# Sensitivity of solar panel energy conversion at sunrise and sunset on three weather fluctuations in equatorial climate

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**Article Info**

***Article history:***

Received Jul 20, 2022
Revised Oct 5, 2022
Accepted Dec 2, 2022

***Keywords:***

Energy conversion
Equatorial climate
Solar panel
Weather fluctuations

**ABSTRACT**

The high sunlight intensity in tropical and equatorial regions makes the potential for installing photovoltaic (PV) panels. However, the initial design of PV installations must be analyzed. Their implementation is carried out in buildings with load power for household electricity scale. For this reason, the panel reliability system could be efficient by designing the initial PV requirements using systematic measurements. Collecting data on fluctuating sunlight intensity (unpredictable weather) conditions needs the use of manual measuring tools, namely digital light meters and PV data with sensor integration. The research sample consists of three fluctuating hot weather conditions, namely hot-sunny, hot-cloudy and hot-rainy conditions. These weather conditions were taken because the climate of West Sumatra tends to shift clouds which sometimes cover the sun's rays. The peak PV output for direct current (DC) power generated during hot- sunny conditions reaches 1827.17 W, in sunny-cloudy weather it reaches around 1626.85 W and during sunny-rainy weather conditions the resulting output is 1161.81 W. From daily measurements, the results show that the efficiency of the PV system is strongly influenced by the prevailing weather climate.



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## 1. INTRODUCTION

The development of technology and the increasing demand for electrical power has forced the entire world community to switch and penetrate renewable energy. Planning for the development of a renewable power system has very promising effects for the future [1], [2]. The technology that is very popularly used is solar panel technology by exploiting the energy source produced by the sun to the maximum [3], [4]. Although renewable energy sources have great opportunities in Indonesia, the ever-changing climate will have an impact on the conversion of energy produced by photovoltaic (PV) [5], [6]. However, the strategy of integrating additional PV that is connected to the grid will have a large impact to compensate for electric power and very expensive electricity bills [7], [8]. The advantage will occur if the integration between the addition of PV using a Grid tied inverter will have an impact on minimizing the classic optimal power flow and suppressing the use of excess load from the grid [9], [10]. In contrast to the state of previous energy sources such as energy sourced from fossils, it has many weaknesses, one of which causes air pollution which increases free radicals on human health. Therefore, the potential for renewable energy is designed to be able to alleviate the current energy problem and then provide environmentally friendly and sustainable energy [11], [12]. In terms of using renewable energy, there are actually many renewable energies that are suitable to be installed in tropical climates, but the obstacles that arise are the changing conditions of the transition season in Indonesia currently making energy other than PV still being considered in its use. Apart from these conditions, time-consuming installation and an expensive initial investment of energy sourced other than PV technology when combined with the grid is still less effective and feasible for a hybrid system [13], [14]. Meanwhile, Indonesia's radiation potential has a capacity of 4.8 kWh/m$^2$ per day [15], [16]. This makes the opportunity for all of Indonesia to have considerable potential in the development of solar energy, especially the western part of Sumatra. The potential of the geographical position and the high tropical climate is very beneficial for the application of PV technology because the West Sumatra region is at the equator latitude which is in the Bonjol area in order for the potential for solar power and heat energy is very high and efficient [17], [18]. Based on this, PV installation is considered a very potential solution and promises to be a single energy source in the future [19], [20].

In the installation of solar panels, many parameters must be considered such as solar radiation, air humidity, surface temperature of the solar cells will be very decisive in the output of the solar panel installation when installed in a horizontal position above the building [21], [22]. Utilization of the installation of a system connected to the grid is possible because the cost of electricity bills continues to increase, especially for industrial companies and universities [23], [24]. For this reason, the operation of a Grid tied inverter that is connected to the grid and solar panels must be considered so that high electrical loads are monitored continuously so as to make consumers more energy efficient. However, erratic weather fluctuations require in-depth analysis before designing and installing solar panels [25], [26]. Conditions that will be reviewed and analyzed more deeply are hot-sunny weather conditions, hot-cloudy weather conditions and hot-rainy weather. This will have an impact on the reliability of PV operations and the position of the PV installation layout.

