INTEK Jurnal Penelitian
Vol. 10, No. 1, pp. 64-69, April 2023

Prototype of AC Microgrid Solar Power Plant with Off-Grid System

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***Abstract*— AC microgrid solar power plants can be used as an alternative to overcome the problem of unevenly distributed electricity demand in Indonesia. Prior to implementation, a model or prototype is required to test and provide insights about the solar power plant's functionality as an electric energy generator. The aim of this research was to develop a solar power plant for AC loads and assess the performance of AC Microgrid solar power plants using an Off-grid system. The test results lead to the conclusion that the efficiency of the AC Microgrid solar power plant with the Off-grid system is highly dependent on the intensity of solar radiation, whether it is high or low, striking the panel. The solar panel efficiency ranged from a maximum of 5.54% to a minimum of 4.16%, while the system efficiency varied between a maximum of 8.65% and a minimum of 7.95%.**

Keywords: Prototype, Solar Power Plant, AC Microgrid, Off-grid

I. Introduction

Energy stands as a fundamental human requirement, steadily escalating alongside the standard of living. Within the realm of fulfilling national energy demands, fuel oil maintains a highly influential position [1]. The rising energy demand has led to a reduction in Indonesia's oil production, attributed to both natural decline and diminishing reserves. Amidst the ongoing energy crisis, the idea of diversifying energy sources has emerged, aiming to develop alternative sources for meeting domestic energy consumption [2]. The development of renewable energy sources must be prioritized, as the role and price of fuel continue to rise and escalate, making them an essential substitute for sustainable energy providers [3, 4].

Solar energy, a renewable resource, is abundant in Indonesia due to its equatorial location. The country enjoys ample solar energy availability, boasting an average solar radiation intensity of approximately 4.8 kWh/m^2 per day across its entire expanse. With the abundance of untapped solar energy resources, coupled with the fact that some regions in Indonesia remain un-electrified due to their inaccessibility to the national power grid (PLN), Solar Power Plants emerge as a viable solution to be considered as an alternative electricity generation method [5, 6].

The utilization of solar power technology as an alternative energy source to meet electricity needs takes the form of a Microgrid. The microgrid itself can be elucidated as an integrated electrical system within a confined area, incorporating distributed power sources [7]. Presently, numerous microgrid installations are dispersed throughout Indonesia, with one notable example located on Tomia Island. This island employs the microgrid concept, amalgamating a Diesel Power Plant with Solar Power Plant, boasting a substantial capacity of 75 kWp [8]. In the research [9], the application of a smart microgrid system in a campus area is presented. The research [10] explores the implementation of Microgrid Systems in remote areas.

Considering this description, the implementation of a laboratory-scale microgrid becomes imperative to assess the system's performance and establish it as a valuable

DOI : http://dx.doi.org/10.31963/intek.v10i1.4325

learning tool. This research introduces a prototype of a microgrid AC solar power plant integrated with an off-grid system.

II. Methodology

2.1. Component Design

1. Determining Daily Energy Requirements

The initial step involves calculating the daily energy needs. In this study, the cumulative energy demand is established at 660 Wh, equivalent to 0.66 kWh.

2. Calculating peak power and solar modules

The peak power (kW_{peak}) of solar photovoltaic (PV) is provided as follows:

$$kW_{peak} = kWh : \text{daily irradiation} \quad (1)$$
$$= 0.66 : 5.1 = 0.129 \text{ kWp}$$

This value needs to be increased by 15-25% to account for system losses, resulting in a peak power of 0.379 kWp after the system is added

3. Counting the number of solar panels

$$PV = \frac{\text{Solar module peak power (total Wp)}}{Wp\ modul} \quad (2)$$
$$= \frac{379}{150} = 2{,}5$$
$$= 3 \text{ Pcs}$$

4. Calculating energy and battery requirements

Battery Capacity	= 12 Volt
DoD	= 80 %
Autonomy	= 1 Hari
Current per Hour	= 100 Ah

$$Batt = \frac{Ttotal\ electricity\ demand \times 1}{Dod \times Vs} \quad (3)$$
$$= \frac{660 \times 1}{0.8 \times 12} = 68.75 \text{ Ah}$$

Number of batteries required $= \frac{68.75\ Ah}{100\ Ah} = 0.68$ or = 1 pcs.

