Analysis of Maximum Power Point Tracking (MPPT)
Performance in DC/AC Inverter of On-Grid Solar Power Plant

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ABSTRACT

Maximum Power Point Tracking (MPPT) is a technology used in PV solar inverters to optimize output power under ideal sunlight conditions. It can reach the value of the Maximum Power Point (MPP) of the PV system. In addition, this MPPT is used to adjust the power needed by the load on the grid. The presence of MPPT then if the load requires more power due to less PV output, it will regulate the taking of power from the grid to the load so that as a back-up of the load is the grid. The method used is Perturb and Observe for MPPT. Results using this method give rise to oscillations in the output graph but are not too large. On the other hand, MPPT helps divide the output power from the inverter, load, and grid. The division is carried out by MPPT in order to meet the needs of the load used so that the grid becomes back-up if the PV output system does not meet the desired power of the load

Keywords: MPPT, Solar Power Plant System,On Grid, Perturb and Observe Method.

1. INTRODUCTION

The performance of PLTS depends on solar irradiation from an area where the ideal solar irradiation occurs within 4-5 hours so that the output power produced is different causing the quality of the power produced to be different, so technology is needed to control the power output so that there is no change in power change significantly concerning MPPT. In addition, the demand for different loads with intermittent PLTS characteristics causes the power quality to be highly considered to meet the desired load.

## 2. BACKGROUND

2.1 Characteristic of PV Module

The output produced by the PV module is in the form of currents and voltages. The PV module produces an I-V curve (current-voltage) and a P-V curve (power and voltage). Every PV module has this characteristic.

$$I = I_{ph} - I_s \left(\exp \frac{q(V+IR_s)}{NKT} - 1 \right) - \frac{q(V+IR_s)}{R_{sh}} \qquad (1)$$

Where I_{ph} is the short circuit current, I_s is the reverse saturation current of the diode, q is the electron charge ($1,602 \times 10^{-19}$ C), V is the diode voltage, k is the Boltzman constant ($1,381 \times 10^{-23}$ J/K), T is the junction temperature, N is the ideal factor of the diode, R_s is the series ground of the diode, and R_{sh} is the shunt resistance of the diode.

The equivalent circuit image of PV module is shown as this:
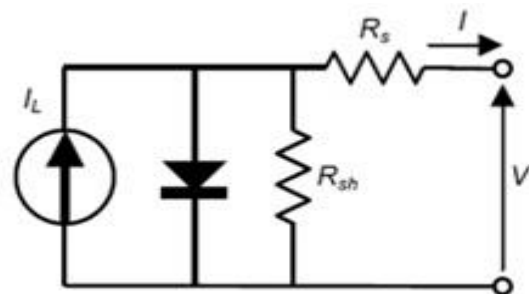
**Figure 1.** The PV Module Equivalent Circuit

In the module PV equivalent circuit, the V-I and P-V characteristics are obtained so that the PV model used is SunPower SPR-230-E WTH-D with a maximum power of 230.4 Wp. This research combines 21 series PV modules and 6 modules installed in parallel on 1 array. The data are obtained from the following formula with a total power is 30kWp and a maximum voltage (Vmpp) is 810 V.

$$V_{mppM} = Ns \, V_{mpp} \qquad (2)$$

Where V_{mppM} is the maximum voltage at the peak to peak of the PV module circuit, Ns is the series circuit, V_{mppM} is the peak voltage value.

$$I_{mppM} = N_p I_{mpp} \qquad (3)$$

Where I_{mppM} is the maximum current generated by a PV system, N_p is a total of parallel circuit, and I_{mpp} is the maximum current generated by one to PV module. Thus, the series of PV modules can produce the following V-I and P-V characteristic curves:
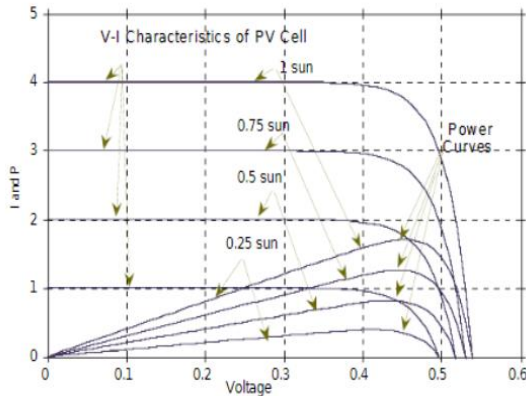
Figure 2 Characteristics of Cells Photovoltaic Against Irradiation Change

