Volume 10. No 1, January 2023
e-ISSN: 2527-9572 / ISSN: 2354-8924

On-Grid PV Performance in Various Irradiation Conditions, Types, and Load Power

Alamsyah Achmad
Teknik Listrik, Politeknik Negeri Ujung Pandang
Jl. Perintis Kemerdekaan KM.10 Tamalanrea, Makassar 90245,
+62(411)585365
alamsyahachmad@poliupg.ac.id

***Usman**
Teknik Listrik, Politeknik Negeri Ujung Pandang
Jl. Perintis Kemerdekaan KM.10 Tamalanrea, Makassar 90245,
+62(411)585365
usman.ose@poliupg.ac.id

Ahmad Rizal Sultan
Teknik Listrik, Politeknik Negeri Ujung Pandang
Jl. Perintis Kemerdekaan KM.10 Tamalanrea, Makassar 90245,
+62(411)585365
rizal.sultan@poliupg.ac.id

Ahmad Rosyid Idris
Teknik Listrik, Politeknik Negeri Ujung Pandang
Jl. Perintis Kemerdekaan KM.10 Tamalanrea, Makassar 90245,
+62(411)585365
ahmadrosyid@poliupg.ac.id

Andarini Asri
Teknik Listrik, Politeknik Negeri Ujung Pandang
Jl. Perintis Kemerdekaan KM.10 Tamalanrea, Makassar 90245,
+62(411)585365
andariniasri@poliupg.ac.id

Fahmi Ryadin
PT. PLN Nusantara Power
Jl. Ketintang Baru No. 11, Surabaya, Indonesia
+62(318)283180
fyrst@ptpjb.com

Abstract – **There are several types of photovoltaic system configurations, one of which is the on-grid PV system. This system is simple compared to other systems. Because there are two different energy sources that can supply the load either together or separately, an analysis of how the irradiation affects the electrical parameters on the load side or the grid itself is required. The goal of this research is to examine the performance of on-grid PV under various irradiation variation, type, and load power to power factor, grid frequency, and load conditions. To measure the performance of on-grid PV, parameter calculations are carried out in the form of PV efficiency, final yield, reference yield, and performance ratio, and the results of measurements of power factor, grid frequency, and load are observed due to variations in irradiation, type, and load power. The results show that the performance of on-grid PV is good; low irradiation can result in a decrease in the grid power factor, while the grid and load frequencies are in normal conditions for various variations of irradiation, type, and load power.**

Keywords: Performance Of On-Grid Pv, Performance Ratio, Power Factor, Frequency.

I. Introduction

Photovoltaic (PV) is a device made of semiconductor material that can convert sunlight directly into electricity. The change occurred by utilizing the photovoltaic effect [1]–[3]. PV module efficiency is influenced by several factors, namely irradiation, solar/ambient module temperature, number of cells and PV module cell relationships [4], [5].

There are various kinds of PV configurations to distribute electrical energy, namely off-grid PV, on-grid PV and Hybrid PV. According to IEEE standard 929-2000 PV systems are divided into three categories, namely small-scale PV systems (<10 kW or less), medium-scale (10 kW - 500 kW) and large-scale (> 500 kW). Each of these configurations has different performance characteristics. PV On-grid is a PV configuration, in which the PV is connected directly to the network/grid on an inverter [3], [4], [6]. PV On-grid solution is an environmentally friendly energy solution for urban residents that can be used for housing or offices. The existence of this On-grid PV system can reduce electricity bills or can provide added value for the owner [3].

Several studies have been conducted regarding the performance of On-grid PV were [3] who analyzed the reliability of the grid tied inverter (GTI) system on On-grid solar PV 9X 80 WP. Then [6] which discusses the design and analysis of a 10 MW On-grid solar power plant in Yogyakarta. Next is [7] which discusses the performance of solar power plants (PLTS) with the On Grid System at BPR BKK Mandiraja Wanayasa Branch, Banjarnegara Regency. Other research in [4] analysis of the performance of the on-grid photovoltaic system at the Gili Trawangan solar power plant (PLTS). Research by [8] conducted performance evaluation of 100 MW On-grid PV in India. These studies discuss the performance of On-grid PV which includes PV and system efficiency, energy production, solar energy and the overall effect of system losses, final yield (Yf), reference yield (YR) and performance ratio.

