage by n-MOSFET Q2-Q5. Then, high-frequency transformer T1 raises the input voltage and provides galvanic isolation between the input and output sides of the GTI. The output voltage of the transformer is rectified again by Diodes D2-D5. The last stage of the circuit is the conversion of DC voltage to AC voltage with a full-bridge converter, which consists of IGBT Q6-Q9 and LC filters (L1 and C4).

2.3. *Solar Photovoltaic*

2.3.1. *Solar cell principle.*

When silicon crystals receive energy in the form of light or heat, for example, energy is also absorbed by electrons. After the electron pair has absorbed enough energy, the electrons scatter so that the free electrons move inside the silicon crystal. Each electron that flows in this way leaves a "hole" in its original location in the crystal lattice. As silicon becomes conductive, this property is known as semiconductor intrinsic conductivity. When the energy supply is disrupted, each electron that flows releases the previously absorbed energy and returns to the free electron-hole.

2.3.2. *Photovoltaic effect*

When light hits the crystal lattice PV cell, light energy is transferred to the lattice, where the atoms are excited to form electron-hole pairs. If this happens outside the p-n junction, the electron-hole pair rejoins very quickly. The electron-hole pair inside p-n junctions is separated by local electric fields. The flow of electrons is generated into the n-type layer, while holes lead to the p-type layer, causing the voltage to arise in the PV cell. If a load is connected to a cell, the current starts flowing.

2.3.3. Characteristic I/V and P/V of PV cells

All measurement points show the results of the characteristics of PV cells. This characteristic is determined by variations in current and voltage. The characteristics of a cell or module function as important assessment criteria in solar technology. Power can be supplied PV modules depends not only on radiation, but also suitable for consumers. The no-load operating point and the short-circuit current operating point, produce output power (P). Between two operating points, the power must reach a maximum value called maximum power point. The maximum power equation uses a formula:

$$P_{MP} = V_{MP} \cdot I_{MP} \quad (1)$$

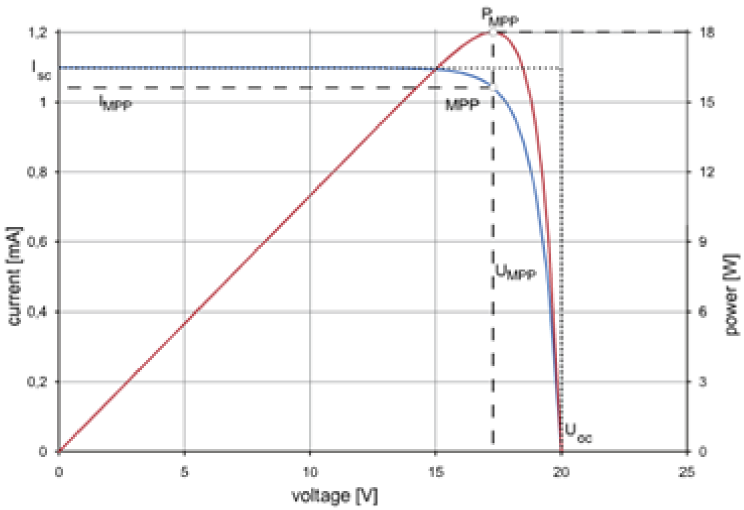


Figure 3. Characteristic I/V and P/V of PV cells

2.3.4. Efficiency

To determine efficiency (η) of a solar cell must be known power of maximum power point (P_{MPP}), solar irradiance (E) and areas (A) of solar cells. Efficiency is calculated using the equation:

$$\eta = \frac{P_{MPP}}{E \times A} \quad (2)$$

$$\eta = \frac{FF \times U_{OC} \times I_{SC}}{E \times A} \quad (3)$$

2.4. Small wind turbines

A small wind turbine is a generator that utilizes wind energy as its energy source. The wind is used to drive wind turbines, which in turn is coupled to a generator to produce electricity. The advantages of small wind turbines are one renewable energy source in remote areas and coastal areas, environmentally friendly green energy sources, obtained freely in nature, and operating costs are relatively cheap.

The wind is the air that has mass and moves at a certain speed. According to classical physics, the kinetic energy of a mass (m) and velocity (v) is E = mv^2. If a collection of air has a swept area, A (m^2) and moves at a speed, v (m/s), the amount of mass passing through a place with the formula:

$$m = A \cdot v \cdot \rho \quad (4)$$

The energy that can be produced per unit time with formula:

$$P = 0,5 \cdot A \cdot \rho \cdot v^3 \quad (5)$$

Where: m = mass (kg)
A = areas (m^2)
v = wind speed (m/s)
ρ = air density (1,225 kg/m^3)
P = power produced (watt)

