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Assessing the Performance of Off-Grid Solar Photovoltaic Power Plants in Supporting Aquaponics Systems

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Keywords

Off-grid; Photovoltaic Solar Power (PLTS); Performance Test; IEC 61724 Standard; Aquaponics.

Abstract

In an aquaponics system, the electricity produced by photovoltaic solar power (PLTS) is stored in batteries and used to power the water pumps. Using natural microorganisms to transform fish waste into plant nutrients, aquaponics is a cultivation method that blends fish and plant cultivation. The aquaponics system helps reduce the amount of trash released into the environment and is beneficial to the environment. The main goal of this study is to evaluate an off-grid PLTS system's functionality as a DC water pump power source in an aquaponics setting. This study's goal is to evaluate how well the PLTS operates when powering the DC water pump that circulates water in the aquaponics system. According to performance tests, the off-grid PLTS generates an average energy of 503.8 Wh, which is enough to power the DC pump for 20 hours a day of water circulation. The water pump uses only 382.6 Wh of electricity each day. With an average solar panel efficiency of 4.97%, an average solar charge controller (SCC) efficiency of 60.51%, and an average pump efficiency of 79.91%, the Off-grid PLTS demonstrates efficiency. With a daily solar irradiation of 7.8 kWh/m2, the average energy loss in the solar panel is 5.29 kWh/kWp, whereas the average energy loss in the system is 0.10 kWh/kWp. All things consider, these results provide insight into how well the Off-grid PLTS functions as a power source for the DC water pump in an aquaponics system.

1. INTRODUCTION

The demand for electricity in Indonesia is continuously rising alongside population growth and technological advancements. Ministry of Energy and Mineral Resources Number 143K/20/MEM/2019 revealed that the ratio of increase in national electricity demand reached 6.9% per year. In September 2022, the growth in electricity demand in Indonesia will be around 7.46% and total sales will reach 201.78 (TWh), compared to September 2021 which reached 187.8 TWh (Prasodjo, 2022). The new renewable energy mix in 2021 has met national electricity needs of 11.5%, while the Ministry of Energy and Mineral Resources (KESDM) estimates that the target can reach 23% of the renewable energy mix in 2025 (KESDM, 2021). Geographically, Indonesia's location on the equator provides various advantages and immense potential for harnessing solar energy (Rachmi et al., 2020),One of the applications of renewable energy is the utilization of solar energy as a power source, known as Solar Photovoltaic Power Plants (PLTS). A Solar Photovoltaic Power Plant (PLTS) is an electricity generation system that converts sunlight into electrical energy through solar cells (Wahyudi et al., 2021). Data from the Ministry of Energy and Mineral Resources states that Indonesia's potential for solar energy is very large, estimated at 4.8 kWh/m2 or the equivalent of 112,000 GWp. However, currently only around 0.05% of this potential has been utilized, with a total capacity of 103,949 megawatts (MW) (Budiyanto *et al*, 2021).

In the context of aquaponics, PLTS is often used as a source of electrical energy to fulfill the system's requirements or as an alternative energy solution. Several studies have successfully implemented Polycrystalline Solar Photovoltaic Power Plants (PLTS) (Hindarti, 2018), and integrated them as power sources to drive water pumps in aquaponic systems. Other research has also focused on designing solar panels

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and water flow control systems that supply nutrients to plants in aquaponic setups (Andansari et al., 2022). Aquaponics is a cultivation system that combines aquaculture (fish cultivation) and hydroponics (plant cultivation using water) by utilizing natural bacteria. In this system, the bacteria are responsible for converting waste and remaining fish food into nutrients that can be absorbed by plants. Thus, aquaponics can be explained as a system where plants and fish grow simultaneously and mutually support each other, as proposed by (Burlian et al., 2021). Utilization of renewable energy is the right solution to replace the use of conventional electricity. Apart from being able to reduce electricity costs, renewable energy also contributes to creating green energy (environmentally friendly energy) and reducing dependence on fossil energy which is increasingly scarce. Good potential in this case is the use of sunlight which lasts for around 7 to 8 hours per day (Krisnandar, 2020).

In general, PLTS (Solar Power Plants) are used as a renewable energy source to meet household electricity needs or as an alternative to other energy sources. In research conducted by (Andansari et al., 2022). Successfully built a PLTS using the polycrystalline type. The PLTS is operated as a power source to drive the air pump. Another research conducted by (Setiawan et al., 2020). Successfully designed a solar power generation system (solar panels) and an air flow control system aimed at supplying nutrients to plants in an aquaponic system. Research conducted by (Andansari et al., 2022) used an AC motor water pump where the circuit used an inverter, whereas in the research I conducted using a DC motor water pump, it was hoped that it would produce a more stable voltage and current. DC motors are direct current motors, as the name suggests, use direct current, used in special applications for high torque ignition or constant acceleration over a wide speed range (Amanda, 2019). Tther research on the use of Plts as an aquaponic energy source in Leuwi Karet Village, Guha Kulon Village, Klapa Nunggal, Bogor Regency (Monika et al., 2022).