## 2. METHOD

The reliability and effectiveness of the PV method utilizing the grid can be analyzed using data that is monitored using a personal computer. Real-time monitoring of solar panels output from solar panels will make it easier to design and install the use of solar panels, especially in areas that have potential or tropical climates [27], [28]. Variables for data collection using Three different weather fluctuation conditions, namely sunny-hot, sunny-cloudy, and sunny-rainy conditions based on changing climatic fluctuation conditions in the West Sumatra region. To see the sample conditions for the location of the equator point in the Bonjol area of West Sumatra, see Figure 1.


Figure 1. The area of West Sumatra which is traversed by the equator in Indonesia

### 2.1. Integrated PV trial design system

To monitor the activity of solar panels, a personal computer that has integrated PV and grid is needed by using the main component of the grid tied inverter for load balancing that supplies power to each other. The control circuit for monitoring uses a PV capacity of 260 Wp x 8 panel units which will later be connected to the main Arduino control to interface to the PLX-DAQ software and also a notepad as data backup if the PLX-DAQ error occurs in data storage. To see the Arduino-PV-grid integration connected to the Grid tied inverter that is monitored on a PC Figure 2.

Based on the initial objective, three different weather conditions were used for the data gathering process, and the results are current in the form of voltage (V) and current (I). From these data, it is formulated so that the total power can be obtained. Data retrieval in one day is carried out between the time range 7.00 am to 6.00 pm. The (1) is the voltage in series based on the specifications of the Grid tied inverter, then the value of active and reactive power (Pg and Qg) is injected into the grid by the Grid tied inverter based on (2) and the total energy generated by PV is based on (3).

$$\text{Vseries} = \sum_{j=1}^{n} V_j = V1 + V2 \ldots\ldots Vn \quad (1)$$

$$P_g = V_g\, I_g\, cos\varphi \quad (2)$$

$$\text{Energy} = \int_0^t p(time)dt \quad (3)$$

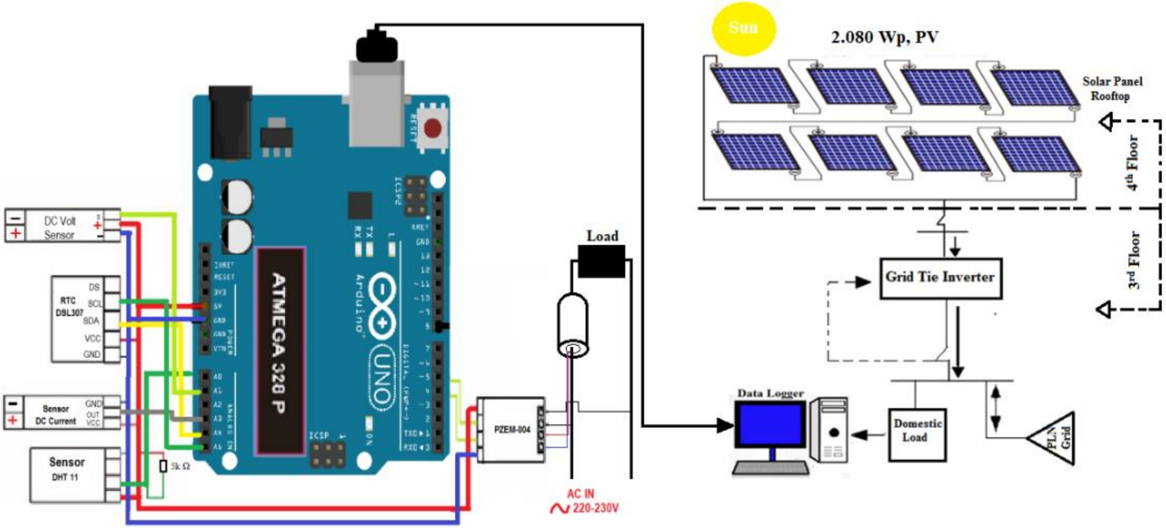



Figure 2. Arduino-PV-grid integration schematic connected grid tied inverter monitored on PC