This curve shows that the relationship between the voltage and the current of the solar irradiation intensity is different. The red graph shows the highest solar irradiation as 1000W/m², producing a Voc value is 1008V, and an Isc is 38.5A. If the solar irradiation is different, the current and voltage values are different.
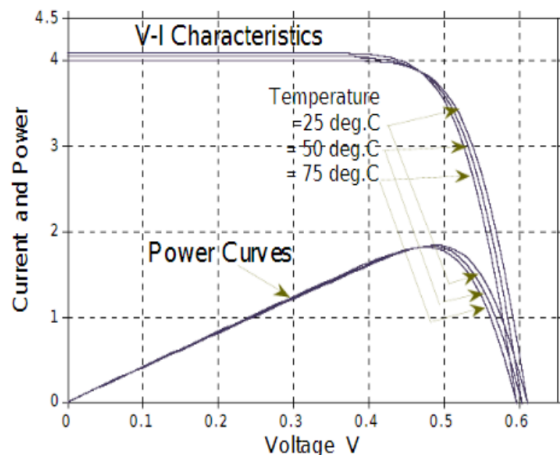
Figure 3 Characteristics of Photovoltaic Cells Against Temperature Changes

2.2 Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking (MPPT) is an electronic system that exists in a PV system so that the system can produce maximum power according to the MPP output on PV. MPPT is not a mechanical tracking system that is used to change the position of the module to the sun's position to get maximum energy. The solar irradiation factor and the module temperature greatly determine the amount of electrical energy produced by the PV system. These two parameters cause the PV cell output power characteristic curve to be non-linear.

By understanding the different levels of solar irradiation, as well as different loads, on the side of the PV module, the voltage is set to be at Vmpp, and does not depend on any load conditions: household electrical loads, batteries, or grids. Therefore the importance of the MPPT circuit lies in the inverter for grid connected systems and lies in the charge controller for off-grid systems. Conditions that affect the voltage on a solar panel include:

1. Solar irradiation shining on the panel.

2. The load caused by solar panels is electricity.

3. Panel temperature

The quality of the MPPT system certainly needs to be measured so that the performance of the MPPT system can be known. Measuring the quality of the MPPT system can be useful in the MPPT system development process. There are three parameters obtained to determine the quality of the MPPT system

a. *Dynamic Parameters*

MPPT system to find the maximum power point when there is a change in environmental conditions (cell temperature and changing solar irradiation). The faster the time required, the better the MPPT system performance.

b. *Static Parameters*

It is the change in the value of the output power when the power point maximum is has been reaching and there is no change in environmental conditions. The smaller the changes that occur, the better the MPPT algorithm

c. *Parameters of Actual Power Ratio and Ideal power*

It is the ratio between the actual output power in a period of time with the maximum power measured in the working conditions of the solar cell. The value of this parameter will range from 0 to 100%.

2.3 Inverter

Inverters can be classified as single-stage and two-stage configurations. The two-stage inverter consists of two-tiered stages. The first stage is a boost dc-dc converter, and the second is an H-bridge inverter. The single-stage inverter must increase the input voltage and convert it to ac voltage.
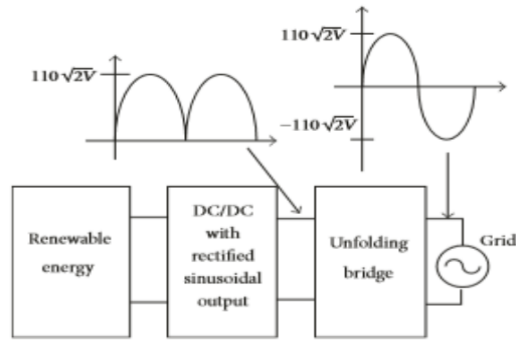
Figure 4 Single-Stage control

The development of network-connected photovoltaic power supply systems is divided into two categories, including centralized converter type and microcontroller converter type. The former uses multiple photovoltaic modules for string and/or parallel combinations to centralize utilities such a frame usually adopts a stable DC bus design and uses a large capacity electrolytic capacitor to obtain a stable DC voltage. The advantage is more flexible than the converter design, but with poorer operating performance for each module while the latter, it usually uses one or several photovoltaic modules for utilities, and the DC bus and small volume capacitor design is adopted. Thus, the photovoltaic module can have better performance. However, each photovoltaic module team requires a special converter to transfer energy to electricity.

3. RESEARCH METHODS

3.1 Data Analysis Techniques

The simulation consists of several simulation blocks, namely the PV system block, the single-stage inverter system block, and the MPPT control algorithm block.

The following data analysis techniques use simulation

1. PV module
   The PV module uses the SunPower SPR-230-E WTH-D type with a maximum power of 230.4 Watt. This PV system uses 1 array consisting of 6 strings and 1 string consisting of 21 modules.

