Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 2	Month	: April
p-ISSN	: 1693-5462	Volume	: 22	Year	: 2024

Article Processing Dates: Received on 2023-11-07, Reviewed on 2024-03-10, Revised on 2024-04-15, Accepted on 2024-04-21 and Available online on 2024-04-30

Optimization and monitoring of solar power plant as a hybrid energy for tea leaf dryer based on SCADA system

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Abstract

Previous research has discussed tea drying machines with energy sources from PLN. Tea drying machines with refrigerant systems require large electrical energy costs. The electrical energy produced by a tea drying machine is proportional to its performance and cost. This research designed a 400 WP solar cell (PLTS) as a power supply for drying tea leaves. PLTS was combined with a PLN electricity source. Hybrid energy from PLTS and PLN was designed to maximize the use of electrical energy used by drying tea leaves. PLC and SCADA were used to monitor input current, output voltage, and output power. PLC and SCADA can optimize load requirements. When the solar radiation received by the solar panels was not optimal, PLN was able to back up load requirements. The average voltage produced by hybrid energy was 232.4 V. Hybrid energy was able to save power usage of 108.92 W or 12.8% of the load power requirements.

Keywords:
Hybrid solar power plant, refrigeration system, PLC, SCADA, tea leaf dryer.

1 Introduction

The processed products of the tea plant are widely consumed by Indonesian. The benefits of consuming tea are not only due to the taste of the tea, but also for health reasons. Tea that is processed in a quality manner will contain vitamins B1, B2, C, E, and K. Apart from that, several previous studies have examined that the minerals fluorine, manganese, calcium, potassium, and potassium can also be produced from the processing of tea leaves [1].

The tea drying process plays a vital role in the quality of the processed tea. The effects of drying tea include the water content, color, pH and aroma of the tea. In previous research, it has been observed that tea drying in Indonesia uses cabinet drying, roasting and drying in an open space using the sun. Sun drying requires a heat of 35 degrees Celsius for 8 hours [2]. However, fluctuating solar heat conditions will cause drying results to be less than optimal.

The design of a green tea leaf dryer with a PLC and SCADA based refrigeration system has been developed in previous research. In this research, it was found that the dryness level of green tea was 48.5% during the 5 hours drying process. The power supply for the green tea dryer comes from PLN. To minimize operational costs caused by electrical energy consumption, in this research a hybrid Solar Power Plant (PLTS) connected to the grid was proposed as a power supplier for green tea leaf dryers. The use of Solar Power Plants (PLTS) was chosen because it is the renewable energy source with the most potential to be developed in Indonesia. Research in the field of new and renewable energy is one of the universities' supports for the government's policy to increase the mix of new and renewable energy to overcome the energy crisis and produce environmentally friendly energy [3], [4].

The previous research developed a small capacity grain drying machine. The machine was controlled with a PLC and monitored using SCADA [5], [6]. The grain drying machine is an alternative to traditional drying of the moisture content of grain, namely with solar heat. The grain drying process has been tested and measured every 10 minutes with an average decrease in water content of 0.5%. Testing was carried out for 90 minutes with a power source from grid. In this case the sun is not used at all in the drying pro-energy utilizing the energy conversion.

The process of drying tea is difficult because tea leaves are easily damaged [7]. Automatic drying using a mechanical system and control system has been carried out. The control system is used to control and monitor the drying process automatically. Microcontrollers and communication systems have been used in previous research [8].

Food dryers with an electricity source from solar cells have been studied in previous research [9]. This tool is used to remove water content in horticultural products. The results of drying food can increase the shelf life of food. Voltage and current tests on batteries and inverters are carried out from 08.00 to 10.00 WIB. The test results showed that the initial battery voltage of 12.17 volts at 08.00 dropped to 11.68 volts at 10.00, which shows that the battery is still functioning normally. In other measurement results, it was found that fluctuating weather affects the performance of solar cell [10].

Research on the use of solar cell in a coffee bean dryer has been conducted. The drying machine in this research is Nordic which is owned by Sintesa Coffee. The total power capacity of the solar panels required is 1163.8 Wp to meet the system's power requirements. Meanwhile, the solar panels used in this research were only 250 Wp. 5 solar panels are needed to meet the power requirements of the system. Solar panels need about 4 hours to reach the capacity desired by the system. With this power capacity, the machine can dry 1 kg of coffee beans in 1 hour. This research explains that the use of PLTS can minimize costs and equipment dimensions. However, drying coffee beans using solar cell energy sources is slower than LPG, because it takes 4 hours to supply the battery capacity of the PLTS [11].

The previous research stated that fishermen use sunlight to dry fish. This method has weaknesses, including lack of hygiene, the need of larger area, uncontrolled temperature, and longer duration of drying. A fish dryer with a refrigerator used to heat the drying rack space with a solar cell energy source is discussed in this research. Testing is carried out from 09.00 to 16.00 WIT. The tool is measured every 1 hour. The results obtained were an average solar panel output voltage of 39.9 VDC and an average drying room temperature of 36.2°C [12].