The studies mentioned previously have not discussed how the performance of on-grid PV is related to irradiation on power factor, grid frequency, and load. So, the goal of this study is to examine the performance of on-grid PV at various irradiation, type, and load power to power factor, grid frequency, and load.

II. Method and Design

A. On-grid PV Performance Analysis

The performance parameters carried out in analyzing the performance of On-grid PV in this paper include:

- PV efficiency is the fraction of sunlight that can be converted into electricity [9]. Based on [10] there are 2 types of PV efficiency, namely PV conversion efficiency/module conversion efficiency and normalized power output efficiency. The two parameters are given by

$$\eta_p = \frac{P_{act}}{G \times A} \times 100\% \quad (1)$$

$$\eta_n = \frac{P_{act}}{P_{STC}} \times 100\% \quad (2)$$

- *Final yield* (Yf) is the energy exported to the network (E) divided by the power to the network (Po) from the number of PVs installed. This parameter represents the number of hours that the PV needs to operate at its nominal power to provide the same energy and is given by [5], [6], [8]

$$YF = \frac{E}{P_{out}} \quad (3)$$

- *Referensi yield* (YR) is the amount of irradiation in the PV field divided by the reference PV irradiation (G). This parameter represents the number of hours equivalent to global irradiation. YR describes the solar radiation resource for a PV system calculated by [5], [8].

$$YR = \frac{H}{G} \quad (4)$$

- The performance ratio is the final result divided by the reference result. Performance ratio can be defined as the ratio of plant output compared to plant output which can be achieved taking into account irradiation, panel temperature, grid availability, PV area, nominal power output, temperature correction values

$$PR = \frac{Y_F}{Y_R} \quad (5)$$

In addition to the parameters above, other things used to see the performance of On-grid PV in this paper are the effect of irradiation on the grid power factor, the effect of the type of load used on the grid power factor, and load or frequency. Thus, the scenarios carried out in this test are varying the type of load and load power. The types of loads used are incandescent lamps and LED lamps with different powers, namely 40 W (incandescent lamps), 30 W (LED lamps), and 100 W (LED lamps).

B. Setup Testing and component specifications

The circuit of tests carried out in the data collection process are presented in Figure 1. Testing the performance of the On-grid PV, the PV capacity used is 1 kWp and the inverter capacity is 2 kW. In detail the