In the framework of aquaponics, this study focuses on assessing the effectiveness of an off-grid solar photovoltaic power plant (PLTS) system used as a power source for DC water pumps. Analyzing the PLTS's ability to meet the energy requirements of the aquaponic system's water circulation pumps is the goal of this study. The IEC 61724 standard technique is used to test the PLTS's performance (Setiawan et al., 2020). Since every interested National Committee is represented on each technical committee, the formal decisions or agreements of the IEC on technical matters reflect, as far as practicable, an international consensus of view on the pertinent subjects.

2. METHODS

This test was conducted on the rooftop of the engineering building at Politeknik Negeri Jember using the Standard IEC 61724 Performance Test Method for Photovoltaic Systems. The guidelines for measurement, data exchange, and analysis for photovoltaic (PV) system performance monitoring are outlined in the Photovoltaic System Performance Monitoring - Guidelines for Measurement standard. This standard provides guidelines related to measurement, data exchange, and result analysis within PV systems. It helps ensure that PV systems function as intended and deliver the expected performance during their operational lifespan (El Hacen Jed et al., 2020)

This study was conducted over 10 working days, from June 14, 2023, to June 27, 2023, with data collection taking place for 6 hours at 5-minute intervals. The efficacy of an off-grid photovoltaic system as a power source for the water pump—which circulates water in an aquaponic system—was the main focus of the study. The water pump operated continuously for 24 hours, with a timer setting of 5 hours ON and 1 hour OFF, repeated throughout the 24-hour period.

2.1 Test Design

The deasign is off-grid solar photovoltaic system is oriented northward and consists of components such as a 200 Wp solar panel, a 30 A solar charge controller (SCC), a 12 V 100 Ah battery, a 12V water pump, and an aquaponic setup with dimensions of 100 cm x 52 cm x 102 cm. The aquaponic system features 4 levels of 1.5" pipes and a total of 20 netpots trays. Solar panel meter use to measure solar irradiation, Tang meter, Avometer, Multimeter use to measure voltage and current

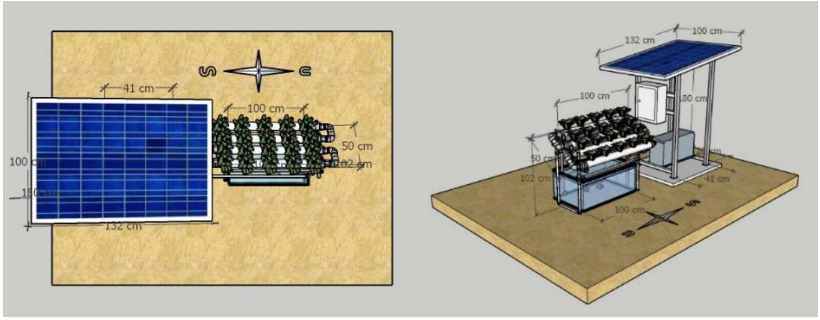
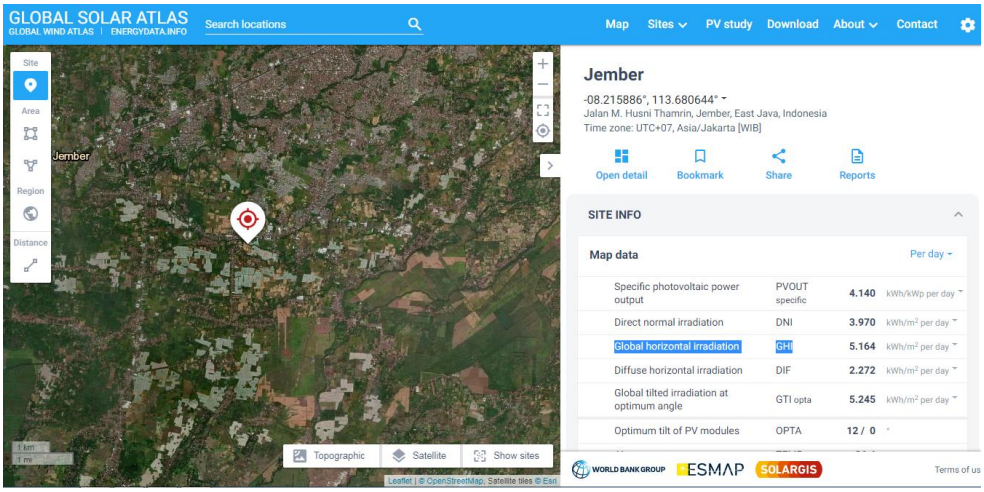