Based on the Minister of Energy and Mineral Resources regulations, the standard solar cell generation capacity is 20% of the electricity used from PLN. Previous research shows that solar cells can operate optimally from 09.00–15.00 WIB. The average voltage produced by solar cells is 17.41 V. The highest output current is at 13.00 when the weather is sunny [13]. The output from solar panels is not optimal during cloudy weather, PLN must be able to supply the load in these conditions. Integration of power supply from solar cells and PLN can use PLC and SCADA [14], [15], [16].

In the application of machines in industry, of course solar cells cannot be used as a complete energy source because it still depends on the weather. However, efforts to develop solar cell as an alternative source have been supported by the Indonesian government since 2018 in the Rooftop Photovoltaic Solar Systems (RPVSS) policy. Customers and industries can generate their own electricity from solar cells and export excess electricity to the national grid. According to Setyawati, 2020, the use of hybrid energy sources (solar cell and PLN) which have been designed based on the required capacity can supply electrical energy continuously [17]. The working principle of the hybrid system in this research is with an Arduino Uno microcontroller and a relay as control of the electricity source used, the source will be transferred to grid if the solar cell's battery voltage runs out or does not match the required capacity.

Research on PLC and SCADA to monitor and control hybrid energy sources has been conducted. Testing was carried out at 08.00 in the Semarang State Polytechnic Electrical Engineering Laboratory Building. Data collection on solar cells is carried out every 1 hour. The peak solar cell power is generated at 12.00, which is 618 watts. At 18.00, PLTS experienced a decline in performance, so that PLTS was no longer able to supply the load. Then, a hybrid energy source was tested, showing that from 11.00 to 14.00 WIB the average supply from solar cell was 421.5 watts and the average supply from grid was 11.4 watts. From 15.00 to 17.00 the power supply from solar cell decreased, while the supply from grid experienced a very significant increase. The load can be supplied continuously with a hybrid energy source. PLC and SCADA in this research are used to monitor data [18].

The purposes of this researchis to optimize and monitor solar cells as a hybrid energy for tea leaf dryer based on a SCADA system.

2 Research Method

The research method carried out to design optimization and monitoring of solar cells as hybrid energy for tea leaf dryer based on a SCADA system consists of the literature study stage, design, and manufacture of the hybrid photovoltaic system, design of SCADA-based monitoring systems for hybrid photovoltaic system, system testing, and system analysis. The research method shown in Fig. 1.

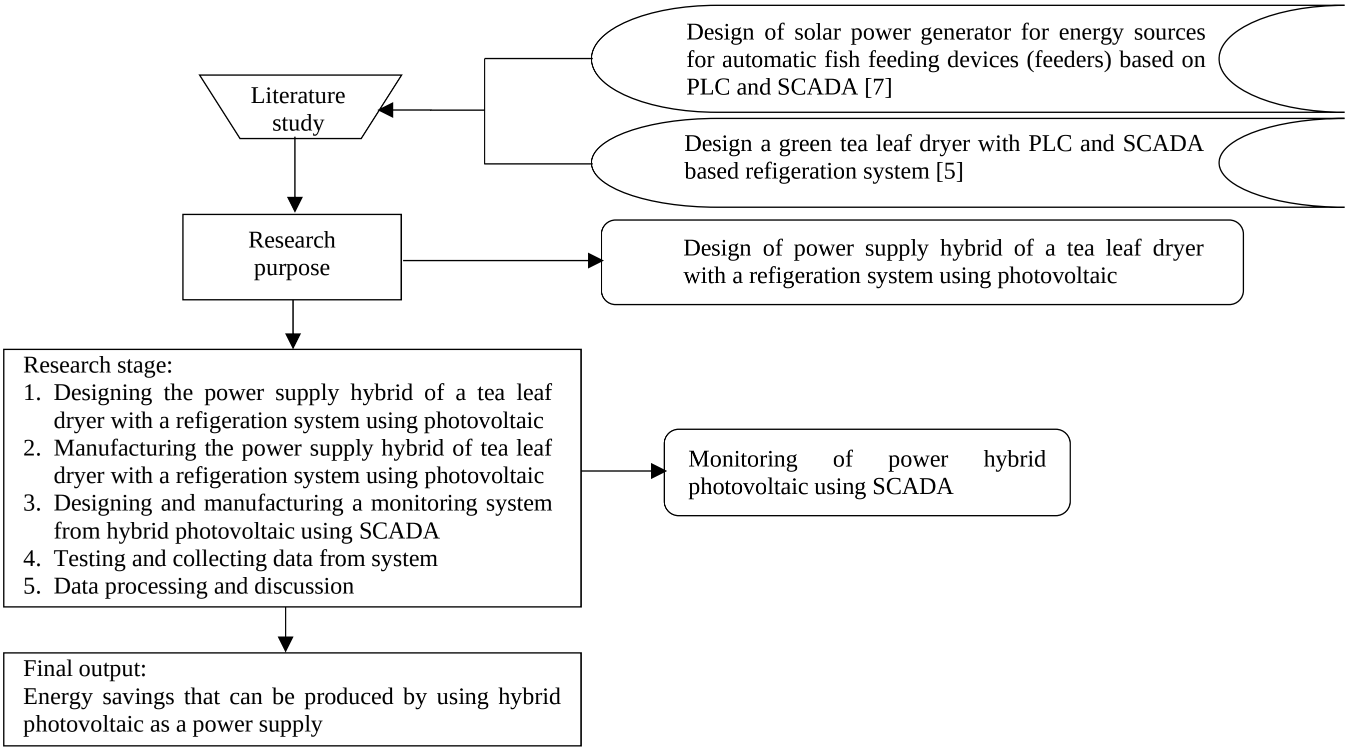

Fig. 1. Research flowchart.