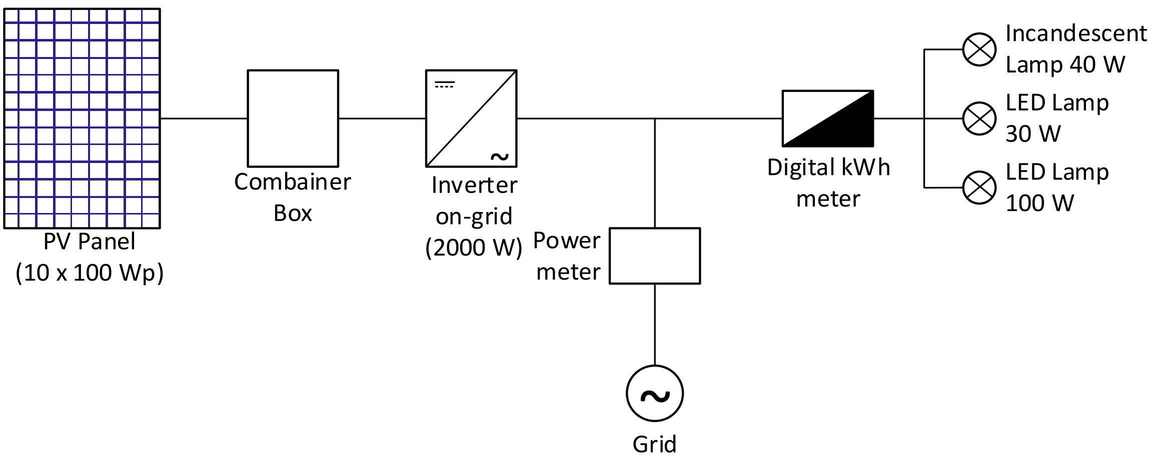


Figure 1. On-grid PV test circuit

Table 1. Components and specifications for testing

No.	Component	Specifications
1.	Photovoltaic Module	Monokristal dan polikristal Model: Staryu-100Wp, Pmax: 100Wp, Vmp: 17.6v, Imp: 5.71A, Voc:21V, Isc: 6.4A
2.	Combainer Box	Fuse: 1000Vdc, 32A, MCB 2P: 400Vdc, 10A, DS: 1500Vdc, 60A SPD DC: Un 1000Vdc, Uc 1200 Vdc, In 20KA, Imax 40KA, Up<3.2 Vdc
3.	Inverter on-grid	Model: MIC 2000TL-X Vmax PV: 500 Vdc, PV Voltage range: 50 – 500 Vdc, PV Isc: 13 Adc, Imax: 13 Adc, Max Output power: 2000W, Vnom: 230 Vac, Iout max: 9.5 Aac, fnom output: 50/60Hz, class I, IP65
4.	Digital kWh meter 1P	DDS238-2 SW, standar IEC: 62035-21, Vnom: 230 Vac, Fnom: 50Hz, Imax/Imin: 65A/0.04A, class 1, display: LCD 5+1 digit
5.	Power Meter	V: 80-260 Vac, I: 0-100 Aac, foperation 45-65 Hz, class 1
6.	Solar Power Meter	Spectral response: 400-1100 nm, measuring unit: W/m^2, BTU/(ft^{2}h), range mesurment: 0.1 W/m^2 < 1000 W/m^2, 1 W/m^2 ≥ 1000 W/m^2, accuracy: ± 10 W/m2, ±3 BTU/(ft^{2}h)

components and specifications used can be seen in Table 1.

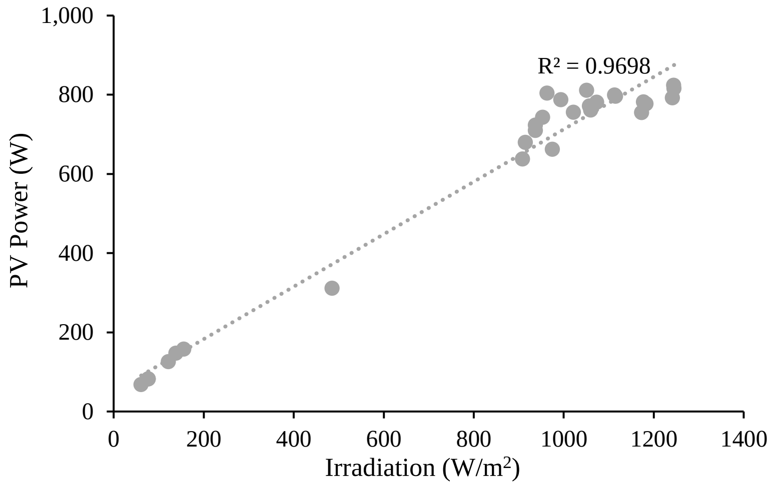
III. Result and Discussion

PV power is generally very dependent on 2 parameters, like as, irradiation and temperature. This irradiation will also affect the efficiency of a PV. A comparison of irradiation to PV power and efficiency based on data collection conducted on December 3, 2022 for 4 hours is presented in Figure 2. Based on Figure 2(a), the power generated by PV will tend to increase as irradiation increases. This condition has been previously disclosed in [2], [11]. In addition, it can also be seen from the coefficient R^2 from Figure 2(a) which is 0.9698. The value shows that the linearity between irradiation and PV power is very high. The average actual energy conversion efficiency obtained is 10.50%. The average energy conversion efficiency is lower than the standard efficiency of the PV modules used, namely 14% for monocrystalline and 12% for polycrystalline.