Figure 1. Solar system Design



Fugire 2. Image of GHI Data Site Location on the page https://globalsolaratlas.info/

The location of the research site is in the Politeknik Negeri Jember, Engineering Department Building which is located at coordinates –8.1580697 South Latitude and 113.7228278 East Longitude. The site location is located in a building with a height of 22 m with a frame as shown in Figure 4.1. Based on the image, only 1 off-grid solar module is used. The site location which is at a height of 22 m above a 5-story building allows the solar module to avoid the risk of shading. The solar panels installed in the Jember State Polytechnic Engineering Department Building are oriented north with a tilt angle of 9˚ facing north. In fact, the tilt angle of solar modules in Indonesia generally ranges between 6 – 11˚ according to Indonesia's geographical location, namely at 6˚ N – 11˚ S. This mismatch in tilt angle can cause less than optimal sunlight reception so that the energy produced is also less than optimal.

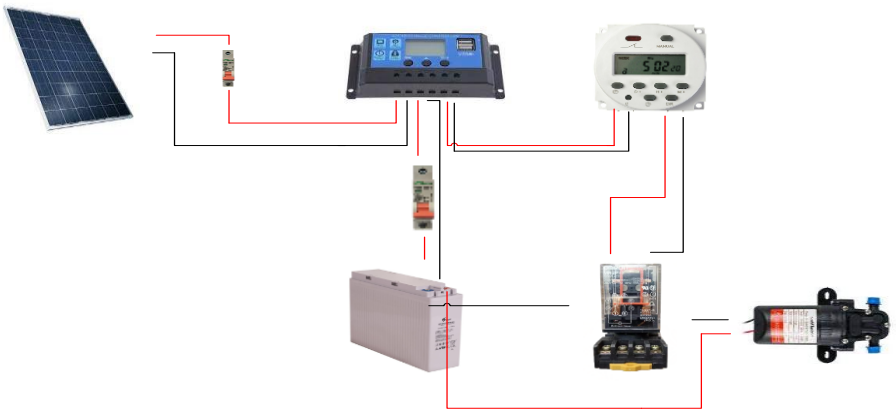


Figure 1.3. Wiring Solar system

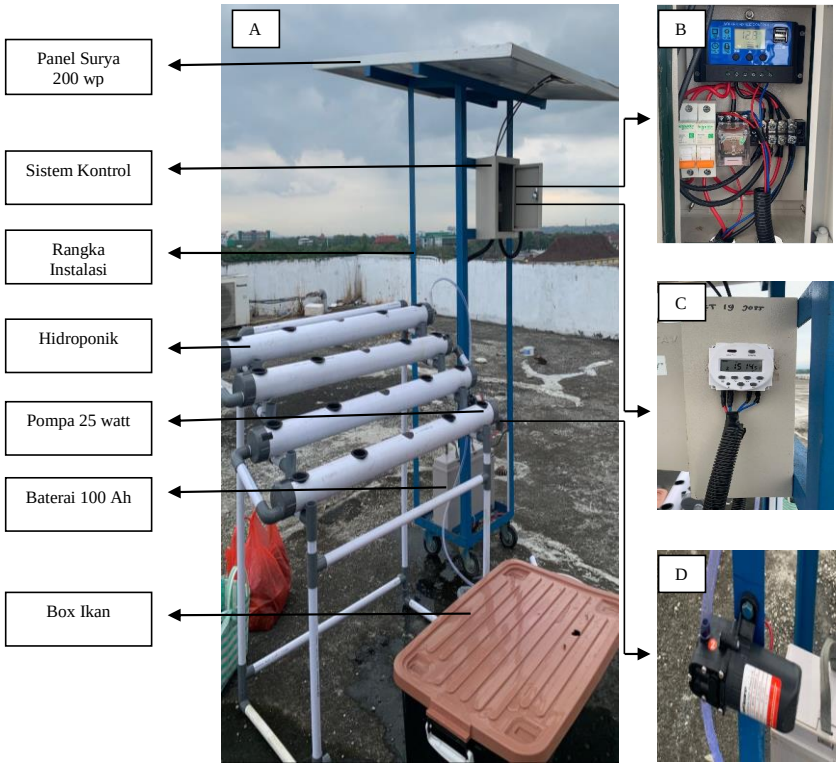


Figure 4. Test Equipment Design

2.2 Performance Evaluation of PV Array

Performance parameters of PV array are established by the international energy agency. They are described in IEC standard 611724. the normalized indicators gather energy output, array yield, final yield, reference yield, module efficiency, inverter efficiency, system efficiency, performance ratio, capacity factor, and energy loss (array capture loss and system loss).