### 2.2. PV data collection based on three fluctuating weather variables

The test was carried out using eight units of solar panels with each panel unit with a capacity of 260 Wp of the type of polycrystalline arranged in a series circuit and connected to a grid tied inverter with a domestic load. Meanwhile, the supporting components of the data acquisition tool consist of a temperature sensor, DC power sensor, AC power sensor, Arduino Uno microcontroller, real time clock (RTC) to show the time, and a typical digital light meter to gauge how much sunlight is current. The series of real condition testing is shown in Figure 3.

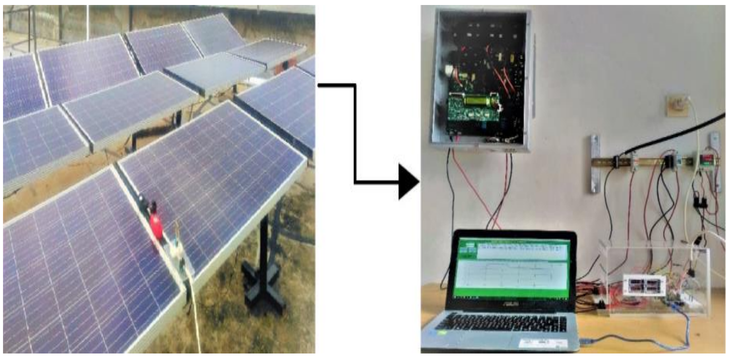


Figure 3. Measurement of the PV on-gird monitoring system for three variations of fluctuating hot weather

## 3. RESULTS AND DISCUSSION

The data collection process is based on weather conditions which will later display graphical data. Then a digital light meter is used to gauge the strength of the sun is used to see the daily weather conditions that are taken manually and the real conditions in the field. For more details, the results of the intensity of sunlight can be seen in Table 1. Information on time and weather conditions obtained data taken one day with three fluctuating weather conditions and also based on data analysis with a manual system using field observations. The amount of electricity consumption value generated by PV connected to the grid will be displayed based on a graph.

Table 1. The performance intensity of the weather fluctuates using the digital light meter measurement tool

| Time | Sunlight Intensity (Lux) | Weather | Sunlight Intensity (Lux) | Weather | Sunlight Intensity (Lux) | Weather |
|---|---|---|---|---|---|---|
| 07.00 to 08.00 am | 39400 | Hot-Sunny | 18400 | Hot-Cloudy | 12500 | Hot |
| 08.00 to 09.00 am | 43500 | Hot-Sunny | 27000 | Hot-Cloudy | 17600 | Hot |
| 09.00 to 10.00 am | 75400 | Hot-Sunny | 39000 | Hot-Cloudy | 23200 | Hot |
| 10.00 to 11.00 am | 93400 | Hot-Sunny | 42700 | Hot-Cloudy | 26400 | Hot |
| 11.00 to 12.00 am | 137100 | Hot-Sunny | 64500 | Hot-Cloudy | 38200 | Hot |
| 12.00 to 13.00 am | 144900 | Hot-Sunny | 72000 | Hot-Cloudy | 41000 | Hot |
| 13.00 to 14.00 pm | 132400 | Hot-Sunny | 42700 | Hot-Cloudy | 32000 | Hot-Rain |
| 14.00 to 15.00 pm | 95800 | Hot-Sunny | 23500 | Hot-Cloudy | 20300 | Hot-Rain |
| 15.00 to 16.00 pm | 67900 | Hot-Sunny | 19700 | Hot-Cloudy | 15400 | Hot-Rain |
| 16.00 to 17.00 pm | 46700 | Hot-Sunny | 14400 | Hot-Cloudy | 11500 | Hot-Rain |
| 17.00 to 18.00 pm | 33400 | Hot-Sunny | 9500 | Hot-Cloudy | 6500 | Hot-Rain |

### 3.1. Data generated hot-sunny weather

The data retrieval process for hot-sunny conditions based on the graph shows that when it is sunny and hot, the fluctuations in sun conditions are quite maximum. To find out graphs when conditions are hot and sunny, the display received includes graphs of temperature conditions, graphs of DC and AC voltages, graphs of DC and AC currents, graphs of DC and AC power. For a clearer result of the intensity of sunlight in hot-sunny conditions such as in Figure 4.