2. Inverters
   The inverters used in MATLAB/SIMULINK include: specifications as follows

Table 1. Inverter specifications

V_{out}	380 V
Frequency	50 Hz
Switching Frequency	50 kHz
L filter	10.21 mH
R filter	0.25 Ohm

3. MPPT

The MPPT algorithm used is Perturb and Observe. The algorithm usually uses changes to the duty cycle but this time changes are made to the reference current from the input to the PV.

3.2 Simulation Specification Data on MATLAB/ SIMULINK

In this section, component specification data and calculations are needed in making MATLAB/ SIMULINK simulations:

3.2.1 PV Module

The PV module used in this research is SunPower SPR-230-E WTH-D with a maximum power of 30kWp. In this PV system, 1 array consists of 6 strings, and 1 string consists of 21 modules. The SunPower module specifications are as follows:

Table 1. SunPower SPR-230-E WTH-D Module Specification

Parameter	Value
Tested at	1000 W/m²
Surface Temperature	25 ºC
Pmax	230.04 W
Vmpp	40.5 V
Impp	5.68 A
Voc	48.2 V
Isc	6.05 A
Temp coefficient of Voc (%/deg.C)	-0.31 ºC
Temp coefficient of Isc (%/deg.C)	0.016 ºC
Cells per module (Ncell)	72
Rsh (ohms)	396.8073
Rs (ohms)	0.34627
Tolerance *error*	± 5%

The solar radiation data is obtained for 24 hours which can represent monthly solar irradiation data. This test used solar irradiation, as shown in the following graph:
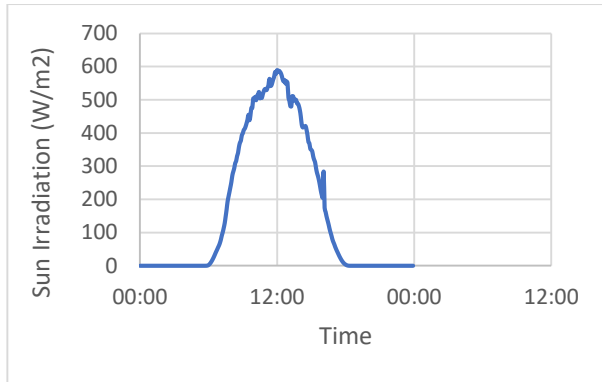
Figure 5. Solar Irradiation for 24 hours

In the graph there is an average irradiation data against time for 24 hours, then the irradiation data is taken 12 hours where the sun starts to shine and is applied to SIMULINK with a time span of 20 seconds so that it will get some output that moves for 20 seconds.

3.2.2 Inverter

The inverter uses DC voltage inverter on PV that can be directly converted into AC voltage. This inverter has an output voltage of 380V, which if there is excess production power it can be channeled to the grid. This inverter is transformless and uses IGBT which gets a pulse signal from the MPPT. The filter calculations for the inverter are as follows:

$$Lf = \frac{0.1\ U^2}{2\ \pi\ f\ Pmin}$$
$$= \frac{0.1\ 380^2}{2\ \pi\ 50Hz\ 4.5\ kW}$$
$$= 10.21421057\ mH$$
$$RLf = Lf * 25$$
$$= 10.21421057\ mH * 25$$
$$= 0.2554\ Ohm$$

3.2.3 Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking (MPPT) used is the Perturb and Observe algorithm. This MPPT gets input from the value of PV voltage, PV current, and delta duty where the value of deltaD has been determined because of the current regulated setting on this MPPT to produce a reference current as a reference for the inverter output current. This MPPT is designed to find the Maximum Power Point (MPP) value at the PV output and adjust the load changes.

3.2.4 Three Phase V-I measurement

Three Phase V-I measurement measures the current and voltage at the output of the inverter, load, and grid.

3.2.5 Three Phase Series RLC Load

Three Phase Series RLC Load functions for loads that vary in power.

3.2.6 Grid

The grid serves to channel excess PV output power or take power from the grid when there is a lack of power on the load.

3.2.7 Signal Builder

The signal builder functions to enter solar irradiation data in real time.