2.2.1. Energy generated by the PV array system (Edc)

The total daily recorded value of DC power output (Edc,d) is given by the following equation:

$$Edc = Pdc\ x\ T \qquad (1)$$

Where :
T is Recording time interval
Pdc is the DC power (result of the current times the voltage). It is given as follows:

$$Pdc = Vdc\ x\ Idc \qquad (2)$$

2.2.2. Reference Yield (Yr)

The ratio of the total solar radiation Ht (kWh/m2) that is absorbed by the PV solar panels' surface to the quantity of reference radiation G0 (1 kW/m2) is known as the reference efficiency (Yr). It shows how many hours there are when the lighting is the same as the reference. The PV system's solar resource is defined by Yr. It is provided by:

$$Yr = \frac{Ht}{Go} \qquad (3)$$

Where :
Yr is Reference yield
Ht is Total irradiance on the array
Go is Reference irradiance

2.2.3. Array Yield (Ya)

The ratio of the total energy generated by the PV rows Edc (kWh) over a specified time period (day, month, or year) to the nominal power P0 (kWc) of the rows under standard conditions (STC: irradiation = 1000 W/m2, ambient temperature = 25 C, and AM 1.5-G reference spectrum) is known as the PV field's efficiency (Ya). The following formula yields the PV field's daily efficiency (Ya,d):

$$Ya = \frac{Edc}{Ppv(rated)} \qquad (4)$$

Where :
*Y*a is Array yield
Edc is Energy output generated by a Solar Panel
Ppv (rated) is total installed module capacity.

2.2.4. Final yield of the PV system or system yield (Yf)

The total energy generated by the PV system Eac (kWh) divided by the installed nominal power P0 (kWp) is the final efficiency (Yf). The number of hours that the PV field should run at its rated power is represented by this value. The following equations yield the daily final efficiency (Yf,d) and the monthly final efficiency (Yf,m):

$$Yf = \frac{Edc}{Ppv(rated)} \qquad (5)$$

Where :
*Y*a is Array yield
Edc is Energy output generated by a Solar Charge Controller
Ppv (rated) is total installed module capacity.

2.2.5. Pv module efficiency (hpv)

The effective energy produced by the module in relation to the available radiation is shown by the module efficiency, also known as energy efficiency (hpv). The following formula yields the daily PV array efficiency:

$$\eta PV = \frac{Edc}{G\ x\ Am}\ x\ 100 \qquad (6)$$

Where :
Edc is daily output energy of the PV array
G is Solar radiation
Am is total solar panel area

2.2.6. Solar Charge Controller Efficiency (ηSCC)

The efficiency of the Solar Charge Controller (SCC) is the ratio of battery power to solar power. The more efficient an SCC is, the better it can regulate the electric current and voltage flowing to or from the battery according to the installed PV system. SCC efficiency can be calculated using the equation

$$\eta SCC = \frac{PAh}{Ppv}\ x\ 100 \qquad (7)$$

Where :
PAh is Battery Output Power
Ppv is Solar Panel Output Power

2.2.7. System Efficiency (ηSys)

The PV generator and inverter module balance of the system affects the efficiency of the photovoltaic system. The following formula can be used to determine the monthly system efficiency:

$$\eta Sys = \eta PV\ x\ \eta SCC \qquad (8)$$

Where :
ηPV is Efficiency of Solar PV
ηSCC is Efficiency of Solar Charge Controller

2.2.8. Standardized performance index (PR)

The entire impact of losses in the energy production of a PV system's rows is shown by the performance ratio, or PR. The PR values show how close a photovoltaic system is to achieving optimal performance in practical operating circumstances. The ratio of the final yield to the reference yield is known as PR. It is a dimensionless number that looks like this:

$$PR = \frac{Yf}{Yr}\ x\ 100 \qquad (9)$$

2.2.9. System losses by conversion (Ls)

The losses of the system by conversion (LS) are due to the SCC conversion losses are defined by the difference between the yield of the PV field Ya and the final yield Yf. The system losses are given as follows:

$$Ls = Yf - Ya \qquad (10)$$

2.2.10. Array capture loss (Lc)

PV array energy loss is the difference between the reference yield (Yr) and the array yield (Ya). Array energy loss is assumed to represent losses due to factors such as solar module temperature, cables, shading, dust, and other factors that can impact the PV array's performance (El Hacen Jed et al., 2020). To calculate PV array energy loss, the equation :

$$Ls = Yr - Ya \qquad (11)$$

2.2.11. Offgrid Solar system Component Specifications

a. Solar Panel

No	Solar Panel	specifications
1	Brand	SUNASIA
2	Model	SP200-36P
3	*Peak Power (Pmax)*	200W
4	*Cell Efficiency*	16.93%
5	*Max. Power volt (Vmp)*	35.6V
6	*Max power current (Imp)*	5.62A
7	*Open Circuit volt (VOC)*	43.6V
8	*Short Circuit Current*	6.05A