2.1 Preparation

This stage contains the preparation of equipment and materials needed to design and build hybrid solar power plants as the main supply of tea leaf drying machines using a refrigeration system. The photovoltaic systems designed to have a capacity of 400 Wp are equipped with a SCADA system which is used to monitor the output power produced by photovoltaics. The use of hybrid PLTS aims to reduce electrical power from PLN which is used for the refrigeration system on tea leaf drying machines.

2.2 Designing and Manufacturing Hybrid Photovoltaic for Power Supply

A block diagram of the hybrid photovoltaic planning working system for a tea leaf drying machine with a refrigeration system shown in Fig. 2.

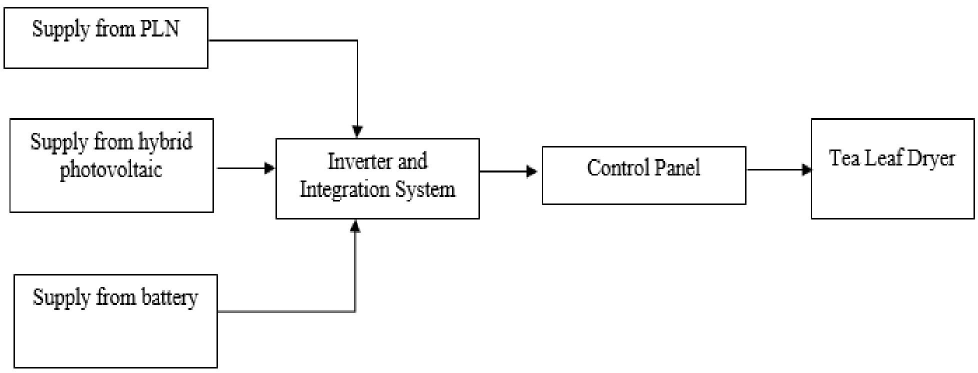

Fig. 2. Working system of hybrid photovoltaic.

Based on the picture above, it shown that there are three energy sources used to supply tea leaf drying machines with a refrigeration system, consisting of PLN supply, hybrid photovoltaic, and batteries. The three supplies are integrated into the on-grid inverter which is then controlled in the control panel of the tea leaf drying machine based on the refrigeration system. The equipment inside the control panel consists of overvoltage and overload safety equipment as well as PLC and SCADA systems used for monitoring the output power of hybrid photovoltaic. The design block diagram of Hybrid Photovoltaic for a tea leaf dryer based on a refrigeration system shown in Figure 3.

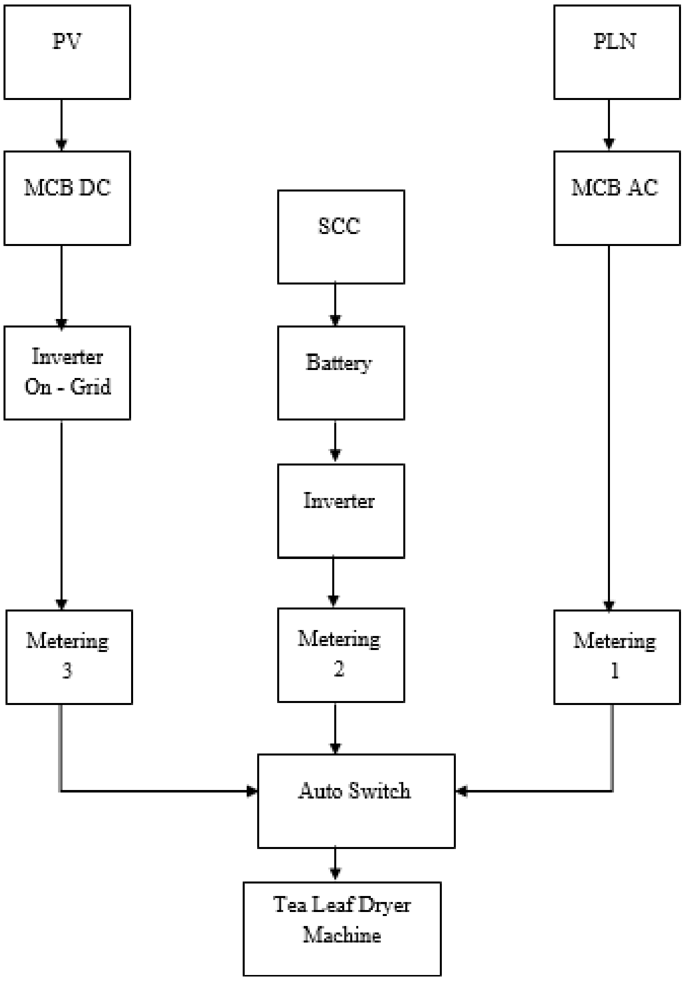

Fig. 3. Diagram block of hybrid photovoltaic system.