3.3 Testing and Analysis of Simulation Results

Testing for the system uses SIMULINK on MATLAB with the arrangement on a PV system that uses 1 array.
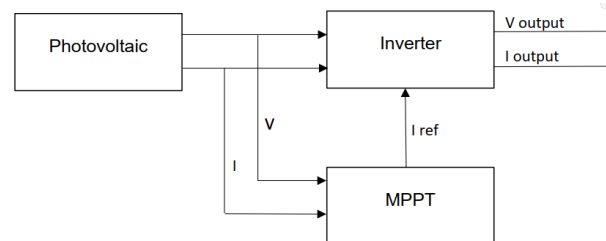
Figure 6. PV Controller Block Diagram

Figure 6. is a control block diagram performed on this PV system simulation. The results of the MPPT algorithm control will be read through the output voltage and current from the inverter. After that, by comparing the overall results of the MPPT control system testing, an analysis of the advantages and disadvantages of the perturb and observe algorithm used in this system will be written.
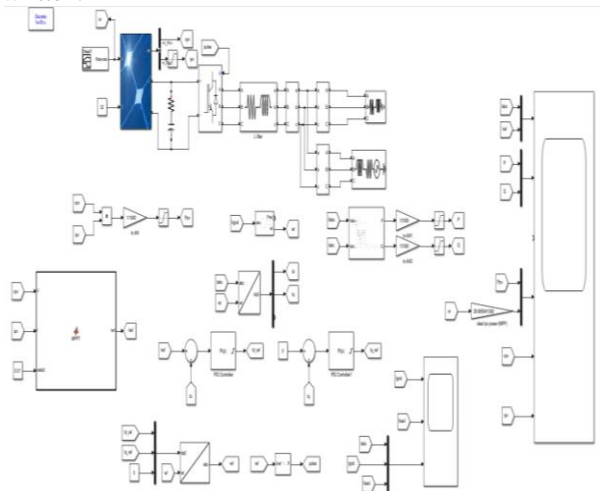
Figure 7. Block Diagram of Matlab / Simulink Simulation on on-grid PLTS system testing on MPPT Inverter

This is engineering of making algorithms for MPPT with changes in solar power plant radiation that vary and according to different load demands, as follows :
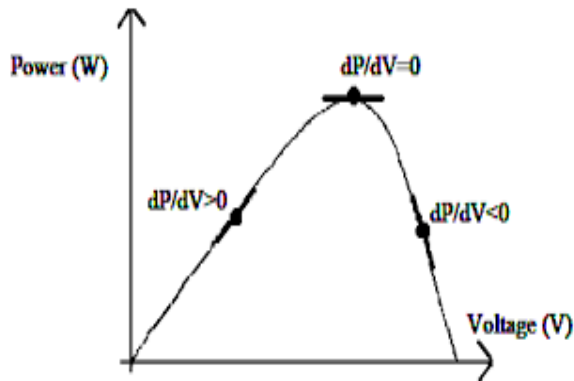

Figure. 8. Perturb and Observe Curve

In this curve there are 3 conditions where the left-peak dP / dV> 0, the peak of the curve dP / dV = 0, and dP / dV <0. These conditions indicate the use of perturb and observe.

When perturb works, it functions to increase or decrease the Iref, every change in Iref causes a change in its power. If the present power is greater than the previous power, the Iref will be raised again. If the present power is less than the previous power, the Iref will be reduced.

Therefore this method requires the input power output value to determine the power that falls in the load. The following is a flowchart of perturb and observe method.
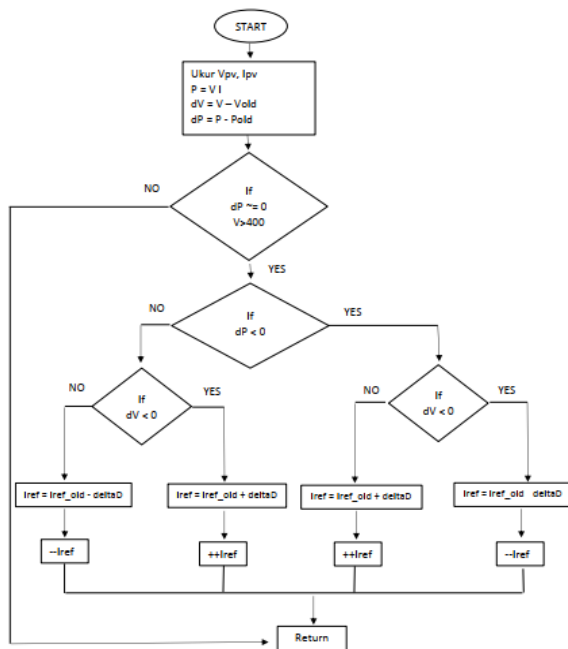
Figure 9. Perturb and Observe Flowchart