5. Selection of inverters

$$P_{inv} = W_{max} + (25\% \times W_{maks}) \quad (4)$$
$$= 660 + (25\% \times 660)$$
$$= 825 \text{ Watt}$$

6. Calculating Solar Charge Controllers

$$P_{scc} = I_{sc} \times \text{Number of Panels} \quad (5)$$
$$= 9.19 \text{ A} \times 3$$
$$= 27.57 = 30 \text{ A}$$

7. Calculating PV Slope

In the process of constructing solar panels, precision is essential when calculating the angle of inclination for optimal sunlight exposure. The orientation and tilt of the solar panels at coordinates 5.12° south latitude and 119.48° east longitude, determined using the formula provided in equation 6, are as follows:

$$\alpha = \delta - lat \quad (6)$$
$$= 23.45° - 5.12°$$
$$= 18.33°$$

2.2. Testing Procedure

The testing procedure comprises four main steps: the no-load test, the loaded test, the loaded battery test, and the efficiency test. The prototype system's configuration is illustrated in Figure 1 below.

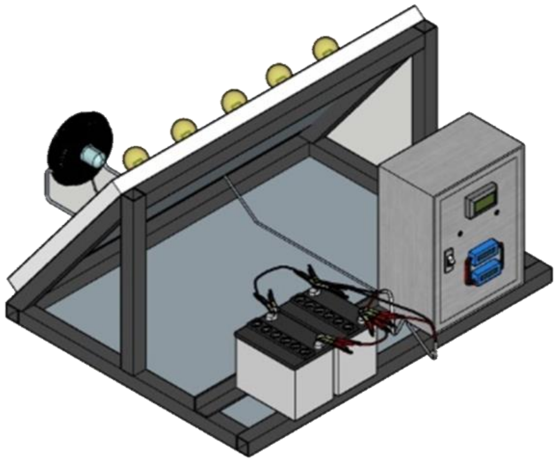

Figure 1. System Prototype

1. Load testing procedure

1) Installing and assembling solar panels, panel boxes and loads for testing.
2) Turn on the light load switch and turn on the fan.
3) Record the measurement results into the observation table.

The parameters to be measured are:

a. Solar radiation intensity, Ir (Watt/m^2)
b. Solar panel output voltage, V (Volts)
c. Solar panel output current, I (Ampere)

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d. Battery input voltage, V (Volts)
e. Battery input current, I (Ampere)
f. Inverter input voltage, V (Volts)
g. Inverter input current, I (Ampere)
h. AC Load Voltage, V (Volts)
i. AC load current, I (Amperes)

4) Analyze the results of observations.
5) Make conclusions about the tests that have been carried out.
6) Testing completed.

Figure 2 shows a load test.

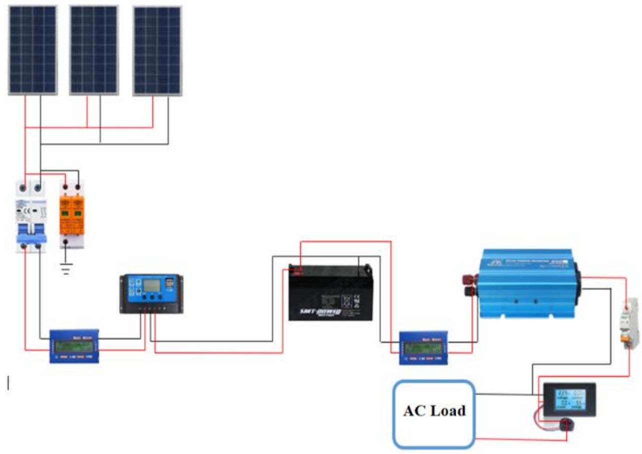

Figure 2. Load testing

2. Loaded battery testing procedure

1) Installing and assembling box panels and loads for testing.
2) Activate the light load switch and turn on the fan.
3) Record the measurement results into the observation table.

The parameters to be measured are:

a. Battery Output Voltage, V (Volt)
b. Battery Output Current, I (Ampere)
c. Inverter input voltage, V (Volt)
d. Inverter input current, I (Amperer)
e. AC Load Voltage, V (Volt)
f. AC load current, I (Ampere)

4) Analyze the results of observations.
5) Make conclusions about the tests that have been carried out.
6) Testing completed.

Figure 3 shows the control circuit for testing a loaded battery.