A tea leaf drying machine with a refrigeration system requires electrical power of 900 W. If the length of drying tea leaves for 5 hours, then the amount of electrical energy needed by the tea leaf drying machine is 4500 Wh/operation. In the design of hybrid Photovoltaic, photovoltaic only serves to reduce the amount of electrical energy needed from PLN. Photovoltaic together with PLN together to supplies power in the tea leaf dryer, while the battery is used as a backup energy source.

The capacity of solar panels to supply electrical energy to the leaf dryer machine can be calculated using the Eq. 1 [19].

$$Cap.PV = \frac{energy\ needs}{min.radiation} G_{STC} \quad (1)$$

Where energy requirements are the total load requirements for one day (kWh), minimum radiation is the minimum radiation received by the area in one year (kWh/m^2/day), GSTC is the standard radiation received by solar panels which are 1000 W/m^2 at a temperature of 25°C. According to https://globalsolaratlas.info/ the minimum radiation amount for Semarang City occurs in December of 2.28 kWh/m^2/day. Assuming the magnitude of the efficiency of the hybrid photovoltaic system by 80%, it is found that the PV capacity requirement to supply tea leaf drying machines based on the refrigeration system is 246.4 Wp. The solar panels used in this design are 2 Monocrystalline 200 Wp type solar panels. The photovoltaic installation has a configuration installed in series to get an output voltage of 24–48 Vdc by the input voltage of the inverter. The inverter used in this design has a capacity of 1000 W equipped with MPPT.

The design of a photovoltaic hybrid equipped with a battery that serves as a backup energy source increases the reliability of the hybrid photovoltaic system [20], [21]. The battery used has a specification of 12 V 20 Ah which is assembled in series and parallel to adjust to the needs of the system. The battery will be intelligently regulated by PLC and SCADA to ensure dispensing according to the needs of the tea leaf drying machine.

2.3 Designing and Manufacturing a Monitoring System Using SCADA

The monitoring system for hybrid photovoltaic used for the supply of tea leaf drying machines has 3 setting modes, namely PLN mode, backup mode, and automatic mode. PLN mode is a mode where the tea leaf dryer is supplied entirely from PLN, this system will automatically work if the voltage generated by the battery and PV cannot reach the inverter's MPPT limit voltage (24–48 Vdc). Backup mode is the mode of the tea leaf drying machine supplied from the battery because the voltage generated by photovoltaic to MPPT is less than 24–48 Vdc. Automatic mode is the mode of the tea leaf drying machine supplied by photovoltaic hybrid and PLN automatically. The block diagram of a hybrid photovoltaic monitoring system for tea leaf dryer supply shown in Fig. 4.

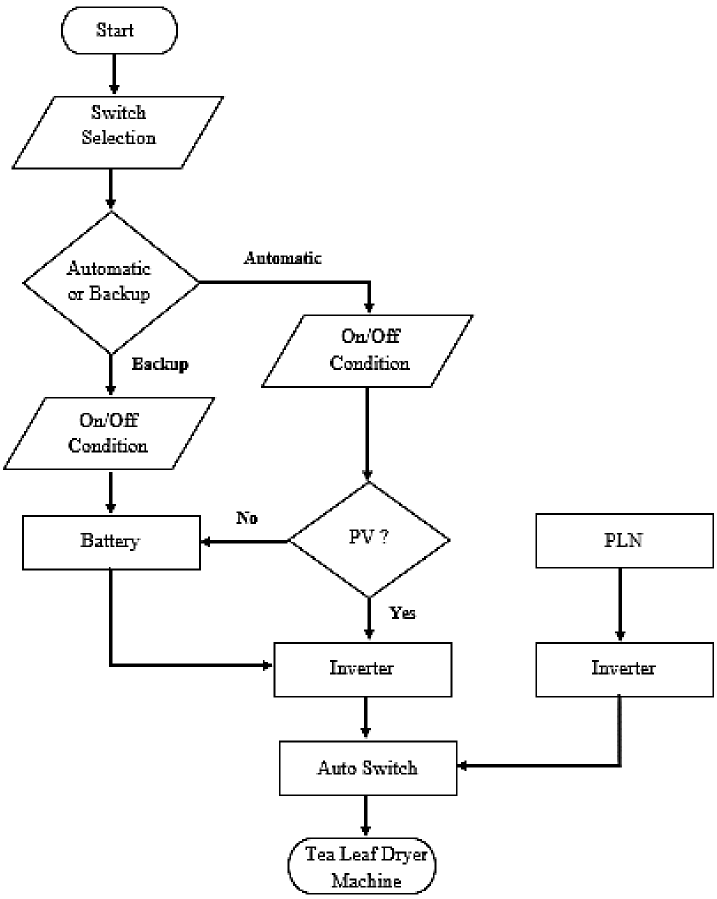

Fig. 4. Flowchart monitoring hybrid photovoltaic systems.

The PLC programs was developed using Ecostruxture Machine Expert software while the SCADA programs was made using Vijeo Citect Explorer software. Fig. 5 – Fig. 8 is a look at the SCADA program used for monitoring systems in hybrid photovoltaic tea leaf drying machines.

