Application of user-defined unilluminated PV simulator on a microgrid

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Abstract. To get a renewable energy source where the characteristics of the source can be easily adjusted according to user requirements is one of the keys to success when testing a microgrid system. This research proposes an unilluminated PV method with temperature and irradiance parameters that can be set using a programmable power supply that is remotely regulated from a PC. The energy generated from the unilluminated PV simulator is connected to a grid tie inverter to be integrated in a microgrid. The simulator performance test produces a maximum power of 102.87 VA when using PV 120 WP with an irradiance setting of 1000 W/m2.

1. Introduction

Microgrid represents the next generation electricity grid paradigm, introducing unique opportunities in the operation and planning of power systems. A microgrid can cover a variety of energy sources. Microgrid can consist of micro-electrical energy sources such as PV, Wind Turbine, fuel cells, micro-turbine, biomass, geothermal, steam or gas turbines and other energy sources [1]. The challenges faced by microgrid include the protection, control and monitoring systems [2, 3]. With the application of microgrid can increase the use of renewable energy resources, microgrid can have the ability to increase power quality, network efficiency, reliability and economics [4]. Microgrid can make it possible to reduce energy delivery costs, increase reliability on the load side, improve power quality for its customers, reduce power plant emissions, reduce investment costs in power transmission, and reduce vulnerability in large-scale power systems [5].

PV is one of the renewable energy sources which is currently developing rapidly. PV is also one of the most widely used energy sources in the application of microgrid. Where PV has unique characteristics compared to other sources of electrical energy. PV has a current curve against voltage (I-V), and power to voltage (P-V). Therefore, accurate and appropriate methods are needed to be able to study and simulate PV in order to develop it further. The characteristics of PV depend not only on its specifications, but also on irradiance and temperature. Therefore, PV is very dependent on weather conditions and also time, where the weather and time are something we cannot determine. Therefore, we need a simulator that can simulate PV according to its characteristics in accordance with specifications, irradiance and temperature but does not depend on weather conditions or time.

How to simulate PV has been discussed in various ways and with the results of the resulting simulator characteristics also vary. Ways to simulate PV by installing in parallel between PV and DC

Power Supply have been discussed [6, 7]. How to simulate PV using a buck converter has also been discussed [8-10]. PV simulators are applied using software and hardware, where in utilizing Simulink which is connected with a microcontroller to regulate the Adjustable power supply output current [11]. In this simulator the power generated from the adjustable power supply is equal to the maximum power from the irradiance value simulated on Simulink. However, the characteristics of the I-V and P-V curves have not been obtained that are in accordance with the characteristics of PV.

By utilizing a PV simulator with the Unilluminated PV method it is expected to be able to simulate the conditions of solar power plants on microgrid. Therefore, we need a PV simulator that can be remotely controlled using a PC for use in microgrid testing. By utilizing an unilluminated PV simulator that is expected to be able to simulate the condition of solar power plants on microgrids.

2. Method

2.1. The characteristic of PV simulator using unilluminated PV

The current PV simulators are very diverse with the same goal of producing the same characteristics as the real PV characteristics. In this paper, used unilluminated PV which is installed in parallel with a DC power supply.

PV panels are made of PV cells, and PV cells are usually simple p-n junction diodes that convert solar irradiance into electricity [7]. Where the equivalent circuit consists of diodes, series resistors (Rs), and parallel resistors (Rsh). The equivalent circuit of PV is illustrated in Figure 1. In this model, the Ipv output current, generated by PV cells, can be calculated by Kirchhoff's law (KCL) as in Equation (1), and the diode current (Id) is given in Equation (2). From Equation (1) and Equation (2) the Ipv output current is obtained as in Equation (3) from the single-diode PV cell model in Figure 1.

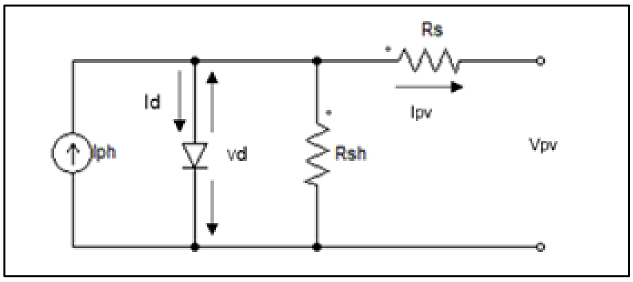

Figure 1. PV equivalent circuit.