b. Solar Charge Controller

No	***Solar Charge Controller***	specifications
1	brand	Mediatech
2	*Rated Voltage*	12V/24V
3	*Rated Current*	30A
4	*Max PV Voltage*	50V
5	*Max PV input POWER*	390W (12V) 780W (24V)

c. Battery

No	Battery	specifications
1	Brand	SHOTO
2	Model	6-XFMJ-100B
3	*Nominal Voltage*	12V
4	*Capacity*	100 Ah @ 10hr to 1.80 V per cell @ 25˚C (77˚F)
5	*Weight*	37.5 kg(82.7 Ibs)
6	*Dimensions*	Length: 520 mm (20.47 in) Width: 110 mm (4.33 in) Height: 254 mm (10.00 in)
7	*Internal Resistance (full charged)*	5.00 mΩ
8	*Short- circuit Current*	2526 A
9	*Recommended Charging Current*	15 A
10	*Capacity Affected by Temperature(C10)*	105% @ 40˚C(104˚F) 85% @ 0˚C(32˚F) 60% @ -20˚C(-4˚F)

d. Aquaponic

No	Aquaponic	Keterangan
1	Dimensions	1,15M x 0,567M x 1,24 M
2	capacity	4
3	Ø Netpot	15 cm
4	Ø Pipa	2 inch
5	Distance between holes	18 cm
6	Dimensions *Container Box*	72,4cm x 46,8cm x 47,3cm
7	capacity	160L

e. Pump

No	Pump	specifications
1	Brands	TaffWare
2	Model	DP-521
3	*Max discharge*	3,5L/Min
4	*Rated Voltage*	12V
5	*Max Current*	2A

f. Rellay

No	*Rellay*	specifications
1	Brand	OMRON
2	Model	MK2P-I
3	*Rate Voltage*	12V
4	*Rated Curent*	10 A
5	*Rated Load*	10 A at 28 VDC

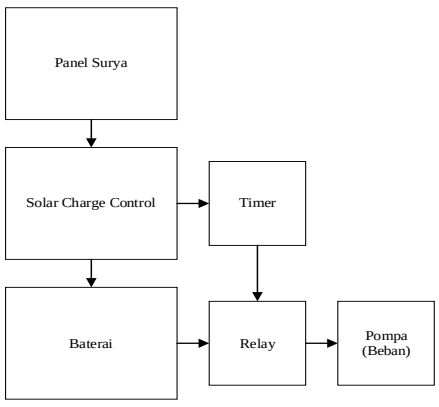


Figure 5. Solar system the circuit schematic in the system starts from the solar panel then goes to the solar charge controller to check the battery then the battery to the relay then turns on the pump.

Calibration of Measuring Instruments and Test Equipment

Calibration of measuring instruments and test equipment is carried out to ensure they are ready to be used for testing and to detect damage. Test equipment or measuring instruments that do not function normally will be repaired by identifying problems or errors with the equipment.

Repair/Settings

Repair/Set Ups are carried out due to problems or malfunctions of either the test equipment or measuring instruments. Repairs carried out can be in the form of replacing spare parts or adjusting and calibrating test equipment and measuring instruments. Repairs require replacement parts such as bolts, nuts, paralon, pipe covers and cables. Tools for repairs that require a screwdriver, pliers, wrench, soldering iron, cable.

Tool Testing

Tool testing is carried out to avoid using tools that do not suit your needs so that the tool can function optimally. It should be noted that the average sun exposure in Indonesia is optimal for 4-5 hours (Huda, 2022). So, to run the pump within 24 hours, several calculations need to be done to meet the electricity needs of the water pump for aquaponics.

Data retrieval

Data collection for testing is required as support for analyzing the specified data. Data collection on system performance is carried out for 10 days starting from 09.00 WIB to 15.00 WIB with a data collection interval of 5 minutes. This is done according to how aquuaponics works and how the equipment works. Determination of collection time is carried out based on the location's Peak Sun Hour which can be measured using the equation

PSH =(Solar Energy on the surface in 1 Day)/(1kW/m^2)

= 5.16 Hours

The average solar irradiation energy on the surface of a location in 1 day is obtained through GHI data via the globalsolaratlas. The data required for the test is solar irradiation, current and output voltage of the solar panel, solar charge controller, battery and pump.