3.3.1 Output PV

The PV output includes the output voltage and current that varies according to changes in solar irradiation. The first graph produced is the value of the PV output power that reaches maximum power point tracking which is shown by the following graph :
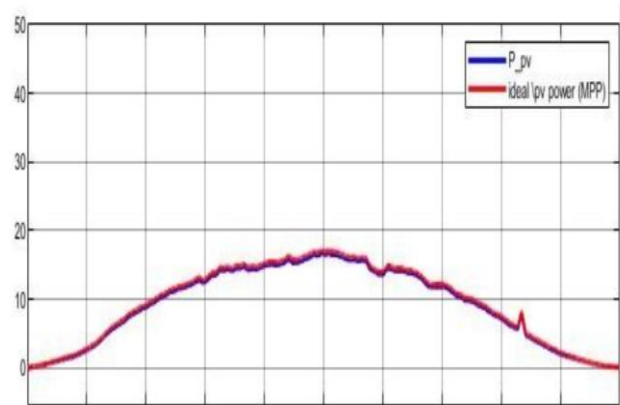
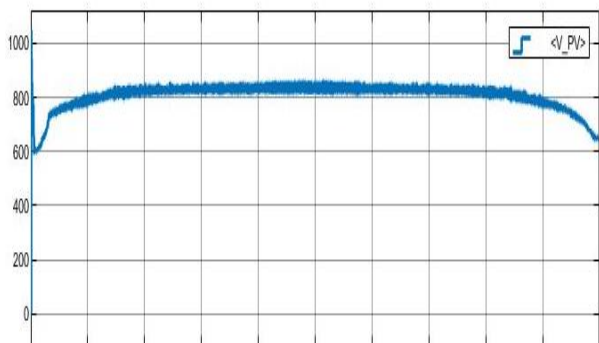**Figure 10.** Graph of PV Power Output

Figure 11. Output curent PV

Figure 11 shows a graph of the PV voltage output where it can be seen that the voltage is very stable due to the influence of MPPT which is very closely related to Figure 11.
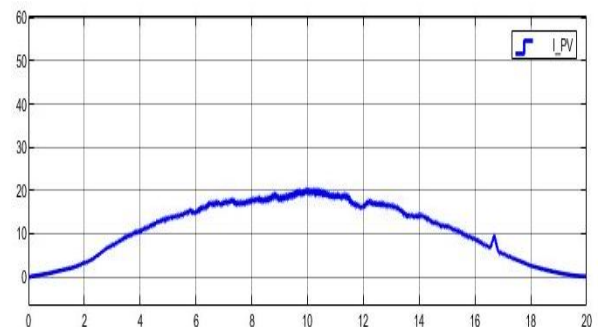

Figure 12. Output current on PV

Figure 12. shows the current output in the PV where the current can be shaped like that following the existing solar irradiation.

3.3.2 Daya Output Inverter

Figure 13 shows the active and reactive power results that will be supplied to the load or grid. The graph shows the relationship between power and time for 20 seconds where the power is multiplied by 1000 watt/m^2.
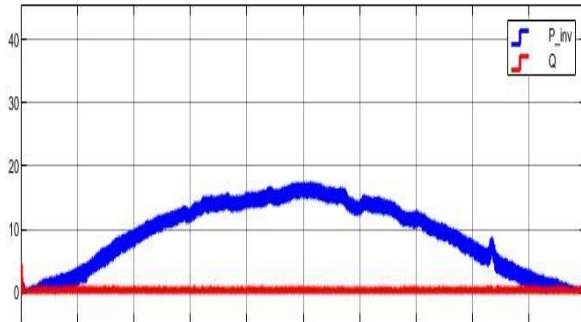
Figure 13. Power Active and Reactive of the Inverter

3.3.3 MPPT Performance Efficiency

MPPT performance is needed to adjust the output power of the inverter to show the MPPT value and adjust the power to the grid. This MPPT performance uses the Perturb and Observe method so that the MPPT performance efficiency is obtained as follows:

The maximum output P value shows 17.44 kW, while the P$_{maximum}$ at PV is 17.86 kW.

$$\eta\ MPPT = \frac{Pout\ (tracker)}{Pmax\ (rated)} = \frac{17,44kW}{17,86kW} * 100\% = 97,64\%$$

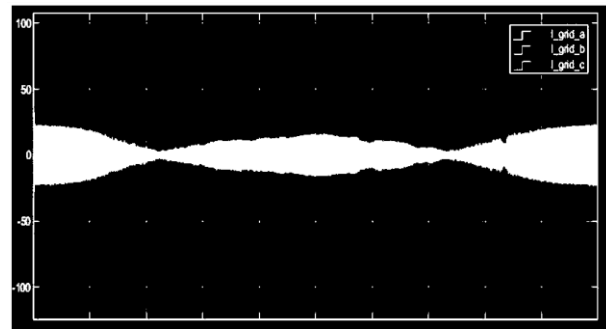so, MPPT performance efficiency is 97.64%