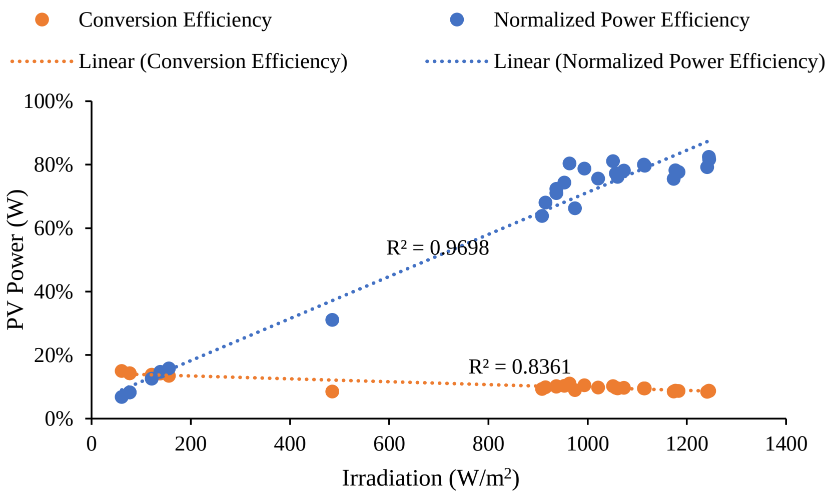
Unlike the case with the power conversion efficiency in PV, this conversion efficiency is inversely proportional to irradiation, this can be seen in Figure 2(b). This phenomenon has been confirmed by previous research [5], [11]. This occurs as a result of increasing irradiation will increase the surface temperature of the PV. While the temperature itself can result in a voltage drop.

Whereas the normalization efficiency is comparable to irradiation, this is because this value is obtained between the ratio of the actual power generated to the PV power under STC conditions, thus increasing irradiation will cause an increase in normalization efficiency. The coefficient value of R^2 for these two efficiencies is 0.8361 for conversion efficiency, while the normalization efficiency is 0.9698. The value illustrates that the correlation between irradiation and PV power is very high.

Energy production and energy exported to the grid during the 4 hours of testing can be seen in Figure 3. The total energy produced is 2.7 kWh and the energy exported to the grid is 2.3 kWh. PV produces an average of 0.675 kWh of energy per hour, while the energy exported to the grid is 0.582 kWh per hour. Energy production from PV experienced a high increase and the energy exported to the grid was also



(a)



(b)

Figure 2. Comparison of irradiation versus, (a) power, dan (b) PV efficiency

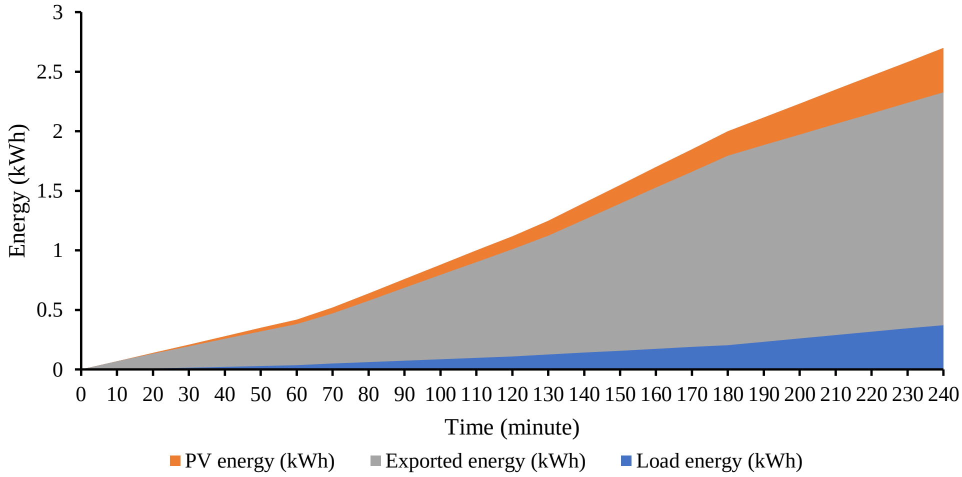
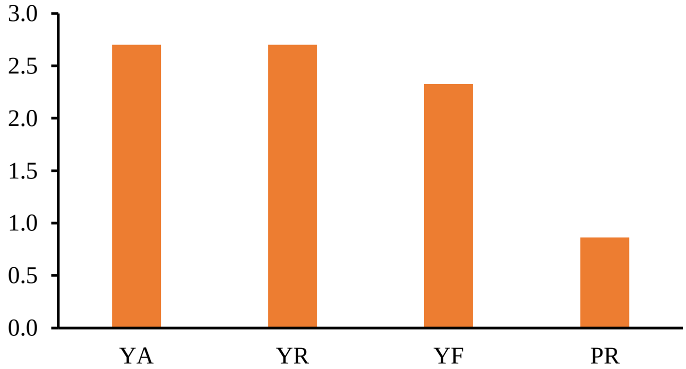