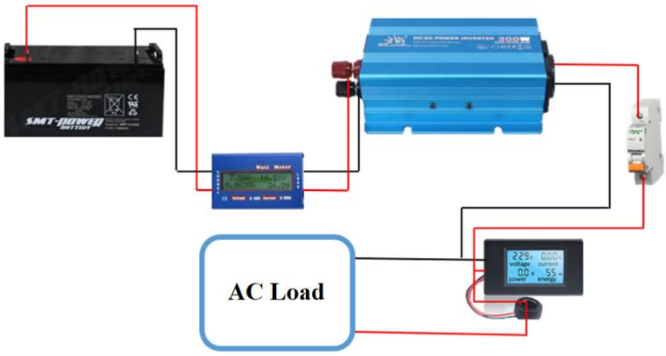

Figure 3. Loaded Battery Testing

3. Procedure for testing the efficiency of solar panels

1) Installing and assembling shear resistance, voltmeter and ammeter for testing.
2) Record the measurement results into the observation table.

The parameters to be measured are:

a. The intensity of solar radiation, Ir (Watt/m^2)
b. Solar panel output voltage, V (Volt)
c. Solar panel output current, I (Ampere)
d. Shear resistance voltage, V (Volt)
e. Shear resistance current, I (Ampere)

3) Analyze the results of observations.
4) Make conclusions about the tests that have been carried out.
5) Testing completed.

Figure 4 shows the test control circuit.

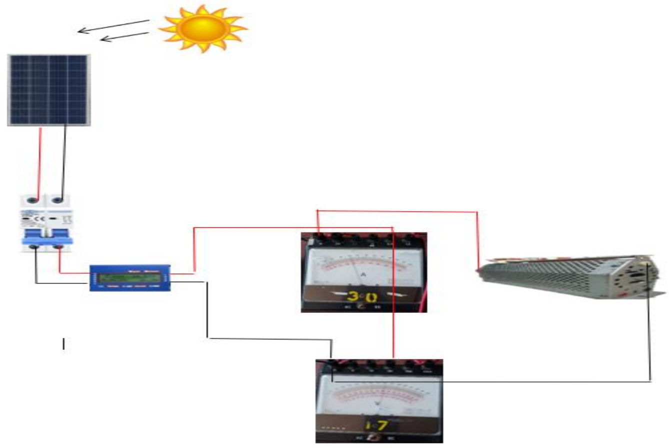

Figure 4. Solar Panel efficiency testing

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2.3. Data Analysis Techniques

The data analysis technique is derived from the equations that will be employed in the following manner:

- Calculate the input power of solar panels using the formula in equation 7.

$$P_{in} = Ir \times A \quad (7)$$

With:

P_{in} = Solar panel input power, (Watt)
Ir = The intensity of solar radiation, (Watt/m^2)
A = Solar panel area, (m^2)

- Calculating the output power of solar panels using the formula in equation 8.

$$P_{out} = V \times I \quad (8)$$

With:

P_{out} = Solar panel output power, (Watt)
V = Voltage, (Volt)
I = Current, (Ampere)

- Calculating the efficiency of Solar Panels using the formula in equation 9.

$$\eta_{pv} = \frac{Pout}{Pin} \; x \; 100\% \quad (9)$$

With:

η_{pv} = Solar panel efficiency, (%)
P_{out} = Solar panel output power, (Watt)
P_{in} = Solar panel input power, (Watt)

- Calculating Inverter efficiency using equation 10.

$$\eta_{Inv} = \frac{Pout\ Inverter}{Pin} \; x \; 100\% \quad (10)$$

Dimana :

η_{Inv} = Inverter efficiency, (%)
$P_{out\text{-}Inv}$ = Inverter output power, (Watt)
P_{in} = Solar panel input power, (Watt)

- Calculating system efficiency using equation 11.

$$\eta_{sys} = \frac{Pout\ batt + Pout\ Inverter}{PIn} \; x \; 100\% \quad (11)$$

With:

η_{Sys} = system efficiency (%)
$P_{out\text{-}Batt}$ = Battery output power, (Watt)
$P_{out\text{-}Inv}$ = Inverter output power, (Watt)
P_{in} = Solar panel input power (Watt)

III. Results and Discussion

This test is conducted to determine the operational functionality of the constructed circuit. The test is performed in three distinct phases. In the first phase, the battery is charged from morning until afternoon. Subsequently, the charging process is immediately followed by applying a load to the circuit with electrical components. Lastly, the battery is promptly discharged right after charging until the reminder indicator, which is the buzzer, activates to signal a low battery condition. Prior to commencing the test, the output of each component is linked to the panel box to facilitate the reading of the measured parameters. This test is conducted with the objective of assessing the output power produced by each utilized electrical component.