3. Results and Discussion

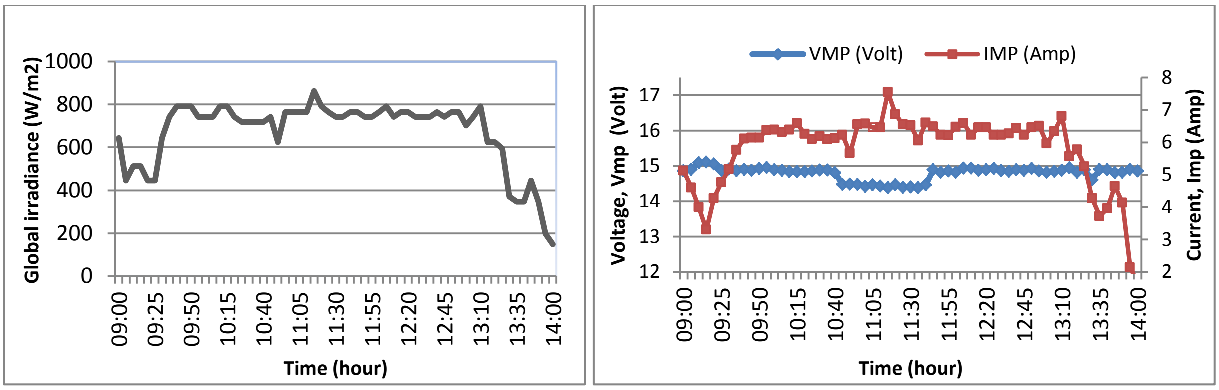
The setup is an experimental of equipment and loads in the testing of GTI performance on microgrid from solar PV shown in Figure 4. Based on a scheme in Figure 1, Tests carried out on 2 (two) condition: 1) sources of microgrid from solar PV and power grid utility, and 2) sources of microgrid from solar PV and small wind turbines as a reference voltage of GTI (*islanding condition*).

Figure 4. Setup experimental equipment and loads on a renewable energy laboratory

3.1. Analysis of GTI performance for first condition

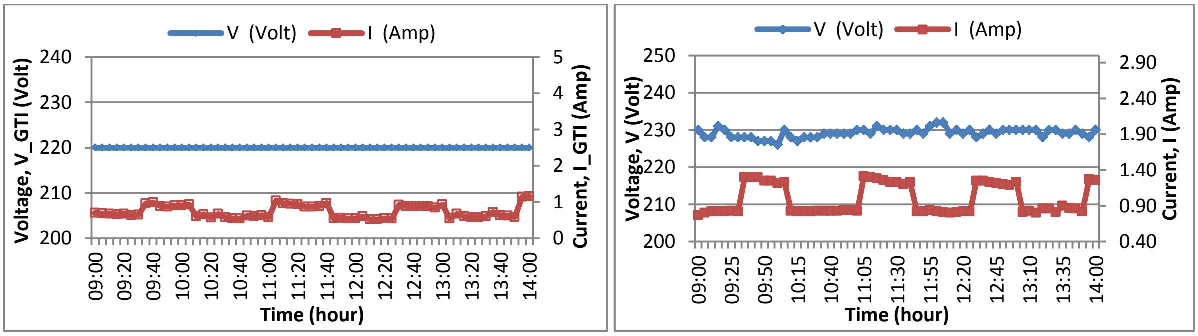
Solar irradiance during the test showed that the maximum value as shown in Figure 5a., causing to increased performance of solar PV. The performance of solar PV analyzed based on electrical quantity i.e. voltage of maximum power point (V_{MP}) and current of maximum power point (I_{MP}) produced. The value of V_{MP} tends to be constant with varying intensity of solar radiation, while the value of I_{MP} increases sharply with increasing intensity of solar radiation, as shown in Figure 5b.

At GTI performance testing, a voltage is generated solar PV is relatively constant and the reference voltage of power grid utility is at allowable standard so that GTI can operate normally. Figure 6a. and 6b. show voltage profile and current flow in GTI and load on the microgrid system. The voltage profile in both the GTI and load is relatively constant, while the amount of current flows depends on the load used. The current rating at the moment tends to fall, due to a standby position of one of the electrical appliances (refrigerator).



(a) (b)

Figure 5. (a) Graph of global irradiance E_G (W/m^2); (b) graph of voltage and current maximum power point of solar PV