Figure 3. PV energy generated and energy exported to the Grid for 4 hours.



(a)

Figure 4. Comparison YA, YR, YF dan PR.

high, occurring at 120 to 180 minutes or at the 3rd hour of measurement. During this period the energy generated by PV increased by 0.9 kWh, this was because during this period the irradiation reached its maximum value at 12.30 – 13.30. Meanwhile, the lowest increase in energy production by PV occurred in the first hour period, which was 0.4 kWh. This condition was caused by the cloudy weather during this measurement period, so the irradiation value was at a minimum condition of up to 60.6 W/m2. While at 3 hours the average irradiation measurement reached 1169.86 W/m2. For energy exported to the grid, the pattern is the same as energy produced by PV, with the 3rd test period, the increase can reach 0.8 kWh. Whereas in the first period of testing the increase was only 0.4 kWh.

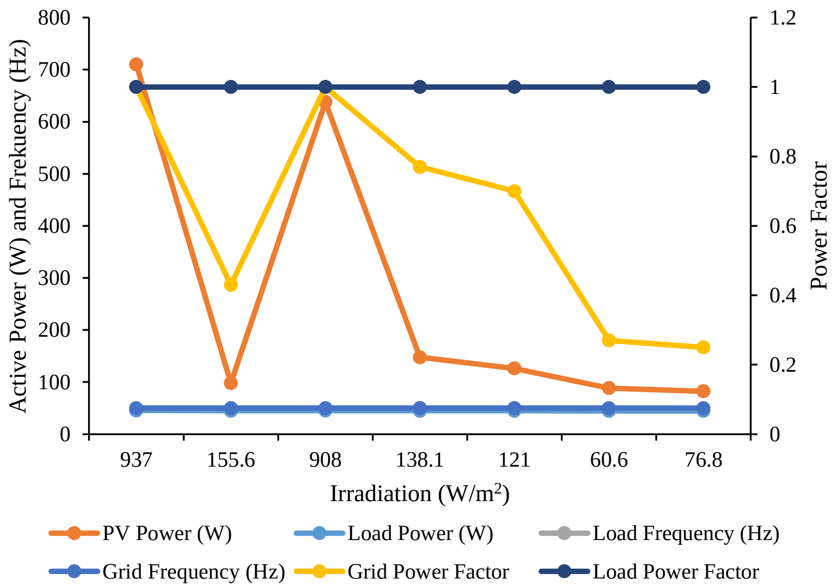
Figure 4 shows YA, YR and YF with a test time of 4 hours. YA, YR and YF got 2.7, 2.7, and 2.3 respectively. Based on the figure, the YA and YR values have the same value, this is because the nominal capacity of the installed PV is 1 kWp. YA illustrates that the time that the PV generator must operate at nominal PV power to produce energy is only 2.7 hours during the test. Similar to YA, YR provides an