3.4 Discussion Result

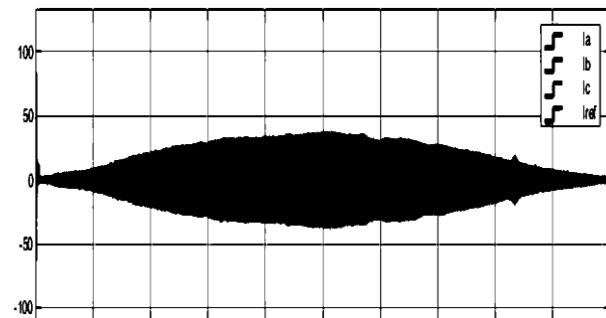### 3.4.1 PV Output Power > Load Power

At the with the following data P output inverter = 17.47 kWp; Q output inverter = 4,496 kVAR ; P load = 12 kW; Q load = 2kVAR. So that the graph of the simulation results can be shown as follows:
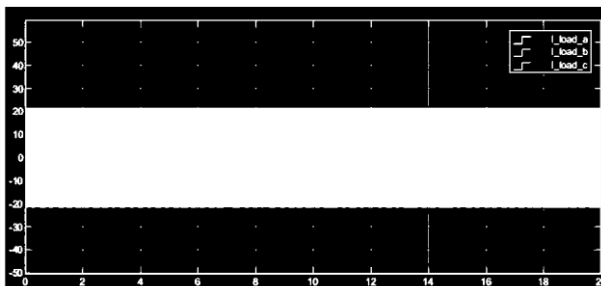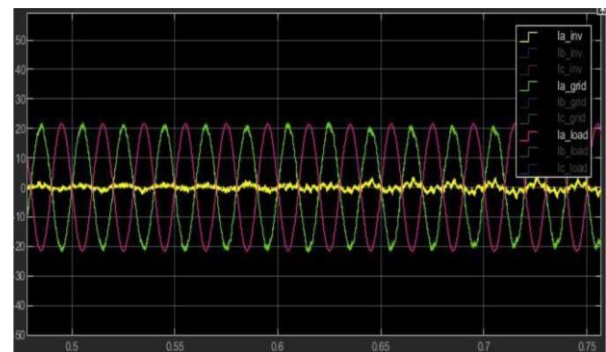

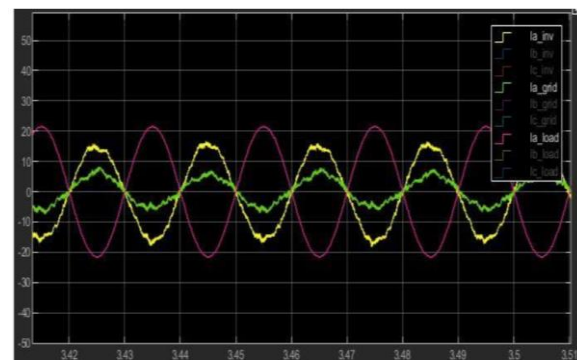**Figure 14.** The current Graph at Load where PV Output Power > Load Power

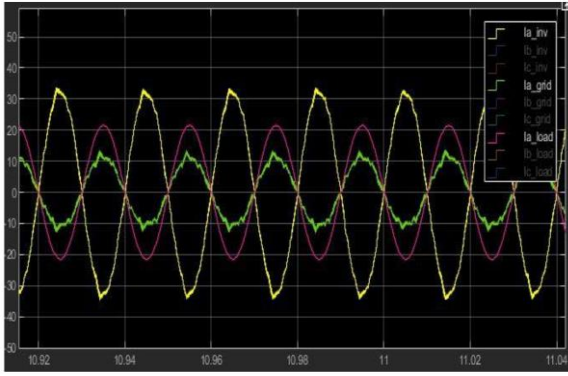**Figure 15.** The current graph on grid PV Output Power > Load Power

Figure 16. The current on Inverter PV Output Power > Load Power

Figure 17. The current graph on Inverter, Load, and Grid During Irradiation Low Sun PV Output Power > Load Power