Based on Figure 4(a), temperature condition graph during the hot, bright conditions starting at sunrise at 07.00 am. A significant increase in temperature occurred during the time interval starting at 12.15 to 15.1 and even reached a temperature of 45 ˚C. Then in Figure 4(b) weather fluctuations occur in hot conditions until the DC current reaches 8.66 A and AC reaches 8.13 A. While in Figure 4(c) the AC voltage is observed to be very stable while the DC voltage is occasionally observed to drop the voltage due to cloud-covered sun conditions. based on the graphs of AC and DC power, it can be seen in Figure 4(d) for the relationship between AC power and DC power, the two graphs are relatively synchronous. Power increases slowly and power fluctuations start to become irregular. Peak power (Wp) reaches 1827.17 Watt for DC while peak power AC (Wp) reaches 1829.0 Watt. The activity of decreasing power occurs because the sun has started to set until 06.00 pm. Furthermore, to see the accumulation of data produced by 8 polycrystalline solar panels which are arranged in series in sunny weather conditions, just Table 2. The peak load data was collected during eleven hours, showing the average power of 5.23 kWh for DC power, while the average power for AC power was 5.25 kWh.

### 3.2. Hot-cloudy weather test

PV-grid testing in hot-cloudy weather conditions is displayed in the form of graphs including temperature, DC and AC voltage graphs, DC and AC current graphs, DC and AC power graphs. Taking hot-warm conditions is very necessary because the geographical area of West Sumatra is almost experiencing hot-cloudy fluctuations. Temperature in hot-cloudy conditions resulted in the highest temperature rating of 39 ˚C. Hot-cloudy weather conditions as shown in Figure 5.

Based on Figure 5(a), temperature conditions graph monitored. Fluctuating heat-cloudy conditions on the PV-grid occur unstable temperature changes on the surface of the solar panel. Then in Figure 5(b), voltage (AC and DC) graph, there is a voltage drop many times which is caused by the surface of the solar panel being occasionally covered with clouds then the weather is hot again while the voltage is low. For Figure 5(c), current (AC and DC) graph is monitored in fluctuating heat-cloudy conditions, DC current reaches 7.64 A and AC current is 7.48 A. Then in Figure 5(d), Power (AC and DC) is observed that graphical measurement of both DC and AC power in hot-cloudy conditions over the span of time that occurred. The relationship between both AC and DC power is monitored in sync. For the power that was monitored starting at 7.00 am and at 8.00 am fluctuations began to occur irregularly. However, the peak power (Wp) reaches 1,626.85 Watt for DC while the peak power (Wp) for AC reaches 1,677 Watt. And there is a decrease in power until 6.00 pm until the data collection is complete.

The accumulation of data generated by eight solar panels that are connected in series under sunny cloudy weather conditions is shown in Table 3. Data on the peak load for DC power was obtained for 11 hours, the average power was 1.02 kWh and the average AC power generated was 1.11 kWh. Energy consumption obtained during cloudy weather is also covered by smog conditions that occur in the West Sumatra region.