3.1. No-load testing

Figure 5 illustrates the performance of the no-load test. The test outcomes exhibit a graphical pattern characterized by an increasing or directly proportional trend. As the intensity of solar radiation generated rises, the voltage value across the solar panel correspondingly increases. This phenomenon is attributed to the fact that, during this test, the solar panel charges the battery without any connected load.

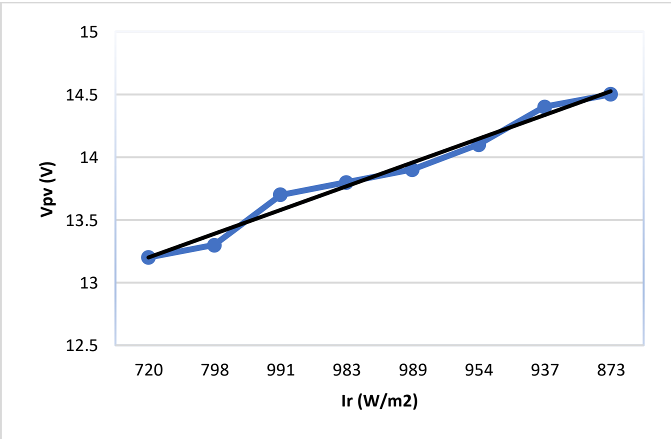

Figure 5. Relationship Between Solar Radiation Intensity and Panel Voltage

The peak radiation intensity reaches its maximum at 991 W/m² around 11:00 WITA. Conversely, the lowest solar

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intensity recorded is 720 W/m² at 10:00 WITA. The highest panel voltage reading is 14.5V at 13:30 WITA, while the lowest panel voltage is 13.2V at 10:00 WITA.

3.2. Load Testing

Figure 6 depicts the correlation between solar panel efficiency and time. The test outcomes indicate that the peak solar panel efficiency is achieved at 12:30 WITA, reaching 5.54%, whereas the lowest efficiency is observed at 11:30 WITA, measuring 4.16%. This fluctuation occurs due to the influence of weather conditions: solar cell efficiency tends to rise during sunny periods and decline during cloudy conditions. The trend chart clearly illustrates the oscillation in efficiency, attributed to the alternation between sunny and cloudy weather patterns.

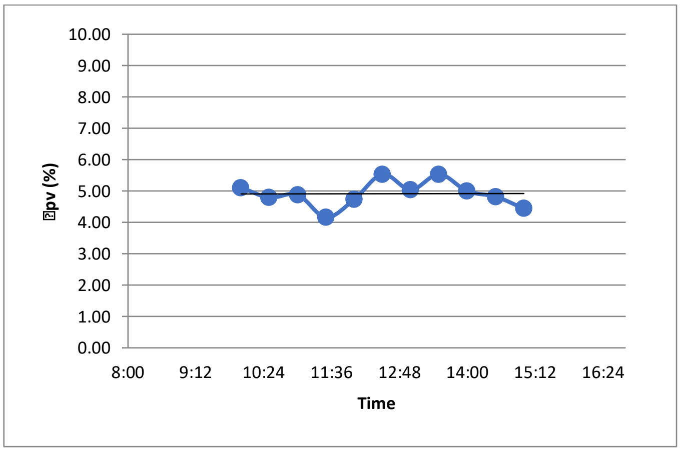

Figure 6. The Relationship Between Solar Panel Efficiency and Time

Figure 7 illustrates the connection between solar radiation intensity and panel input power. As evidenced by Figure 7, there exists a direct correlation between the intensity of solar radiation and the value of solar panel input power: higher solar radiation intensity corresponds to greater input power, and conversely, a decrease in solar radiation intensity leads to a decrease in the solar panel's input power. The most noteworthy solar radiation intensity recorded is 945 W/m², aligning with an input power measurement of 2811.19 Watt. Similarly, the lowest recorded solar radiation intensity is 864 W/m², corresponding to an input power value of 2570.23 Watt.