In the equivalent circuit in Figure 1, Iph represents the photocell current in the PV cell. The Iph value is approximately the same as the value of the short circuit current (Isc) owned by PV. The current source Iph or similar to Isc is related to the amount of solar irradiance (W/m^2) and also the temperature as shown in Equation (4).

$$I_{pv} = I_{ph} - \frac{Vd}{NsRp} - I_d \tag{1}$$

$$I_d = I_o\left(e^{\frac{qVd}{nkTNs}} - 1\right) = I_o\left(e^{\frac{q(Vpv+IpvRs)}{nKTNs}} - 1\right) \tag{2}$$

$$I_{pv} = I_{ph} - I_o\left(e^{\frac{q(\frac{Vpv}{Ns}+IpvRs)}{nkT}} - 1\right) - \frac{\frac{Vpv}{Ns}+Ipv.Rs}{Rp} \tag{3}$$

$$I_{sc} = (I_{scn} + K_i(T-T_n))\frac{G}{Gn} \tag{4}$$

$$V_{oc} = V_{ocn} + K_v(T-T_n) \quad (5)$$

G is solar irradiance (W / m2), Gn is solar irradiance at Standard Test Condition (STC) (1000W/m^2). T is the cell operating temperature (in K), and Tn is the cell reference temperature at STC (25°C or 298K). Iscn is the short circuit current from the PV panel and Vocn is the open voltage of the PV panel at STC. It can be seen from Equation (5) that the open circuit voltage of PV is mainly affected by temperature changes. Ki and Kv are each produced with a short-circuit current (A/K) temperature coefficient and an open circuit voltage (V/K).

In Equation (4), the effect of PV cell temperature on Isc can be ignored because the Ki value is lower than Kv. This short circuit current is more influenced by the value of solar irradiance and it can be concluded that the value of the short circuit current (Isc) is a linear function of solar irradiance.

The purpose of solar panel emulation is to obtain the I-V curve and the P-V curve that follows the I-V and P-V curves that are owned by the actual PV panel. Here, the current source (Iph) in the PV panel equivalent circuit shown in Figure 1 is set to zero (Open Circuit). The current source is replaced by operating the DC Power Supply in Constant Current mode.

2.2. Experiment setup

Before conducting the overall test, some preparations and tests are carried out. Among them are testing the characteristics of a PV simulator using the unilluminated PV method and designing an application program using Microsoft Visual Studio. Testing the characteristics of PV simulators is carried out aiming to observe the characteristics result from the unilluminated PV method. While this program application is become the regulator of the irradiance and the temperature setting in the PV simulator.

Testing the characteristics of the PV simulator is carried out to test the suitability of the characteristics of the PV using the PV simulator method with the actual PV characteristics. The specifications of the PV used are shown in Table 1.

Table 1. PV specification.

Parameter	Value
Maximum Power (Pmax)	20Watt
Open Circuit Voltage (Voc)	21.6V
Short Circuit Current (Isc)	1.21A
Max Power Voltage (Vmp)	17.56V
Max Power Current (Imp)	1.14A
Number of Cell	36

There are 6 PVs used and installed in parallel. The configuration of the unilluminated PV test circuit is shown in Figure 2 where the PV is conditioned to have an irradiance of 0W/m2. While the current source from PV is replaced by Ics which is the current source generated by DC Power Supply. The irradiance value of the PV setting is changed based on the current setting on the DC Power Supply. Calculation of the conversion between the irradiance value with the current setting of the DC Power supply is calculated based on Equation (4). While the temperature setting is calculated based on Equation (5). Then to get the characteristics of the I-V curve and the P-V curve of PV, the RL is changed and measured the voltage and current at the load. The series of tests performed using the circuit shown in Figure 3.