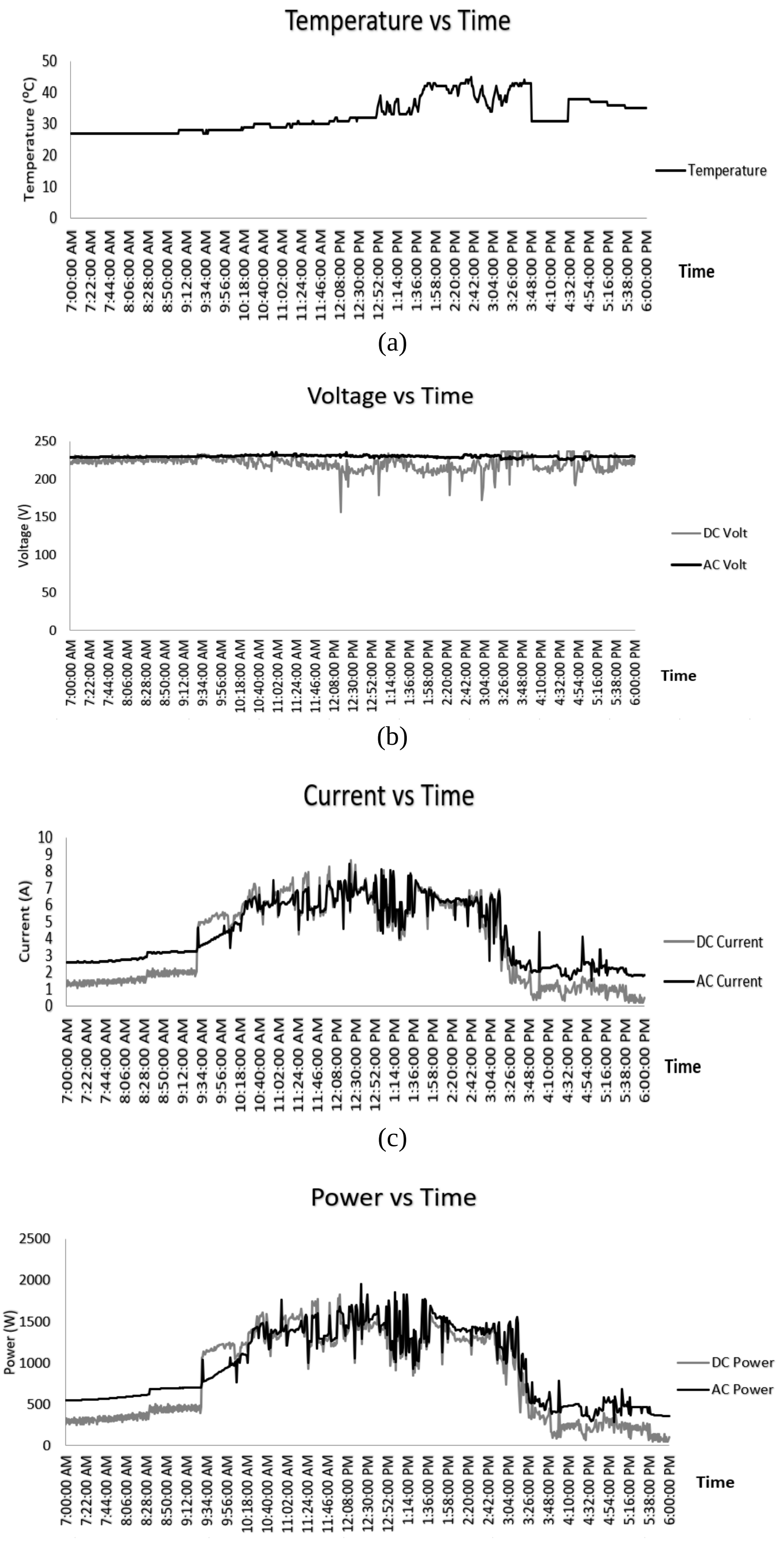
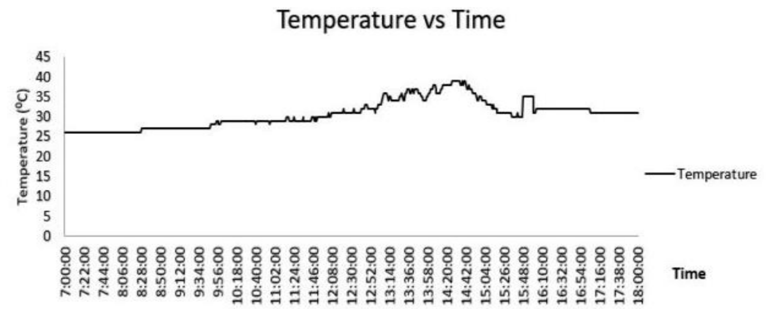