Table 2. Comparison YA, YR, YF and PR versus other study

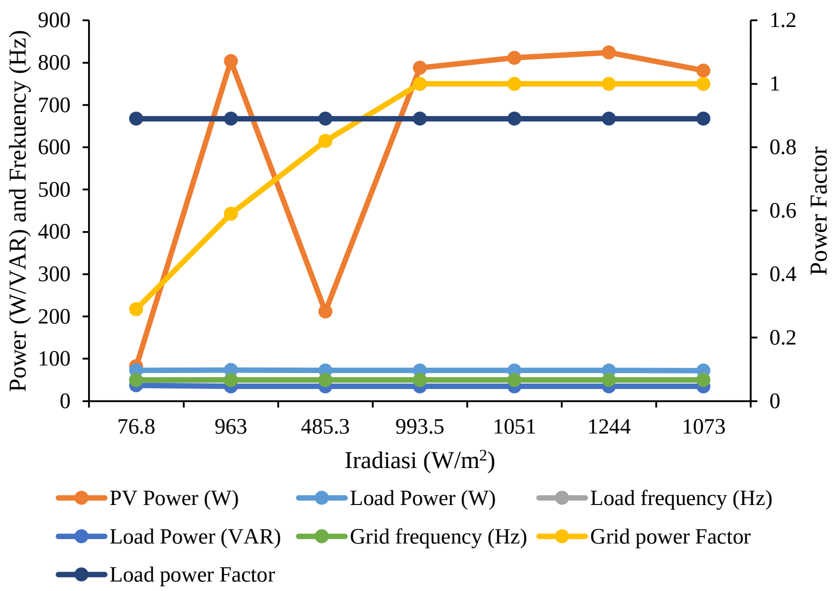
No.	Parameter	This Study	Reference [4] 200 kWp	Reference [4] 400 kWp	Reference [5] 353.3 kWp	Reference [5] 606.7 kWp	Reference [8] 10 MWp
1.	YA (kW h/d*kWp	2.7	NA	NA	NA	NA	
2.	YR (h)	2.7	NA	NA	7.9 (max) 3.5 (min)	7.8 (max) 4 (min)	
3.	YF (kWh/kWp)	2.3	8,89	8,91	6.2 (max) 3.2 (min)		1.96 - 5.07
4.	PR (%)	86	88,9	89,1	52.3	30.4	86.12

Overview of the ideal time to generate electrical energy from PV. While YF is the energy that comes out of the PV capacity inverter under STC conditions. This YF value has a dependence on irradiation. The PR values generated during the operation of the PV within 4 hours, each of which is 86%. PR shows the percentage of energy that is available after deducting energy losses. This value will be affected by irradiation, PV temperature, network availability, area size, nominal power output, and temperature correction values. PR which in this study was included in the good category, typically PR is greater than 80% [5]. A comparison of these parameters with other studies is presented in Table 2.

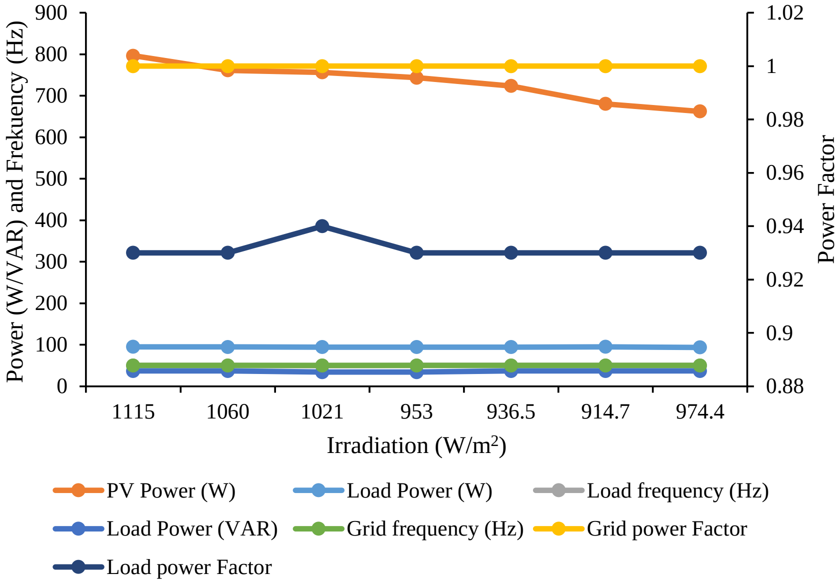
Figure 5 shows the condition of load power, grid frequency and load, grid power factor, and load under various irradiation and load conditions. Low irradiation conditions (cloudy conditions) will cause the power factor on the grid to be low Figure 5a, while the value of the load power factor is close to 1. For both grid and load frequencies in various irradiation conditions and loads, the value is in normal conditions which are at vulnerable 49.96 – 50.03 Hz. Under the load conditions of the LED lamps (Figure 5b, Figure 5c, and Figure 5d), the power factor at the load will decrease. The average value during measurement at each load is 0.89, 093, and 0.93. The reduced power factor value measured at this load is caused by the non-linear component of the LED lamp. This phenomenon has been described in [12] which states that non-linear components can cause a decrease in the value of the power factor. This is also indicated by the presence of reactive power which is measured at the load (see Figure 5b, Figure 5c, and Figure 5d).