Figure 18. The current graph on inverter, load, and grid during Irradiation the sun is starting to rise PV Output Power > Load Power
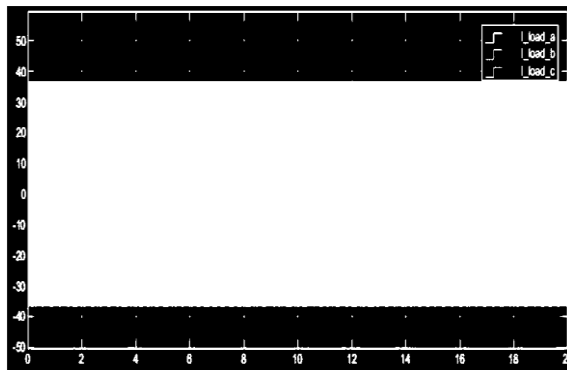
Figure 19. The current graph of Inverter, load and grid at peak Irradiation PV Output Power > Load Power
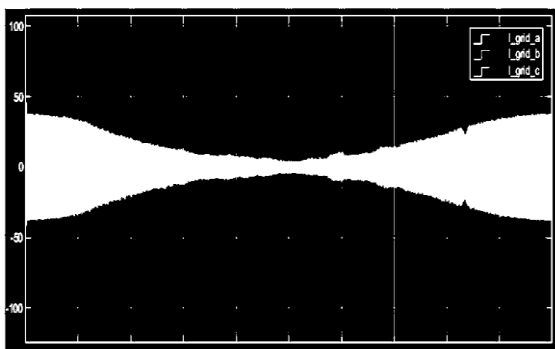
The setting is governed by the work of the MPPT with a power percentage of 39.55%

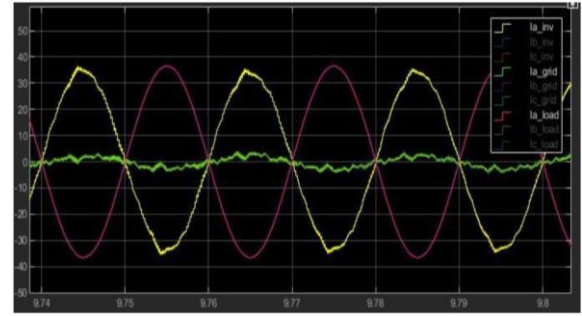### 3.4.2 PV Output Power = Load Power

At the inverter output power equals to the load power with the following data P output inverter = 17.47 kW; Q output inverter = 4,496 kVAR; P load = 17.47 kW; Q load = 4.496kVAR.
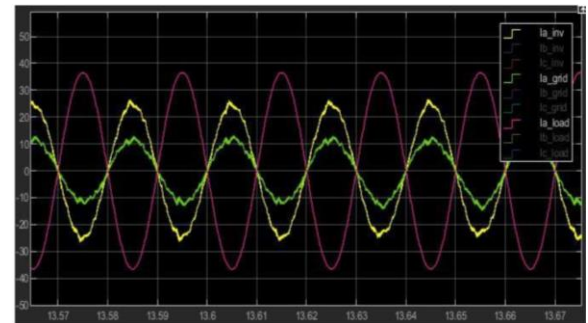

Figure 20. The current graph at Load where PV Output Power = Load Power

Figure 21. The current on Inverter PV Output Power = Load Power

Figure 22. Current graph on Inverter, Load, and Grid During Irradiation Low Sun Output Power = Load Power

Figure 23. The current graph of Inverter, load and grid at peak Irradiation Output Power = Load Power
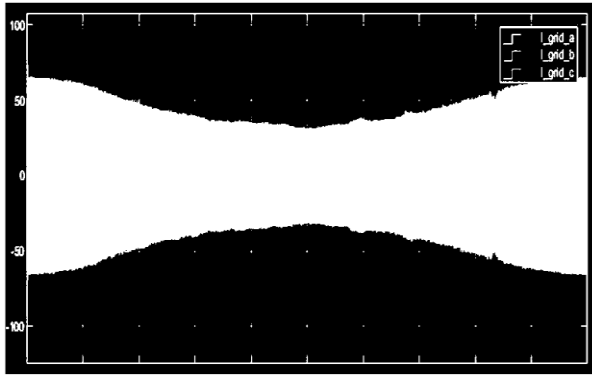
The setting is governed by the work of the MPPT with a power percentage of 5.88%
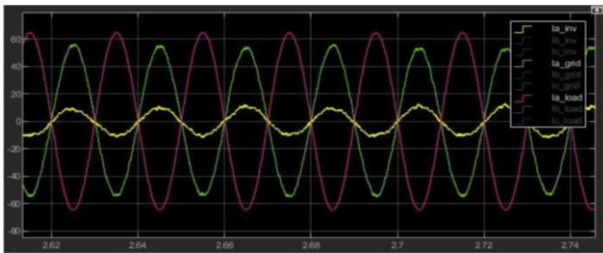
3.4.3 Inverter output power < load power

At the inverter output power is equal to the load power with the following data P output inverter = 17.47 kW; Q output inverter = 4,496 kVAR; P load = 30 kW; Q load = 5kVAR. So that the graph of the simulation results can be shown as follows:
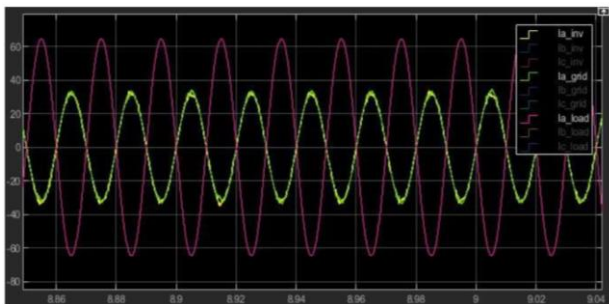