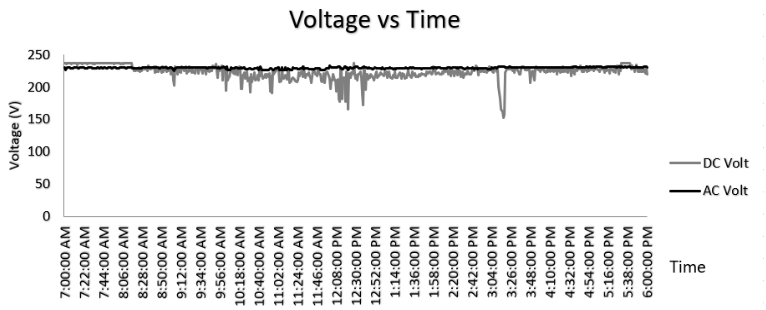

Figure 4. Fluctuation of heat-brightness on PV-grid: (a) temperature condition graph, (b) voltage (AC and DC) graph, (c) current (AC and DC) graph, and (d) power (AC and DC) graph

Table 2. Peak load accumulation of hot-sunny weather

| Power | Time Interval | Max. Current | Power Average |
|---|---|---|---|
| DC | 07.00 am to 06.00 pm | 8.66 A | 5.23 kWh |
| AC | 07.00 am to 06.00 pm | 8.13 A | 5.25 kWh |




(a)

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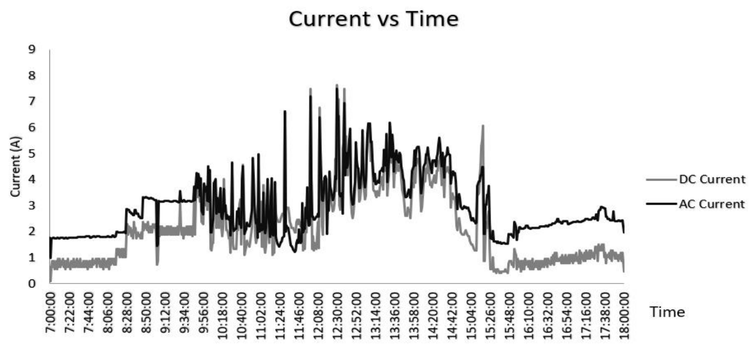


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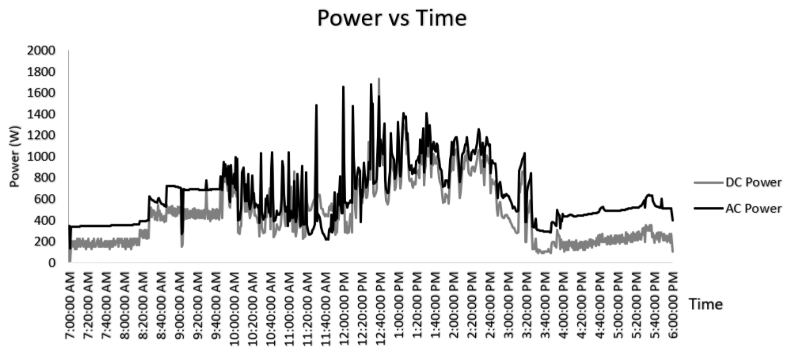



(d)