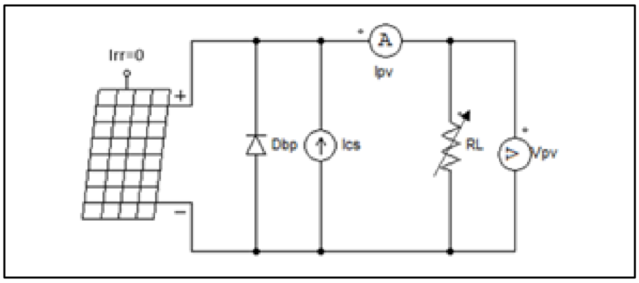

Figure 2. Unilluminated PV test circuit.

Application programs are created using Microsoft Visual Studio applications with the C# programming language. This application program will be used to adjust the irradiance value and temperature settings in the PV simulator through the regulation of the maximum voltage and current from the Programmable DC Power Supply. Where between the PC and Programmable DC Power Supply is connected with the RS232 interface. This application program can adjust the irradiance value and temperature settings on the PV simulator based on a dataset. So that the irradiance value and temperature of the simulator settings can change according to the applied dataset. The interface of the application program that has been created is shown in Figure 3.

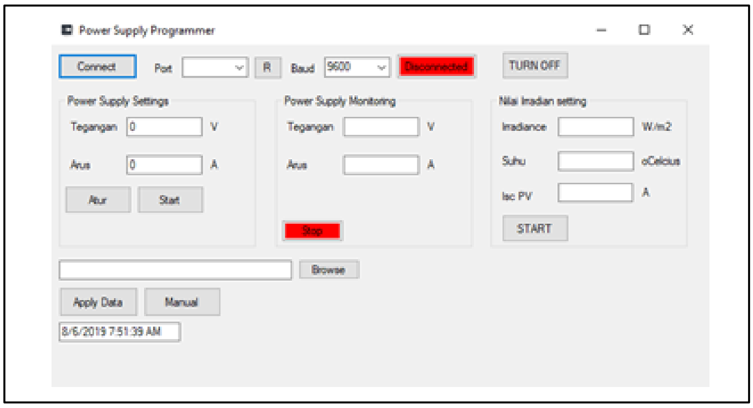

Figure 3. Power supply programmer interface.

Overall testing is carried out by utilizing the power generated from the PV simulator as an input to the grid tie inverter. Where the output parameters of this PV simulator are measured as voltage and current. Then the inverter output is connected to the grid and also the load. The test block diagram is shown in Figure 4. Then electrical parameters are measured at the output side of the inverter, on the grid side of the PLN to the load, and on the load side using a Power Quality analyser. While the PV simulator is set to the irradiance and the temperature value via PC using the application program that has been created.

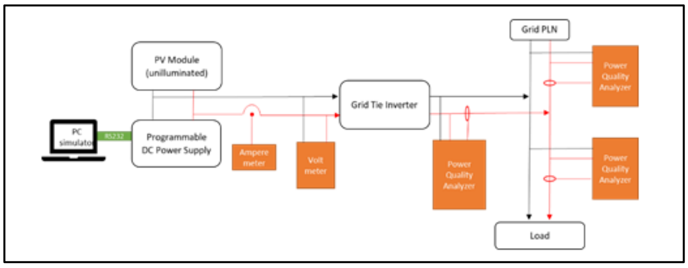

Figure 4. Experiment block diagram.

3. Experiment results and discussion

From the PV simulator testing that has been carried out using the circuit in Figure 4, I-V and P-V curves are obtained from the results of these tests. Where testing is done with several variations of irradiance. Among the variations of irradiance used are 200W/m2, 400W/m2, 600W/m2, 800W/m2, and 1000W/m2. From the test results, I-V curve is shown in Figure 5 and the P-V curve is shown in Figure 6.