3. RESULTS AND DISCUSSION

3.1 Result Generated by Solar Panel

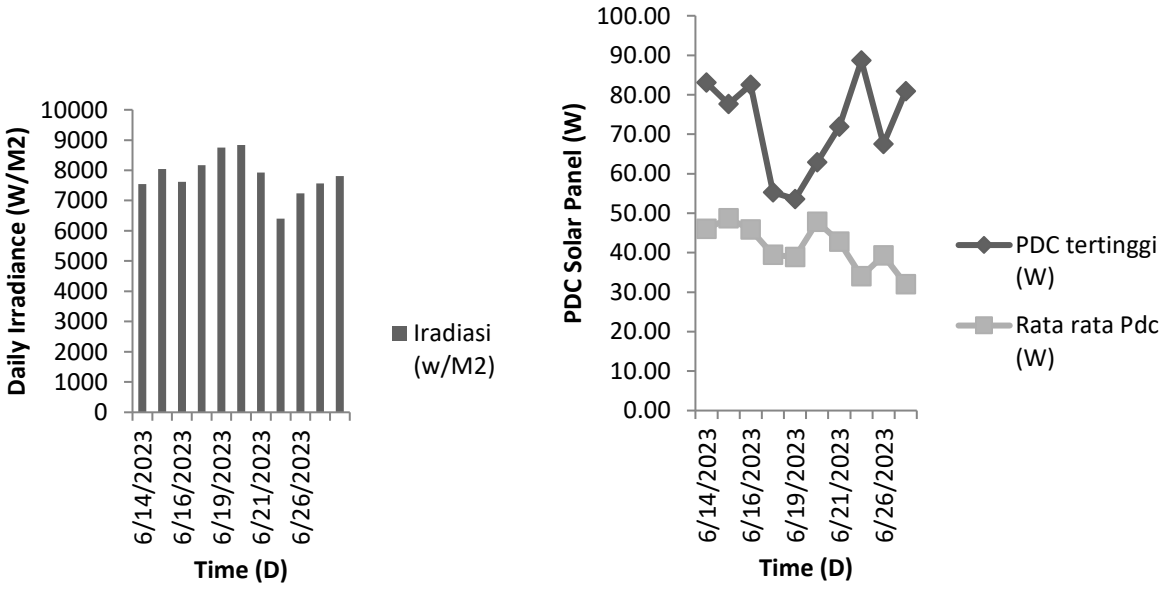
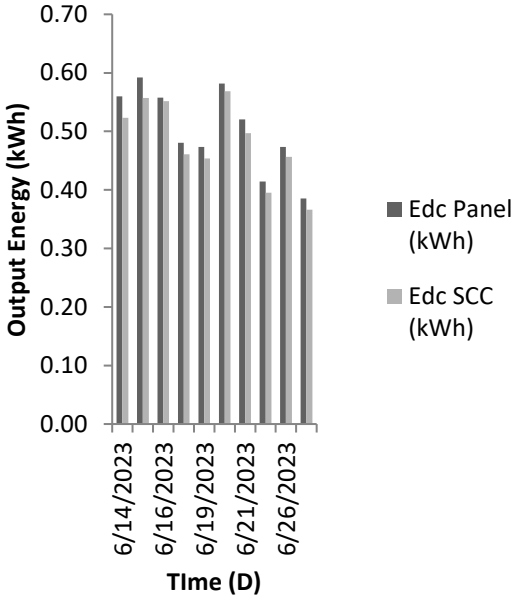


Figure 6. Daily Iradiance

Figure 7. Daily Output Solar PV



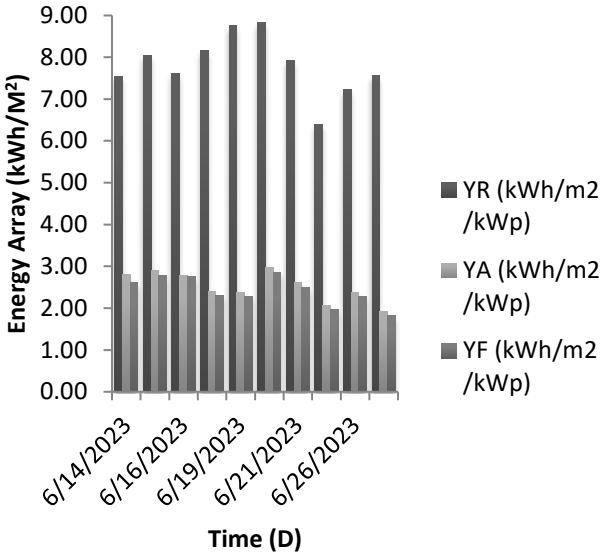
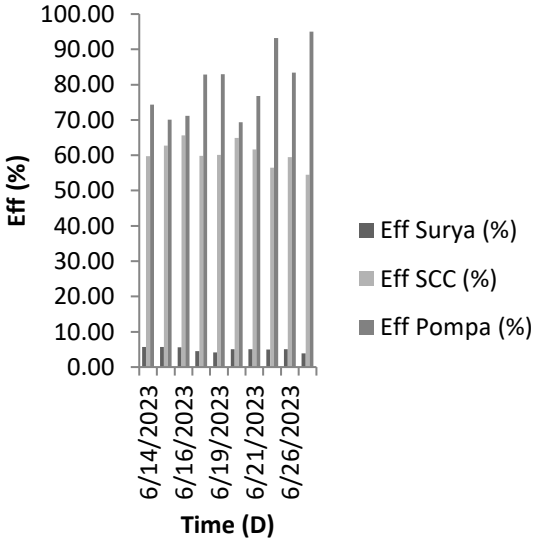