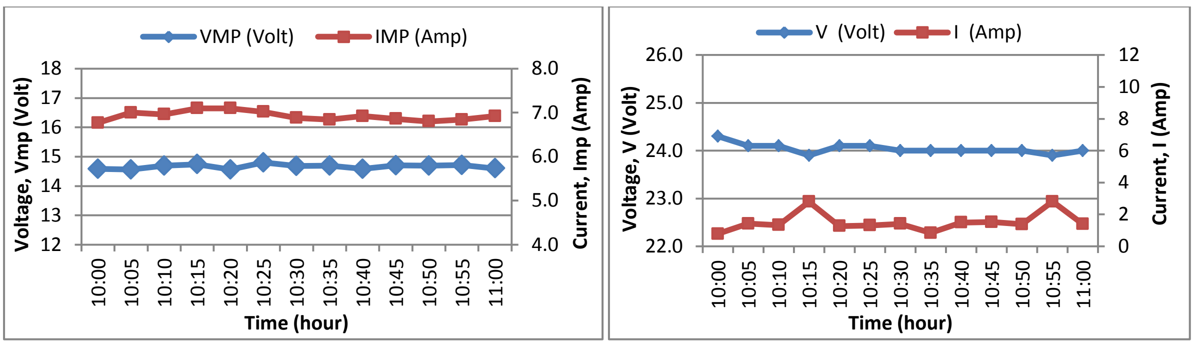


(a) (b)

Figure 6. Graph of voltage and current on (a) Grid Tie Inverter; (b) load

3.2. Analysis of GTI performance for second condition

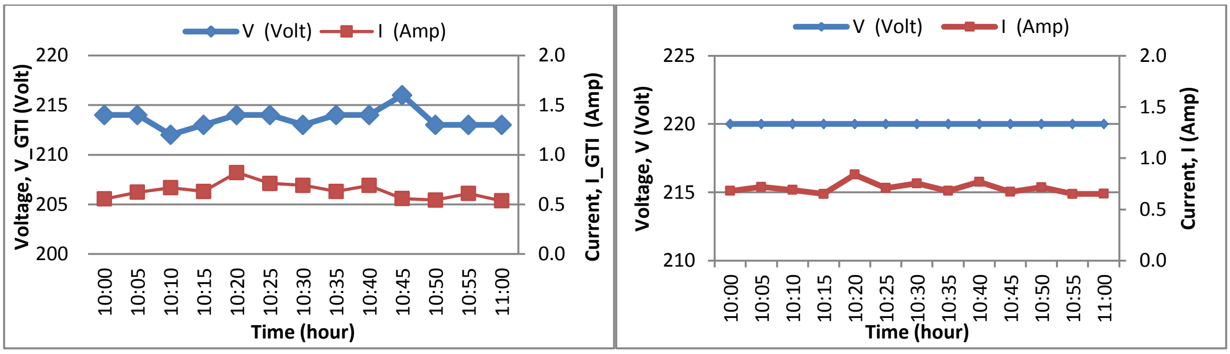
The second condition is operated in case of disturbances or outages on power grid utility as a reference voltage of GTI. The aims to maximize the power generated in the microgrid system and small wind turbines functioned as a substitute for the power grid network. Figure 7a. Show graph of voltage and current maximum power point of solar PV on Monday, 4 November 2019. While Figure 7b. Show voltage and current on battery system of small wind turbines. The output voltage of the dc generator is 24 volt.



(a) (b)

Figure 7. Graph of voltage and current (a) maximum power point of solar PV (operated with small wind turbines); (b) on battery system of small wind turbines

By observing the voltage profile and current flow on GTI as shown in Figure 8. (a), GTI can operate when voltage supply from small wind turbines meets standards and can serve the load provided. The GTI voltage profile is slightly lower than the GTI voltage in the first condition, but still within the specified standard range. The current flowing to load is smaller due to the load being served is relatively small with a total load is 178 watts; consist of incandescent bulbs, CFL, fan and small refrigerator.



(a) (b)

Figure 8. Graph of voltage and current on (a) GTI (operated with small wind turbines); (b) load (operated with small wind turbines)

3.3. Analysis of harmonic on microgrid from solar PV

The use of inverters on solar PV as a harmonic contributor to microgrid system, then this research will measure total harmonic distortion (THD) for voltage and current in inverter, power grid and load. Loads used to measure harmonics are incandescent lamps (2 x 60 Watt) and CFL lamps (2 x 9 Watt). The measurement data are shown in Table 1.

Table 1. Measurement data on the harmonic test

Source	THD_V (%)	THD_I (%)	Active Power (W)	Current (Amp)	Voltage (Volt)	Cos phi
Inverter	3,90	72,70	61	0,38	229	0,74
Load	3,10	13,50	138	0,62	229	0,98
Grid	2,40	58,40	65	0,36	227	0,80

Based on test data obtained the value of voltage in the inverter, grid and load are still within the specified standard limit of ± 10% and the value of THD for voltage is still below 5%.

4. Conclusions

The addition of controlled renewable energy sources such as small wind turbines can improve the performance of GTI to optimize power generated on the microgrid system, when electricity from power grid utility is interrupted or outages.

The variables measured in GTI performance testing on the microgrid system are voltage, current, and THD. The value of voltage generated by GTI to 2 conditions of test carried out is still within the allowable standard limit of ± 10% of nominal voltage (220 Volts). Similarly, the THD value of the result is still below the specified standard (5%).

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