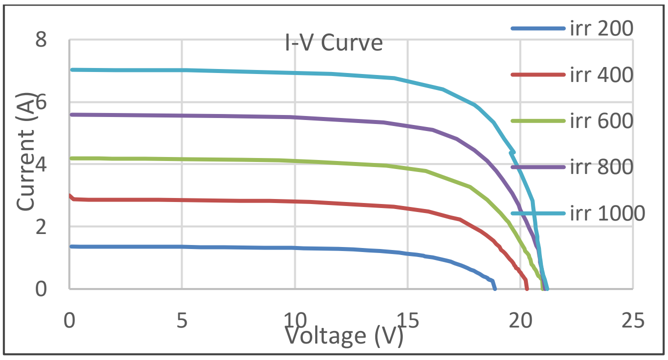

Figure 5. I-V Curve of PV simulator.

From the shape of the I-V curve shown in Figure 5, it can be seen that the shape of the curve result is close to the shape of the I-V curve of the actual PV. As for the curve shape defects, it can be caused by inaccurate and precision data collection and load resistor settings. So that the resulting I-V curve is not perfect.

In addition to the I-V curve shown in Figure 5, there is also a P-V curve shown in Figure 6, which shows the relationship between power and voltage generated by the PV simulator. From the characteristics of the P-V curve in Figure 6, the maximum power value that can be generated from the PV simulator using the PV specifications mentioned in Table 1 with 6 parallel installed is 106.27W at irradiance on 1000W/m2.

Then, from the overall testing performed in accordance with the block diagram in Figure 4, test data obtained at the inverter output parameter, the load parameter and the grid parameter. Whereas if seen in Figure 7. Where Ppem is the active power of the inverter output, Qpem is the reactive power of the inverter output, and Spem is the apparent power of the inverter output. Can be seen here, the inverter output power is linear to the increase the irradiance setting. An increase in the value of active power and apparent power tends to be linear but the value of reactive power is not linear to the active and apparent power. Maximum power that can be produced is 102.87 VA.

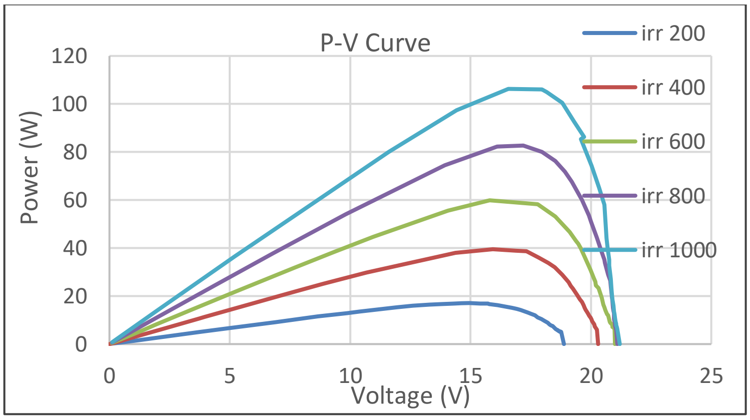

Figure 6. P-V Curve of PV simulator.

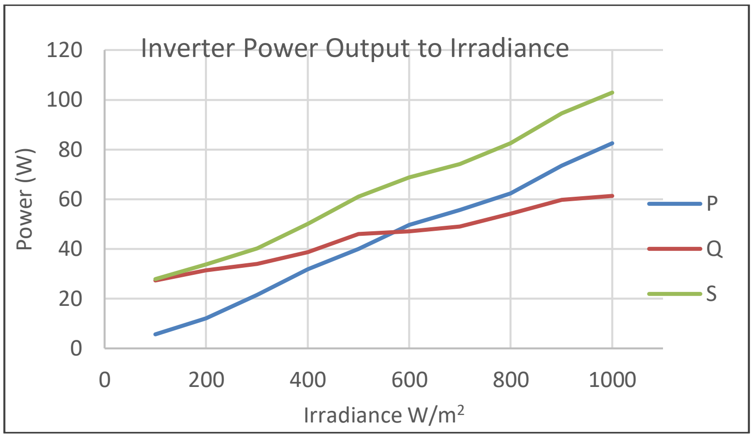

Figure 7. Inverter output power to irradiance on 100W load.