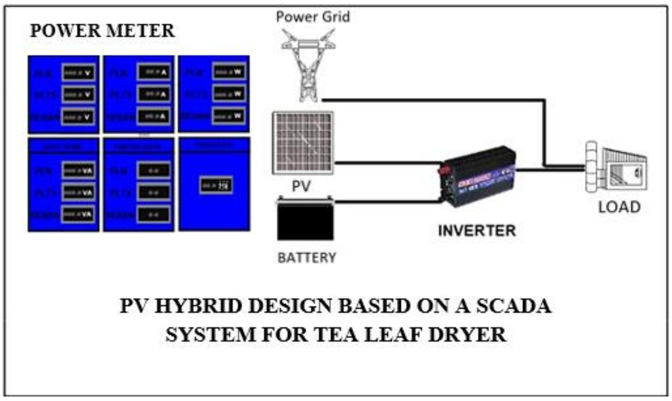

Fig. 5. SCADA simulation display when off condition.

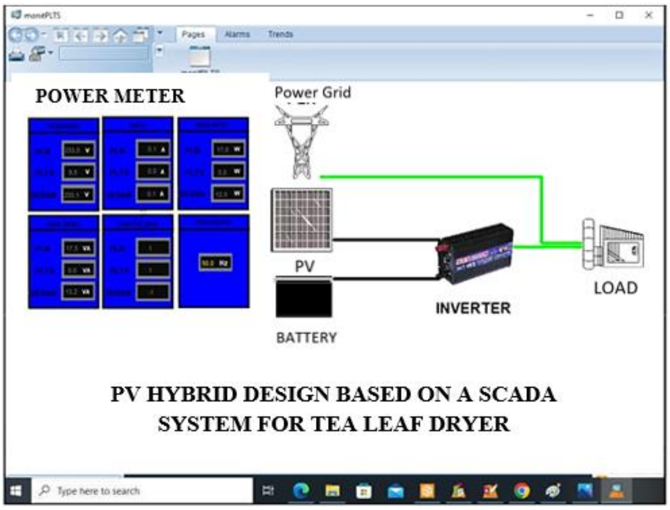

Fig. 6. SCADA simulation display when PLN mode.

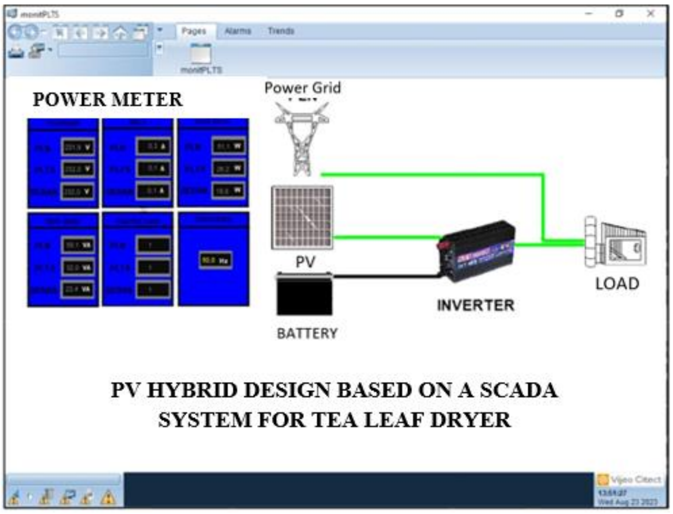

Fig. 7. SCADA simulation display when automatic mode.

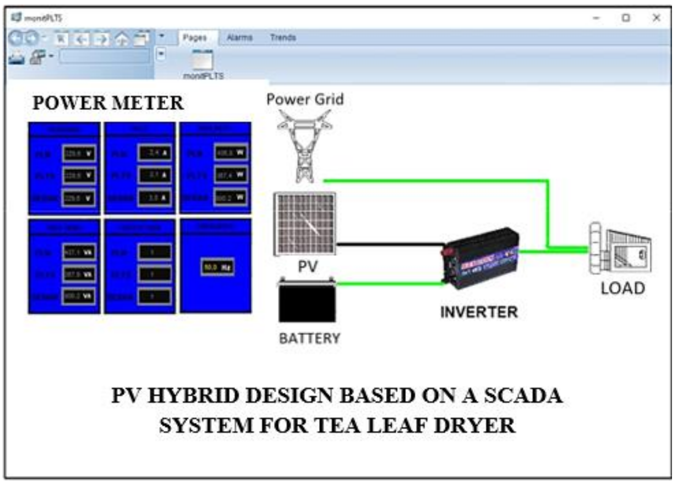

Fig. 8. SCADA simulation display when the Backup mode

3 Results and Discussion

To determine the performance of hybrid photovoltaic monitoring equipment for the power supply of the designed tea drying machine, testing and data collection are needed. Testing and data collection were carried out for 5 (five) days, on Oct 2 – Oct 6, 2023. Data collection was carried out at 09.00 – 16.00 WIB in Semarang City. The test aimed to determine the amount of power generated by photovoltaic hybrid to supply tea leaf drying machines. Data retrieval used several parameters, namely voltage, current, and active power.

3.1 Voltage Analysis

Voltage measurement were carried out for output of PLN , inverter input and load input. Fig. 9 showing a comparison of the results of voltage measurements carried out during the five days of testing.