Figure 8. Daily Output Energy of PV and SCC

Figure 9. Daily Output Array Enegy



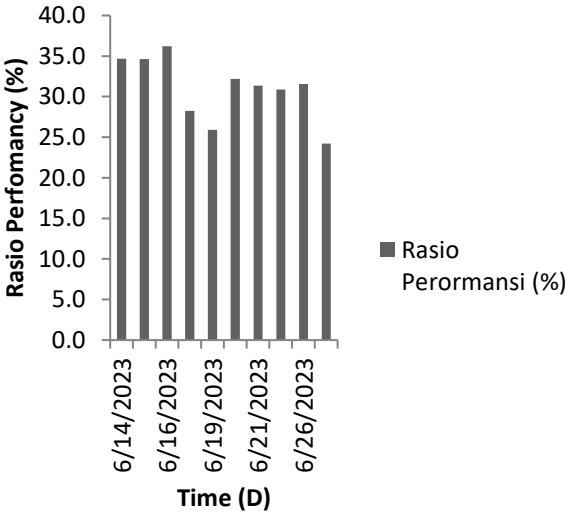


Figure 10. Daily Efficiency

Figure 11. Daily Rasio Performacy

The research was conducted over a period of 10 working days from June 14, 2023, to June 27, 2023, resulting in data on daily irradiance, daily DC power (PDC), daily energy (Edc), component efficiency (Eff), Performance Ratio (PR), array energy loss, and system energy loss. As shown in Figure 2, the highest daily irradiance recorded was 8.4 kW, with an average of 7.8 kW. Daily irradiance is influenced by weather conditions, which in turn affects the variability of daily irradiance levels. (Budiyanto et al., 2021) Figure 3 illustrates Pdc as the daily output from the solar PV, with the highest value recorded at 88.6 W and an average of 46.0 W. The Pdc values are correlated with solar irradiance, where higher solar irradiance results in higher output from the solar PV, indicating a direct proportionality between solar irradiance and solar PV output.

Figure 8. shows the output data generated by solar PV and SCC during the study. The highest value of Edc PV is 0.59 kWh with an average of 0.50 kWh, and the highest value of Edc SCC is 0.57 kWh with an average of 0.48 kWh. The value of Edc PV is influenced by the solar panel's ability to convert irradiance into electrical energy, while the value of Edc SCC is influenced by the SCC's ability to distribute battery charging and supply water pump ignition for circulation, supported by weather conditions that have a high and low impact on Edc values. Figure 5. The value of Yr is the reference yield, which represents the total daily irradiance received in the study. Ya represents the energy obtained from the array field (energy from solar PV), and Yf represents the energy usage from the array field. The highest Yr value is 8.83 kWh/m2/kWp with an average of 7.8 kWh/m2/kWp, the highest Ya value is 2.96 kWh/m2/kWp with an average of 2.52 kWh/m2/kWp, and the highest Yf value is 2.84 kWh/m2/kWp with an average of 2.41 kWh/m2/kWp. This data is influenced by solar irradiance intensity and the output of the solar PV, where the data will increase as the solar PV output increases, indicating a direct correlation.

Figure 9. The data includes three efficiencies: solar PV efficiency, SCC (Solar Charge Controller) efficiency, and pump efficiency. The solar PV efficiency value is 4.97%, which indicates that the ability of the solar PV to convert irradiance into electrical energy is very low compared to the specified value of 16.71%. This is due to several factors where the solar PV cannot reach its peak output, such as irradiance, surface temperature of the solar PV, and air mass (Muna, 2022). The SCC efficiency is 60.51%, indicating that the SCC's ability in battery charging and power supply for the water pump is quite good since the power coming from the solar PV is effectively supplied by the SCC. The pump efficiency of 79.91% indicates that the pump's efficiency in managing the input power and the power output for water circulation is quite optimal. The flow rate of the pump matches the specified value of 3.5 liters per minute, contributing to this high efficiency. This suggests that the pump is performing well in terms of energy conversion and water circulation, making it an effective component in the system

Figure 11. The Off-Grid PV System Performance Ratio is 30.98%, which falls significantly below the standard set by IEC 61724. According to this standard, a PV system is considered viable if the performance ratio is between 70% - 90%. In the study conducted, the PV system has a very low performance ratio, indicating that it does not meet the IEC 61724 standard. This could be attributed to the solar PV's low ability to harvest energy from the reference yield, thereby affecting the performance ratio value.However, it's noteworthy to mention that the SCC and water pump in the circulation system are deemed to be satisfactory and meet the standards, indicating that these components are performing adequately despite the PV system's shortcomings.