Figure 8 shows the effect of the load and the irradiance setting on the current value supplied from the grid to the load. From this graph, it can be seen that the greater the value of the irradiance setting in the PV simulator, the less current is supplied from the grid to the load. This represents the smaller the power consumed by the load coming from the grid. This is due to the increase in power supplied from the inverter grid. Even though if the load is increased, the current flowing from the grid to the load is still higher than the current flowing from the grid to the load when the load is smaller.

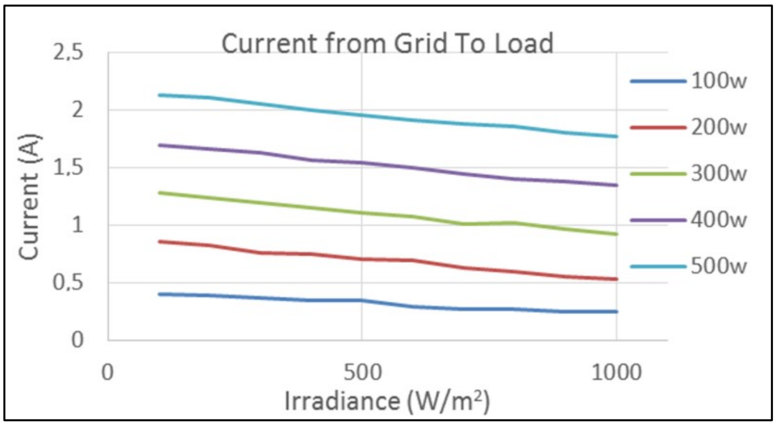

Figure 8. Current value from grid to the load.

Figure 9 shows the comparison between the inverter output current (Iinv), the current flow from the grid to the load (Igrid) and the current entering the load (Iload). From this we can see that the current flowing into the load is the total between the current from the inverter and the current from the grid. Meanwhile, even during zero load conditions, the inverter still produces current that is flow directly to the grid. Likewise, Figure 10 shows the ratio of active power between the output of the inverter (Pinv), the power delivered by the grid to the load (Pgrid), and the power consumed by the load (Pload). Where here shows that the power flowed by the grid only reduces the power supply that comes from the inverter. And if the load condition is less than the inverter output power, the remaining inverter output power will be flowed to the grid.

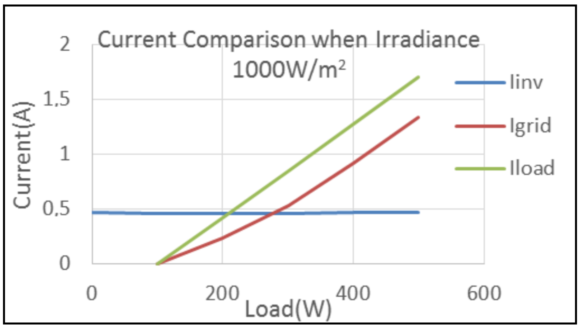

Figure 9. Current comparison between inverter output, grid, and load.

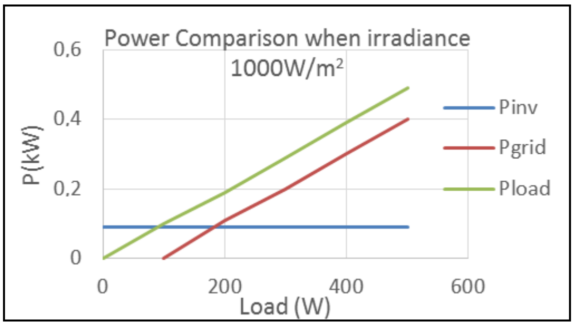

Figure 10. Power comparison between inverter output, grid, and load.

The harmonic value graph is shown in Figure 11. If we look at the harmonic value of the current generated by the inverter output, it has a fairly large value of harmonics, with the largest THDi of 68.4% at the time of irradiance from PV of 100W/m2. Whereas if we average the value of harmonics produced in testing, THDi produced has an average of 45.13%. The THDi value continues to decrease when the irradiance value is raised. In Figure 11 which is a harmonic current graph generated from the inverter output can be seen that the greater the irradiance value in the PV, the THDi value produced decreases. While fundamental harmonics (first harmonics) are increasing. Where when the irradiance value is increased, the value of the power generated by the PV simulator is greater.