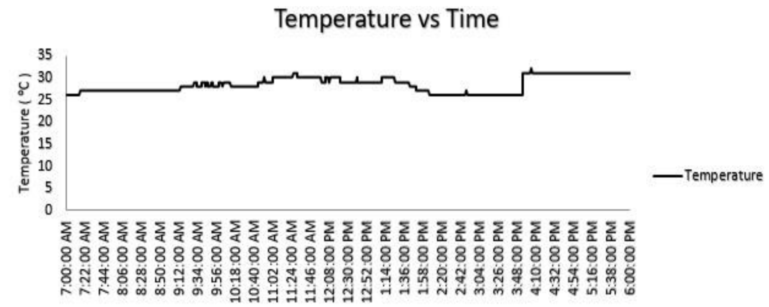
Figure 5. Fluctuating heat-cloudy conditions on the PV-grid: (a) temperature conditions graph, (b) voltage (AC and DC) graph, (c) current (AC and DC) graph, and (d) power (AC and DC)

Table 3. Peak load accumulation hot-cloudy weather

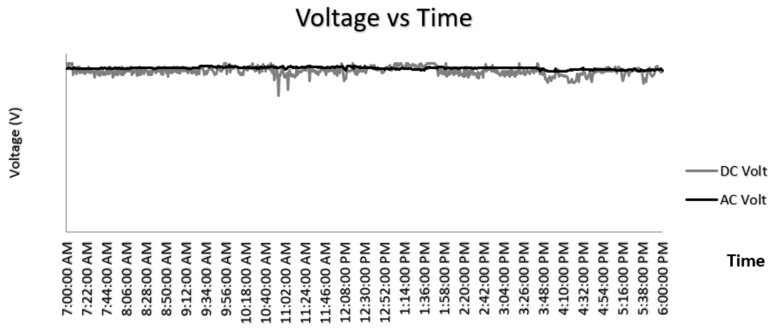
| Power | Time Interval | Max. Current | Power Average |
|---|---|---|---|
| DC | 07.00 am to 06.00 pm | 7.64 A | 1.02 kWh |
| AC | 07.00 am to 06.00 pm | 7.48 A | 1.11 kWh |

### 3.3. Hot-rainy weather test

Testing and retrieval of PV-grid data in hot-rainy weather conditions are displayed in the form of graphs including temperature, DC and AC voltage graphs, DC and AC current graphs, DC and AC power graphs. Taking hot-rain conditions is also very necessary because the uncertain transition season will result in variations that will fluctuation`s affect the output of PV temperature in sunny-rainy weather the highest temperature rating is up to 31 ˚C. To see hot-rainy weather conditions as shown in Figure 6(a)-(d).




(a)

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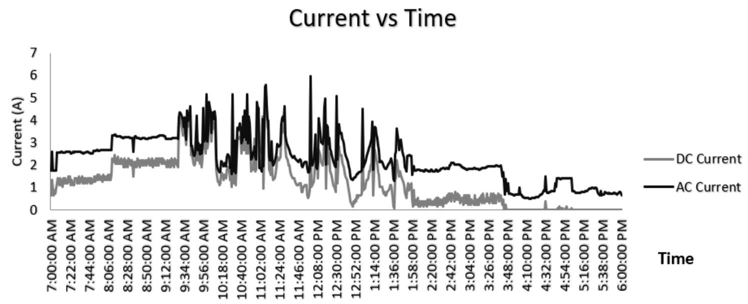
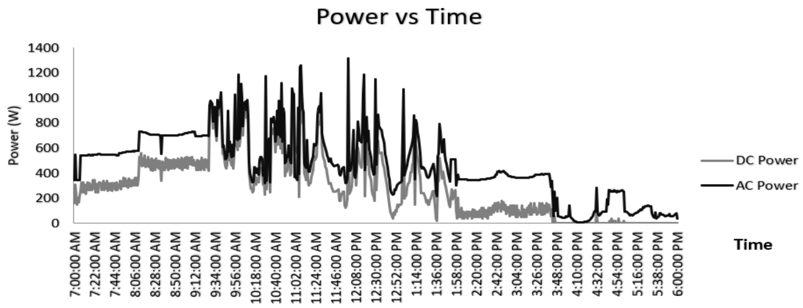



(c)




(d)