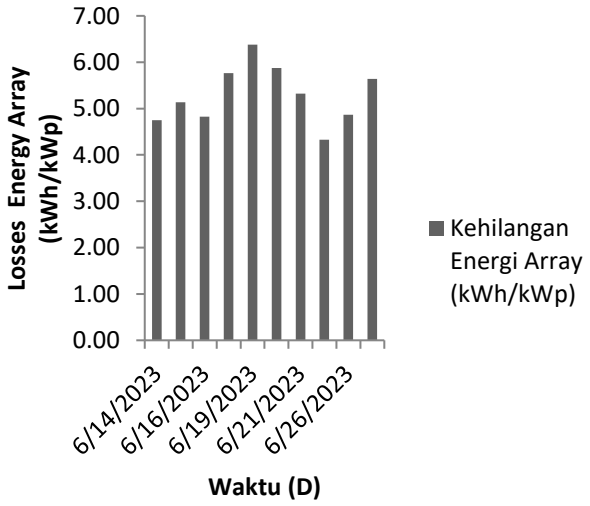


Figure 12. Losses Energy Array

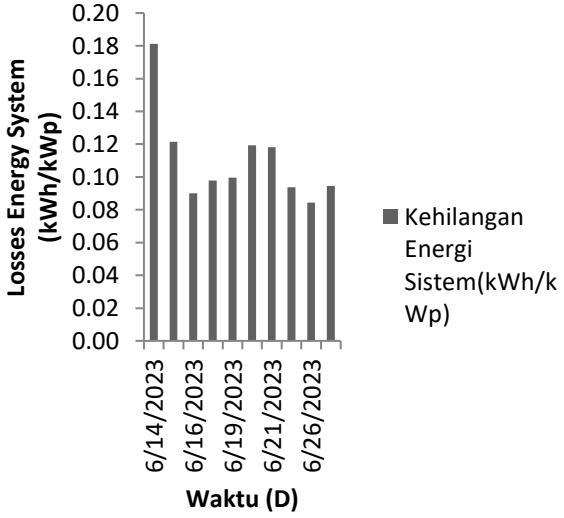


Figure 13. Losses Energy System

Figure 12. The value of energy loss in the array is 5.29 kWhkWp, which represents the energy that is wasted or not utilized by the solar PV due to its limited capacity or capability. This value is influenced by the

efficiency of the solar PV. The value of "Losses energy array" refers to the potential of the solar PV, thus affecting the performance ratio value since the low capability of the solar PV results in a low performance ratio value. Figure 13. The system's energy loss value is 0.10 kWh/kWp, and this value is likely influenced by losses in the cables, leading to a decrease in the energy obtained by the solar PV. The greater the resistance in the cables, the larger the losses.

4. CONCLUSION

4.1. Conclusion

The average energy generated by the Off-Grid PV system is 503.8 Wh, which is sufficient to support the operation of the DC water pump for 20 hours a day, with a total energy requirement of only 382.6 Wh. The Off-Grid PV system has an average efficiency value for the 200Wp Polycrystalline PV panel of 4.97%, an SCC efficiency of 60.51%, and an output power efficiency of the pump at 79.91%. The performance of the SCC and pump in terms of efficiency is good, but the efficiency of the solar PV panel remains low. The efficiency of the PV panel is highly influenced by its ability to convert irradiance.The Performance Ratio (PR) is 30.98%, which is very low due to the limited ability of the PV panel to convert solar irradiance. The Off-Grid PV system, based on this PR value, is considered not viable in terms of the solar panel's ability to convert solar irradiance. However, the system's viability is successful in supporting the water pump for aquaponic circulation.

4.2. Recomendation

Solar panels, utilizing more efficient solar panels, is recommended due to the SUNASIA 200Wp solar panel's efficiency being only 4.97%. The daily energy surplus of 97.1 Wh can be utilized by adding 4 units of 10 Watt ultraviolet lamps to enhance the growth of water spinach plants. An alternative recommendation is to reduce battery capacity by using a 12v 65Ah battery to support cost savings during component replacements. Creating a water reservoir tank for aquaponic circulation when the solar panel and battery are unable to supply power to the pump is necessary because aquaponic growing media must remain moist or have water circulation.

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