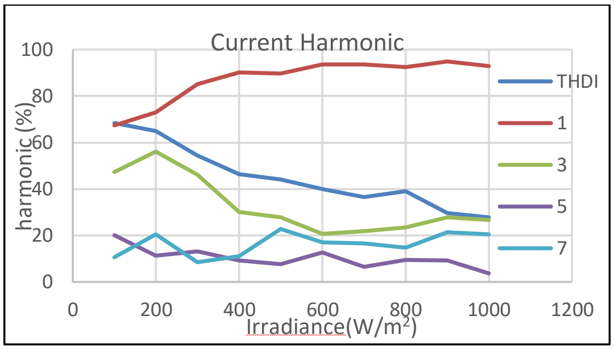

Figure 11. Current harmonic of inverter output.

Table 2 is the data table of the voltage harmonics value of the inverter output when the Irradiance value changes. Harmonic produced by this inverter is very small, with an average THDv of 1.55%. The value of voltage harmonics tends to remain when the Irradiance value changes. From this harmonic value data, it can be seen that the value of the harmonic current generated by the inverter is quite large. While the voltage harmonics are quite small. The value of voltage harmonics can be small because the inverter output voltage follows the reference voltage from the grid. However, the resulting current has considerable harmonics because the resulting wave current is not yet pure sinusoidal.

Table 2. Voltage harmonic of inverter output

Irradiance (W/m^2)	THDv (%)	Harmonic orde			
		1 (%)	3 (%)	5 (%)	7 (%)
100	1.5	100	0.5	1.4	0.3
200	1.5	100	0.1	1.3	0.3
300	1.6	100	0.2	1.4	0.3
400	1.6	100	0.2	1.3	0.3
500	1.5	100	0.2	1.4	0.3
600	1.5	100	0.2	1.3	0.2
700	1.6	100	0.1	1.4	0.3
800	1.5	100	0.2	1.3	0.3
900	1.6	100	0.2	1.4	0.3
1000	1.6	100	0.2	1.3	0.3

4. Conclusions
From the results of experiments on the proposed system, the results show that by using a PV simulator with the unilluminated PV method, it can produce the same curve characteristics as the actual I-V curve and the P-V curve. While the PV power used is 120 WP, the power output of grid tie inverter is 102.87 VA. Beside that after testing connected to the grid, the results obtained that the power generated from the PV simulator using the unilluminated PV method can supply power to the load or to the grid. So it can be concluded that by using the unilluminated PV method, it can be used to simulate a microgrid system.

5. References
[1] Venkatraman R and Khaitan S K 2015 *IEEE Power & Energy Society General Meeting* 1–5
[2] Sortomme E, Venkata S S and Mitra J 2010 *IEEE Transactions on Power Delivery* **25** 2789–2796
[3] Palacios-Garcia E J, Guan Y, Savaghebi M, Vasquez J C, Guerrero J M, Moreno-Munoz A and Ipsen B S 2015 *IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society* 89–94
[4] Abdar H M, Chakraverty A, Moore D H, Murray J M and Loparo K A 2012 *IEEE Energytech* 1–6
[5] Khodaei A and Shahidehpour M 2011 *IEEE PES Innovative Smart Grid Technologies (ISGT)* 1–3
[6] Zhou Z and Macaulay J 2017 *Energies* **10** 2075
[7] Unlu M and Camur S 2017 *2017 9th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)* 1–4
[8] Shinde U K, Kadwane S G, Gawande S P and Keshri R 2016 *IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)* 1–5
[9] Seo Y-T, Park J-Y and Choi S-J 2016 *2016 IEEE Energy Conversion Congress and Exposition (ECCE)* 1–5
[10] Rachid A, Kerrour F, Chenni R and Djeghloud H 2016 *IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)* 1–6
[11] Soetedjo A, Nakhoda Y I, Lomi A and Hendroyono G E 2015 *International Conference on Automation, Cognitive Science, Optics, Micro Electro-Mechanical System, and Information Technology (ICACOMIT)* 96–100

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