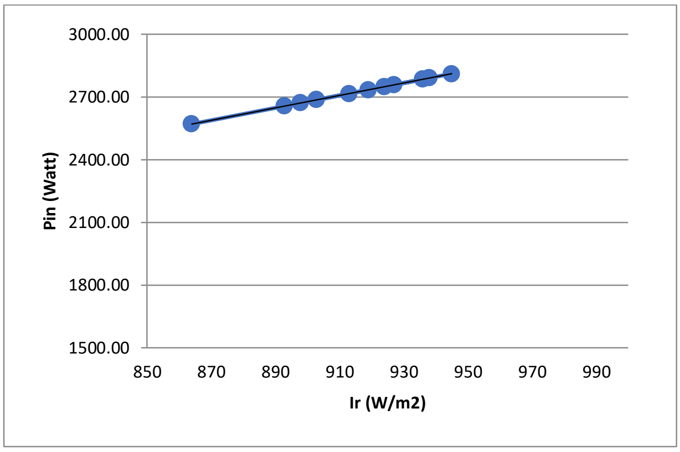

Figure 7. Relationship Between Solar Radiation Intensity and Panel Input Power

Figure 8 demonstrates the correlation between AC load current and time. The graph exhibits a consistent load current of 0.46A from 10:00 WITA to 15:00 WITA. This constancy is attributed to the consistent load configuration employed, consisting of two 25 Watt incandescent lamps, two 10 Watt incandescent lamps, and one 5 Watt incandescent lamp, summing up to a total load of 75 Watt. As a result, the AC load current remains unchanged throughout the specified time interval.

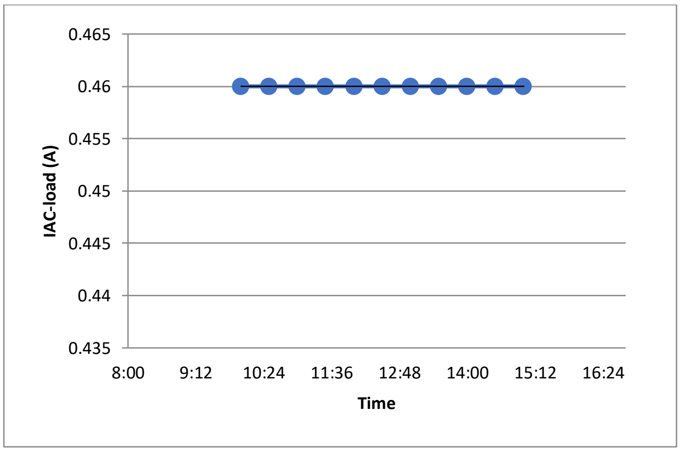

Figure 8. Relationship Between AC Load Current and Time

Figure 9 portrays the connection between voltage and current. The graphical pattern exhibits an upward trend, indicating that as the V_{ac} voltage increases, the battery current (I_{batt}) also increases, and conversely, a decrease in V_{ac} voltage corresponds to a reduction in battery current.

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The peak V_{ac} voltage registered is 240 V, accompanied by a battery current (Ibatt) of 10.8 A. Conversely, the nadir V_{ac} voltage observed is 219 V, coinciding with a battery current of 10.2 A.

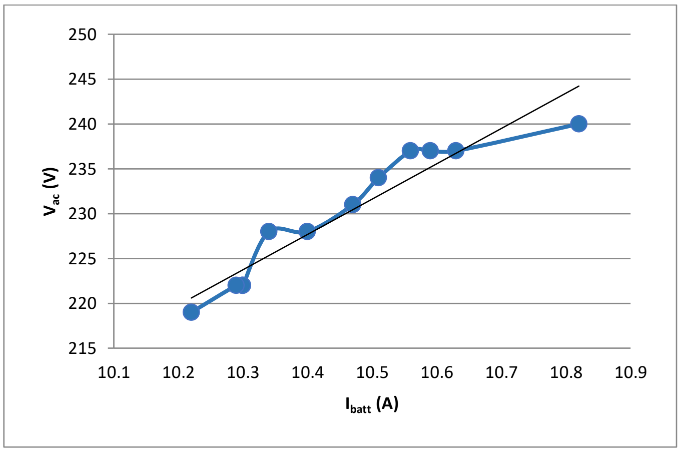

Figure 9. V_{ac} voltage relationship to I_{batt} current

Figure 10 shows the relationship between battery voltage (V_{batt}) and time. The graph shows a downward trend, where the longer the battery is used (loaded), the battery voltage (V_{batt}) will decrease. The highest value for battery voltage is 12.31V at 18.50 WITA and the lowest value is 11.22V at 22.30 WITA.