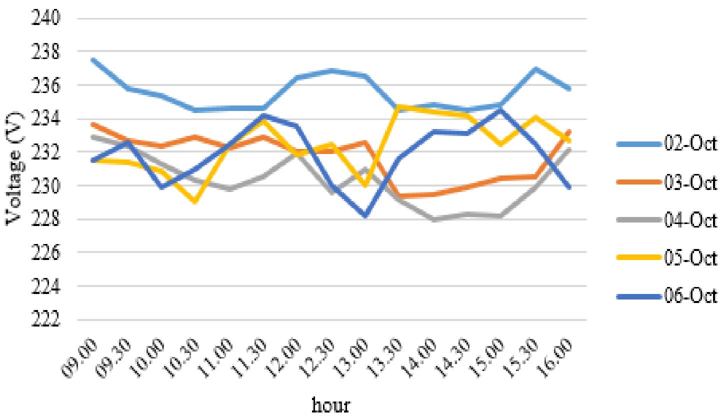

Fig. 9. Voltage measurement at outgoing PLN.

PLN output voltage was the reference voltage used to synchronize between PLN and hybrid photovoltaic to supply loads. Measurements were carried out from 09.00 – 16.00 WIB with an interval of data collection every half an hour. The results of voltage measurements which were carried out for five days on October 2 – October 6, 2023, had values between 228 V – 237.5 V with an average measured voltage of 232.4 V (Fig.10).

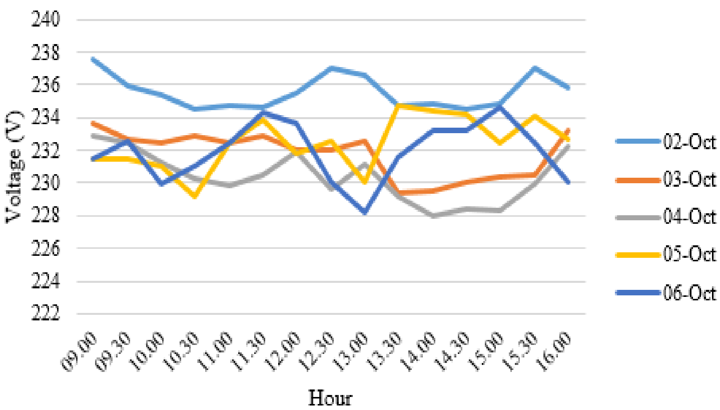

Fig. 10. Voltage measurement at input inverter.

The input voltage of the inverter was the output voltage produced by photovoltaics. Measurements were carried out from 09.00 – 16.00 WIB with an interval of data collection every half an hour. The results of voltage measurements at the inverter input which were carried out for five days on October 2 - October 6, 2023, had values between 228 V – 237.6 V with an average measured voltage of 232.4 V. It showed that the output voltage produced by photovoltaic was following the value of PLN's output measurement results. (Fig. 11).

The load used in this study was in the form of a tea drying machine with a power of 900 W. Based on the measurement results that have been carried out, it was found that the measured voltage value at the load ranged from 228.1 V – 237.6 V with an average measured voltage of 232.4 V. Based on the measurement results of the hybrid photovoltaic system can supply a load of 232.4 V.

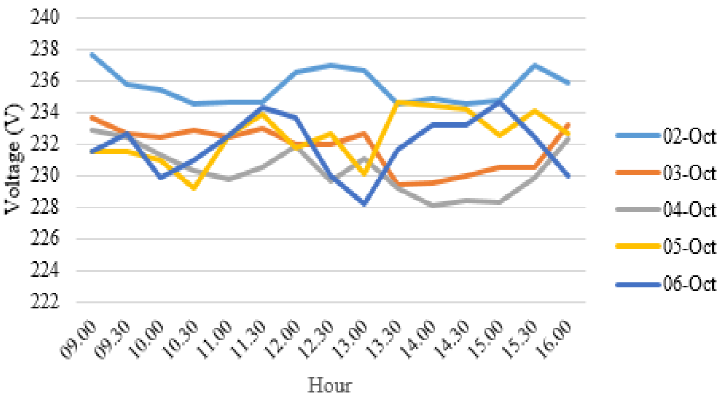

Fig. 11. Voltage measurement at input load.

3.2 Current Analysis

Current measurement was carried out at PLN output, inverter input, and tea leaf drying machine input. Measurements were carried out for 5 days from October 2, 2023 – October 6, 2023, at 09.00 – 16.00 WIB with measurement intervals of 30 minutes. The following is a graph of the current measurement results in PLN outgoing, inverter input, and load input.

Based on Fig. 12, it was shown that the results of measuring PLN's output current tend to increase with the increasing measurement hours. This shows that the more hours of load measurement, the more current supply from PLN is needed. This can be because photovoltaic cannot produce enough power to supply the load requirements. The results of current measurement at PLN's output range from 2.25 A – 3.9 A with an average measured current of 3.26 A. PLN most supplies average current to the load at 15.30 and 16.00 WIB, which is 3.74 A. This can be due to the low intensity of solar radiation at that hour, so it requires a large enough backup supply from PLN.