Figure 24. The current Graph at Load where PV Output Power < Load Power

Figure 25. The current graph on grid PV output power < load power

Figure 26. The current graph on Inverter, Load, and Grid During Irradiation Low Sun PV Output Power < Load Power

Figure 27. The current graph of Inverter, load and grid at peak Irradiation PV Output Power < Load Power

The setting is governed by the work of the MPPT with a power percentage of 44.37%.

4. CONCLUSION

In the discussion of MPPT performance on on-grid PLTS, conclusions can be drawn as follows :

1. MPPT will adjust the output power on the PV so that it can reach the MPPT value on the PV where the MPPT efficiency is 97.53%.

2. Based on this efficiency, with variations in load, the percentage of power from and to the grid as a back-up from this solar power plant system is as follows, when the PV power is greater than the load, the power to the grid is 39.55%, the PV power is equal to the load power, so it should not require back-up from the grid, but in this simulation, there is a residual so that it automatic requires 5.88% power

from the grid, and when the PV power is less than the load it will consume power from the grid by 44.37%.

REFERENCES

[1] M. Ashiquzzaman, N. Afroze, M. Jabed Hossain, U. Zobayer, and M. Mottaleb Hossain, "Cost Effective Solar Charge Controller Using Microcontroller," *Can. J. Electr. Electron. Eng.*, vol. 2, no. 12, Dec. 2011

[2] T. Shimizu, K. Wada and N. Nakamura, "A flyback-type single phase utility interactive inverter with low-frequency ripple current regulation on the DC input for an AC photovoltaic module system", *Proc. IEEE PESC'02*, vol. 3, pp. 1483-1488, 2002-Jun.-23.

[3] Heri Suyanto,*" Technical Analysis Feasibily Study on Smart Microgrid System in Sekolah Tinggi Teknik PLN",* ICENIS 2017, Publisher : E3S Web of Conferences 31, 02011 (2018), doi : https//doi.org/10.1051/e3sconf/20183102011

[4] Budi, M.P. (2020). Design and Build a Solar Power Plant (Plts) on Grid at Ecopark Ancol. TESLA: Journal of Electrical Engineering, 22(1), 23. https://doi.org/10.24912/tesla.v22i1.7333

[5] Sunitha, Prem Kurnar, Nidhi Priya, Jatin Verma. *Design of High Efficient MPPT Solar Inverter*. 10.1051/matecconf/201710814004.

[6] Kawamura, Harada, Ishihara, Todoka, Oshiro, Nakamura, Imataki. 2019. *Analysis of MPPT Characteristic In Photovoltaic Power System*. S0927- 0248(97)00036-6.

[7] Zhang, Q.; Hu, C.; Chen, L.; Amirahmadi, A.; Kutkut, N.; Batarseh, I. (2014). "A Center Point Iteration MPPT Method With Application on the Frequency Modulated LLC Microinverter". *IEEE Transactions on Power Electronics*. 29 (3) : 1262–1274. Bibcode : 2014 ITPE.29.1262Z. doi : 10.1109 /tpel. 2013. 2262806

[8] A. K. Abdelsalam, A. M. Massoud, S. Ahmed and P. N. Enjeti, "High-performance adaptive perturb and observe MPPT technique for photovoltaic-based microgrids", *IEEE Trans. Power Electron.*, vol. 26, no. 4, pp. 1010-1021, Apr. 2011.

[9] L. Piegari and R. Rizzo, "Adaptive perturb and observe algorithm for photovoltaic maximum power point tracking", *IET Renew. Power Gener.*, vol. 4, no. 4, pp. 317-328, Jul. 2010.

[10] Heri Suyanto, *"Study Trends and Challenges of The Development of Microgrids",* : QiR 15 th Interntional Conference, IEEE *Xplore* Digital Library   Date 07 Desember 2017, doi : 10.1109/QIR.2017.8168516

[11] A. Karavadi and R. S. Balog, "Novel non-flat photovoltaic module geometries and implications to power conversion", *Proc. Energy Convers. Congr. Expo.*, pp. 7-13, 2011

[12] Kumara, I., Setiawan, I., & Electrical Engineering Studies, P. (2020). Grid Tie Inverter For Rooftop Plts In Indonesia: A Review Of Standards And Compliance Inverters In The Domestic Market. 7(2), 62.