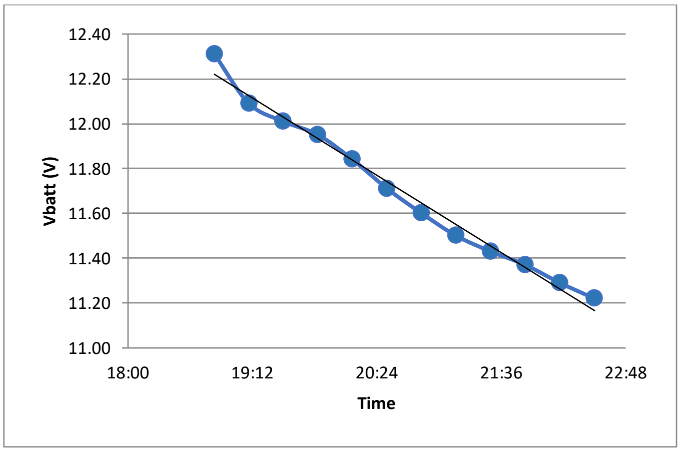

Figure 10. The relationship between battery voltage (V_{batt}) and time

IV. Conclusion

Based on the test results, it can be deduced that the efficiency of the Microgrid AC solar power plant employing the Off-grid system exhibits a strong reliance on the intensity of solar radiation received by the panel. The highest recorded solar panel efficiency occurs at 12:30 WITA, reaching 5.54%, while the lowest solar panel efficiency is noted at 11:30 WITA, amounting to 4.16%. Furthermore, the overall system efficiency follows a similar pattern. The maximum system efficiency of 8.65% is observed at 15:00 WITA, while the minimum system efficiency of 7.95% is registered at 10:00 WITA. These findings underscore the impact of solar radiation intensity on the performance of the Microgrid AC solar power plant, particularly within an Off-grid system configuration.

References

[1] E. K. Stigka, J. A. Paravantis, and G. K. Mihalakakou, "Social acceptance of renewable energy sources: A review of contingent valuation applications," *Renewable and sustainable energy Reviews*, vol. 32, pp. 100-106, 2014.

[2] R. Poudyal, P. Loskot, R. Nepal, R. Parajuli, and S. K. Khadka, "Mitigating the current energy crisis in Nepal with renewable energy sources," *Renewable and Sustainable Energy Reviews*, vol. 116, p. 109388, 2019.

[3] I. Kholiq, "Analysis of Utilization of Alternative Energy Resources as Renewable Energy to Support Fuel Substitution," *Jurnal IPTEK*, vol. 19, no. 2, pp. 75-91, 2015.

[4] F. Firman, N. H. Said, and M. R. Djalal, "Characteristic Analysis of Solar Panels on Clay and Ceramic Roof Tiles," *International Review of Mechanical Engineering (IREME)*, vol. 16, no. 3, 2022, doi: 10.15866/ireme.v16i3.20004.

[5] R. Sianipar, "Dasar Perencanaan Pembangkit Listrik Tenaga Surya," *Jetri: Jurnal Ilmiah Teknik Elektro*, 2014.

[6] S. Suwasti and M. R. Djalal, "Design of Continuous Water Heater Hybrid Solar And Gas System," *Przeglad Elektrotechniczny*, vol. 99, no. 7, 2023.

[7] P. Johansson, M. Vendel, and C. Nuur, "Integrating distributed energy resources in electricity distribution systems: An explorative study of challenges facing DSOs in Sweden," *Utilities Policy*, vol. 67, p. 101117, 2020.

[8] P. Pramana, K. G. H. Mangunkusumo, H. B. Tambunan, and D. R. Jintaka, "Revitalisasi Pembangkit Listrik Tenaga Surya (PLTS) Pada Sistem Microgrid Pulau Tomia," *Jurnal Technopreneur (JTech)*, vol. 9, no. 1, pp. 28-37, 2021.

[9] N. S. Gunawan, I. S. Kumara, and R. Irawati, "Unjuk kerja pembangkit listrik tenaga surya (PLTS) 26, 4 kWp pada sistem smart microgrid UNUD," *Jurnal SPEKTRUM Vol*, vol. 6, no. 3, pp. 1-9, 2019.

[10] T. Ardriani *et al.*, "A DC Microgrid System for Powering Remote Areas," *Energies*, vol. 14, no. 2, doi: 10.3390/en14020493.

DOI : http://dx.doi.org/10.31963/intek.v10i1.4325