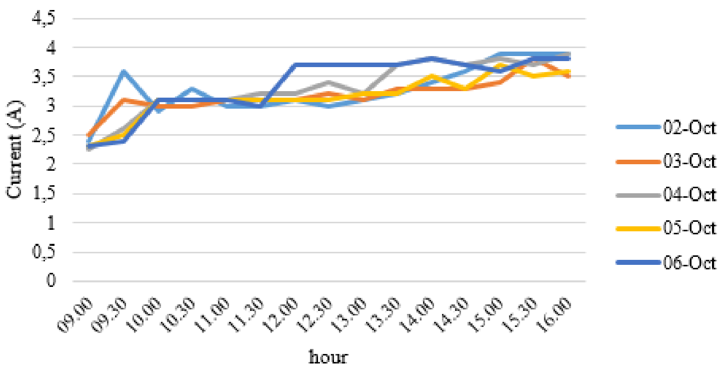

Fig. 12. Current measurement at output PLN.

Current measurement in the inverter aims to measure the output results of photovoltaics. Based on the Fig. 13, it was shown that the measured current in the inverter varies greatly. This can be caused because the amount of current produced by solar panels is greatly influenced by the amount of solar radiation received by solar panels. The results of current measurement at the inverter input are produced at 0.1 A – 1.2 A with an average measurement current of 0.54 A. The average current supplied by solar panels occurred at 11.30 WIB of 0.8 A.

Fig. 14 shows the amount of current required by the load, namely a tea leaf drying machine with a refrigeration system. The measurement results at the input at the load are the result of the integration of PLN and photovoltaic supplies. The amount of measured current at the load input ranges from 2.6 A – 3.8 A with an average measured current of 3.64 A. Based on the measurement results at the load input, it also shown that most of the load is supplied by PLN.

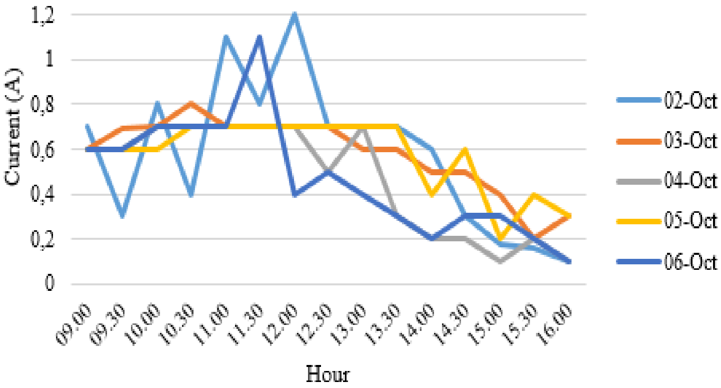

Fig. 13. Current measurement at input inverter.

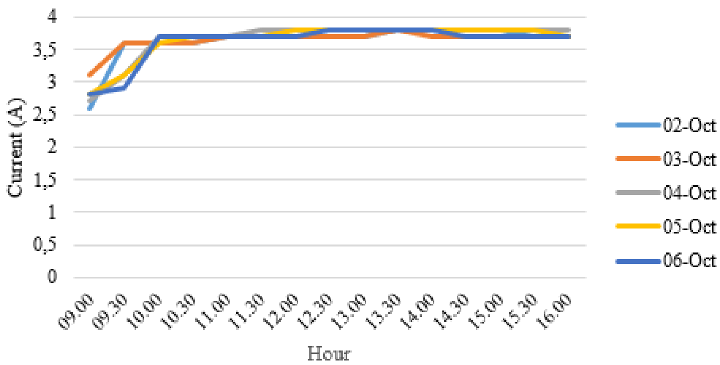

Fig. 14. Current measurement at input load.

3.3 Power Analysis

The tea leaf dryer with a refrigeration system requires 900 W of power. The load is supplied by hybrid photovoltaics, which consists of a solar power plant with PLN backup. The function of this hybrid photovoltaic is to reduce PLN power so that it can save operational costs in the form of electricity account bills caused using a tea leaf drying machine with a refrigeration system. Power measurement was carried out at PLN output, inverter input, and tea leaf drying machine input. Measurements were carried out for 5 days from October 2 until October 6, 2023, at 09.00 – 16.00 WIB with measurement intervals of 30 minutes. Figure 15 shows the power measurement results in PLN output, inverter input, and load input.

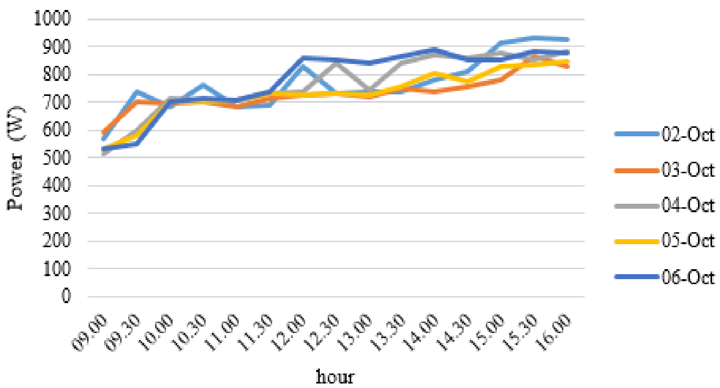

Fig. 15. Power measurement at outgoing PLN.