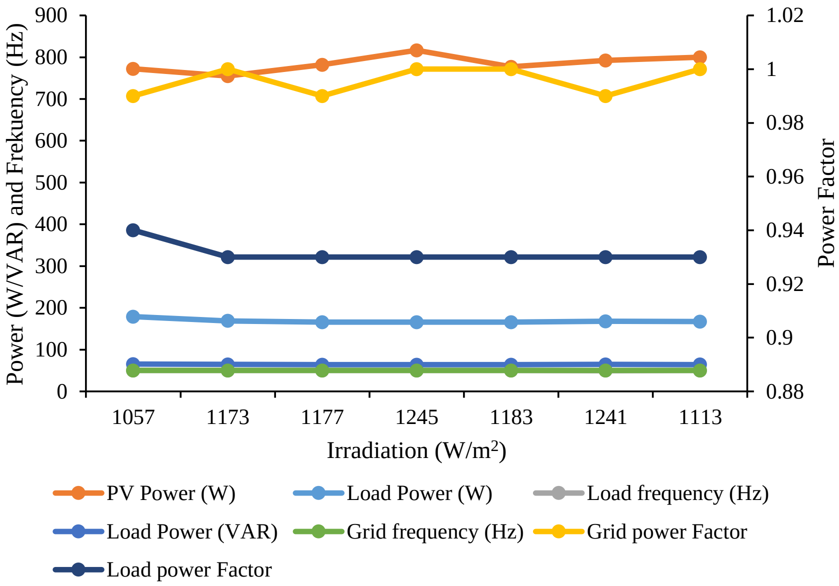
(a)



(b)



(c)



(d)

Figure 5. PV power conditions, load power, load frequency, Grid power factor and load under various irradiation conditions with a load of (a) 40 W (incandescent lamp), (b) 70 W (incandescent lamp and LED lamp), (c) 100 W (LED lamps) and (d) 170 W (incandescent and LED lamps).

IV. Conclusion

The On-grid PV system has shown good performance, this can be seen from the PR produced which is 86%. Whereas in low irradiation conditions (cloudy conditions) will cause the power factor on the grid to be low and the load power factor value is in normal conditions. For both grid and load frequencies in various irradiation and load conditions, the values under normal conditions are in the range of 49.96 – 50.03 Hz.

Acknowledgments

The author thanks to Direktorat Jenderal Pendidikan Vokasi, Ministry of Education, Culture, Research and Technology for funding the implementation of the 2022 Matching Fund activities through kedaireka, in accordance with the cooperation agreement with number:406/PKS/D.D4/PPK.01.APTV/VIII/2022.

References

[1] E. A. Hakim, T. Al Ghufran, M. Effendy, dan N. Setyawan, “MPPT Menggunakan Algoritme Particle Swarm Optimization dan Artificial Bee Colony,” *Jurnal Nasional Teknik Elektro dan Teknologi Informasi*, vol. 9, no. 2, hal. 218–224, Mei 2020, doi: 10.22146/jnteti.v9i2.81.