Figure 6. Fluctuating hot-rainy conditions on the PV-grid: (a) temperature conditions graph, (b) voltage (AC and DC) graph, (c) current (AC and DC) graph, and (d) power (AC and DC) graph

Based on Figure 6(a), graph of temperature conditions during hot-rainy conditions, it is observed that the temperature fluctuates but the surface temperature of the solar panel which is still hot makes the temperature not fall significantly. Then in Figure 6(b), voltage (AC and DC) graph DC voltage drop occurs due to hot conditions and suddenly it rains, inversely proportional to the AC voltage which is still stable. Then Figure 6(c), Current (AC and DC) was observed that the peak current during Hot-rainy conditions reached 5.12 A for DC current and 5.56 A for AC current. In Figure 6(d), it can be seen that the relationship between AC power and DC power is monitored synchronously on both graphs with data collection starting at 7.00 am. Then the weather changes and the sun's position is covered by clouds so that the power fluctuates irregularly. Peak power (Wp) reaches 1161.81 Watts for DC while AC reaches peak power (Wp) of 1251 Watts. The activity ended at around 6.00 pm resulting in a drastic decrease in current. Even though the peak power reached its maximum value, the overall average power was still low. Hot weather conditions occur at 07.00 am until almost 02.00 pm, while hot weather accompanied by rainy weather occurs from 02.00 pm to 06.00 pm. The erratic weather fluctuations make the PV output performance experience a significant decrease which will make the PV security system less than optimal.

The accumulation of data generated by eight polycrystalline solar panels which are arranged in series in sunny and rainy weather conditions is shown in Table 4. The average DC power reaches 342.60 Watts and the average AC power generated is 463.54 Watts. in the same time span, Specifically, the period from 7 am until 6 pm. The lack of energy conversion that affects the output of PV in this study can be explained that solar radiation is one of the most important elements that will impact the output of PV. In addition to weather fluctuations that continue to experience changes that make PV output decrease drastically, there are other factors that will also affect the output of power conversion produced by PV, namely the PV surface will greatly affect the angle of sunlight, as a result in the afternoon the angle of sunlight is not upright. perpendicular to the PV plane or far deviated from the PV surface, the PV output will decrease significantly.

Table 4. Peak load accumulation hot-rainy weather

| Power | Time interval | Max. current | Power average |
|---|---|---|---|
| DC | 07.00 am to 06.00 pm | 5.12 A | 342.60 Watt |
| AC | 07.00 am to 06.00 pm | 5.56 A | 463.54 Watt |

## 4. CONCLUSION

Equipment that uses a solar optimization data acquisition system that is used to determine the amount of current (AC or DC), voltage (AC or DC), and energy/power (AC, DC), the potential of solar energy that can measure energy, current, and power (AC and DC) (AC, DC), temperature using a microcontroller. The graph in hot-sunny weather shows the intensity of light that is occasionally blocked by cloud movement, causing a lack of PV efficiency to supply maximum power. Energy consumption obtained during hot-cloudy weather is also shrouded by smog conditions that occur in the West Sumatra region. The time range in the measurement is the same, namely the time interval from 07.00 am to 06.00 pm. PV with a capacity of 2,080 Wp experiences irregular fluctuations in energy supply, when the sun is blocked by clouds the graph drops drastically and if the sun is not blocked by clouds the energy supply increases drastically. When the weather conditions are sunny and hot, the graphic display looks to move up and is able to approach the 2,000-Watt rating.

## ACKNOWLEDGEMENTS

Thanks to *Direktur Riset, Teknologi, dan Pengabdian Kepada Masyarakat (DRTPM)* for the funds provided under the research scheme with contract number 153/E5/PG.02.00.PT/2022, 056/LL1/LT/K/2022. Thank you to *DRTPM Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi (Kemendikbudristek)* for the publication funds provided.

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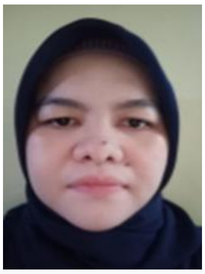

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