Based on the power measurement picture in PLN's output, it is shown that the longer the measurement hours carried out, the greater the power generated by PLN to supply the load. This can be due to the decreasing power generated by solar panels to supply the load, with increasing measurement hours. The results of power measurement in outgoing PLN ranged from 511.5 W – 930.7 W with an average measurement power in outgoing PLN of 755.89 W. The lowest average power supplied by PLN occurred at 09.00

WIB of 546.5 W, while the highest average power supplied by PLN occurred at 15.30 WIB of 872.52 W.

Power measurement at the inverter input aims to measure the power produced by photovoltaics. Based on the power measurement graph above, it is shown that the increasing hours of power measurement produced by photovoltaics are decreasing. This can be caused because the solar radiation received by solar panels is decreasing. The amount of power produced by solar panels at the time of measurement is 4.7 W – 186 W with an average measured power of 108.91 W. At 11.00 WIB the average measured power has a maximum value of 169.28 W while the lowest average power measured occurs at 16.00 WIB which is 2.24 W.

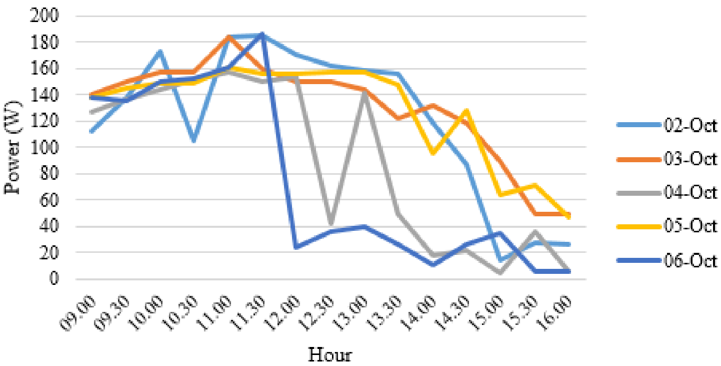

Fig. 16. Power measurement at input inverter.

Based on the graph in Fig. 17, it is shown that at 09.00 WIB which was the beginning of the power measurement required by the tea leaf drying machine was smaller than other measurement time-point. This can be caused by the tea drying machine had not been fully filled with tea leaves so that the power requirement was lower than other measurement time-point when the dryer have been filled with tea leaves for drying. The average load power required to dry tea leaves was 848.82 W. The tea leaf dryers can be supplied using hybrid photovoltaics.

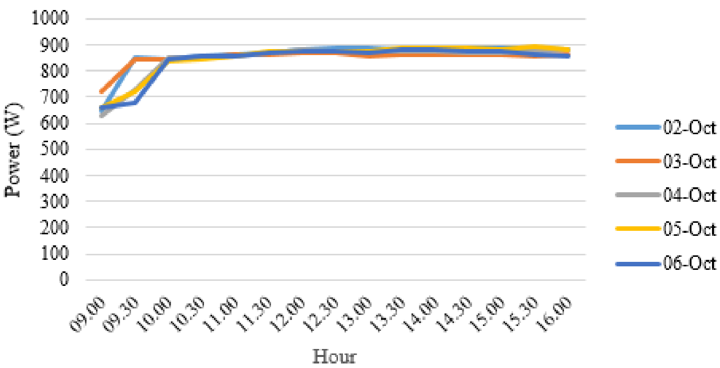

Fig. 17. Power measurement at input load.

The average amount of power generated during one test day on October 2 – October 6, 2023, shown in Table 1.

Table 1. Average power hybrid photovoltaic

Date	Outgoing PLN	Input inverter	Input load
Oct 2, 2023	767.8 W	121.4 W	859.6 W
Oct 3, 2023	733.1 W	130.3 W	850.2 W
Oct 4, 2023	765.1 W	89.3 W	843.6 W
Oct 5, 2023	731.8 W	128.1 W	849.8 W
Oct 6, 2023	781.6 W	75.5 W	841.0 W
Average	755.88 W	108.92 W	848.84 W

Based on Table 1, the average output power produced by solar panels is 108.92 W. The term efficiency of 12.8% is inaccurate, precisely using the term energy contribution or subsidy. The results of experiments carried out in 5 days obtained a total energy of 0.544 kWh. By using a solar power plant to supply tea leaf dryers, production costs can be reduced by eliminating the need for PLN supply for drying machines. In addition, the use of solar power plants is also beneficial for the environment. For further research, it is necessary to improve tea drying machines with higher levels of efficiency, and the reliability of solar power plants can be increased by using hybrids with generators from other renewable energy plants.

4 Conclusion

The voltage produced by PLN and photovoltaic can be integrated to supply load requirements. The average measured voltage at each measurement point was 232.4 V. The PLC and SCADA can monitor and maximize the current released by PLN and photovoltaics according to load requirements. When the current generated by photovoltaics was low due to not maximizing solar radiation received by solar panels, the PLN were able to back up load requirements. The use of solar panels were able to reduce the power generated by PLN for the supply of tea-drying machines with a refrigeration system. Based on the test results produced, the use of solar panels could save PLN power by 108.92 W or 12.8% of required load power.

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