[2] U. Usman, A. R. Idris, Sofyan, dan I. Syamsuddin, “Pemodelan dan Simulasi Photovoltaic Menggunakan

Pendekatan Model Tiga Diode," *Jurnal Nasional Teknik Elektro dan Teknologi Informasi*, vol. 9, no. 4, hal. 423–429, Des. 2020, doi: 10.22146/jnteti.v9i4.688.

[3] M. W. Ainul Fauzi, M. Noor Hidayat, dan W. Anistia, "Analisis Keandalan Sistem Grid Tied Inverter (GTI) Pada On-grid Solar PV 9 X 80 WP," *Jurnal Teknik Ilmu Dan Aplikasi*, vol. 2, no. 2, hal. 29–35, Jun. 2022, doi: 10.33795/jtia.v2i2.60.

[4] E. M. Suryanti, R. Rosmaliati, dan I. B. F. Citarsa, "Analisis Unjuk Kerja Sistem Fotovoltaik On-Grid Pada Pembangkit Listrik Tenaga Surya (PLTS) Gili Trawangan," *Dielektrika*, vol. 1, no. 2, hal. 82–95, 2017.

[5] P. M. Congedo, M. Malvoni, M. Mele, dan M. G. De Giorgi, "Performance measurements of monocrystalline silicon PV modules in South-eastern Italy," *Energy Conversion and Management*, vol. 68, hal. 1–10, Apr. 2013, doi: 10.1016/j.enconman.2012.12.017.

[6] S. Sukmajati dan M. Hafidz, "Perancangan dan analisis pembangkit listrik tenaga surya kapasitas 10 MW on grid di Yogyakarta," *Energi & Kelistrikan*, vol. 7, no. 1, hal. 49–63, 2015, doi: 10.33322/energi.v7i1.582.

[7] E. P. Aji, P. Wibowo, dan J. Windarta, "Kinerja Pembangkit Listrik Tenaga Surya (PLTS) dengan Sistem On Grid di BPR BKK Mandiraja Cabang Wanayasa Kabupaten Banjarnegara," *Jurnal Energi Baru dan Terbarukan*, vol. 3, no. 1, hal. 15–27, Mar. 2022, doi: 10.14710/jebt.2022.13158.

[8] B. Shiva Kumar dan K. Sudhakar, "Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India," *Energy Reports*, vol. 1, hal. 184–192, Nov. 2015, doi: 10.1016/j.egyr.2015.10.001.

[9] A. Asrori dan E. Yudiyanto, "Kajian Karakteristik Temperatur Permukaan Panel terhadap Performansi Instalasi Panel Surya Tipe Mono dan Polikristal," *FLYWHEEL : Jurnal Teknik Mesin Untirta*, vol. 1, no. 1, hal. 68, Okt. 2019, doi: 10.36055/fwl.v1i1.7134.

[10] A. Asrori, I. Mashudi, dan S. Suyanta, "Pengujian Rasio Kinerja Instalasi Panel Surya Tipe Silikon–Kristal pada Kondisi Cuaca Kota Malang," *Jurnal Energi dan Teknologi Manufaktur (JETM)*, vol. 2, no. 02, hal. 11–18, Des. 2019, doi: 10.33795/jetm.v2i02.41.

[11] M. M. Rahman, M. Hasanuzzaman, dan N. A. Rahim, "Effects of various parameters on PV-module power and efficiency," *Energy Conversion and Management*, vol. 103, hal. 348–358, Okt. 2015, doi: 10.1016/j.enconman.2015.06.067.

[12] Usman, A. Muchtar, Sujito, dan W. Mahir Muttaqin, "Comparison between single tuned filter and c-type filter performance on the electric power distribution network," *Journal of Physics: Conference Series*, vol. 1175, hal. 012127, Mar. 2019, doi: 10.1088/1742-6596/1175/1/012127.