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Development of Chili Grinding Machine with Hybrid System of Wind and Solar Energy

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ABSTRACT

This study aims to develop an efficient chili grinding machine that utilizes a hybrid system combining wind and solar energy as a sustainable solution to address the issue of dependence on conventional energy sources, which are often expensive, environmentally unfriendly, and limited in rural areas. The main challenge is how to provide a grinding machine that can operate independently in regions with limited electricity access and high energy costs. The primary objective of this research is to design a machine capable of providing reliable power in these areas. The research involved the design and assembly of a prototype, integrating wind and solar power systems to drive a DC motor for grinding chilies. Testing was conducted to measure the power output from each energy source, with results showing that the wind turbine generates an average power of 6.715 mW, while the photovoltaic (PV) system produces an average power of 14.77 W. Combined, these sources yield a total average power output of 16.466 W. However, observations revealed that the battery charging time was longer than the operational duration of the DC motor. This hybrid-powered chili grinding machine provides a practical application of renewable energy technology, particularly suited for rural areas, and supports broader efforts to reduce carbon emissions.

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1. INTRODUCTION

Chili peppers (Capsicum spp.) are one of Indonesia's essential agricultural commodities, serving as a staple ingredient in many traditional dishes. However, the post-harvest processing of chili, particularly the grinding process, remains inefficient and energy-intensive, especially for small- and medium-scale industries in rural areas. Conventional grinding machines mostly rely on fossil fuels or electricity from the main grid, leading to high operational costs and environmental degradation due to carbon emissions. These challenges highlight the urgent need for a more sustainable and economical energy solution to support the chili processing sector.

Historically, chili cultivation dates back to around 2,500 BC, with the Inca in South America, the Maya in Central America, and the Aztecs in Mexico being the first to domesticate and use chilies for culinary purposes. When Christopher Columbus arrived in San Salvador in 1492, he observed that local populations also used chili as a cooking spice [1]. In Indonesia, chili peppers hold significant economic and cultural value, being integral to a wide range of cuisines across the archipelago.

Given Indonesia's geographical advantage as a tropical country located along the equator, it receives substantial solar radiation, averaging 4.5–4.8 kWh/m² per day [2]. This abundant solar resource presents a major opportunity for renewable energy applications, including small-scale agricultural processing. Solar energy is not only renewable and abundant but also offers a clean and sustainable alternative to fossil fuels.

Besides solar potential, Indonesia also has notable wind energy resources, particularly in coastal regions and areas with steady wind patterns. Studies show that wind speeds between 3 m/s and 7 m/s are common across many parts of Indonesia, making small vertical axis wind turbines (VAWT) a feasible option for decentralized energy production [3]. Like solar energy, wind energy provides an environmentally friendly and sustainable power source that can be harnessed to support agricultural activities.

In this context, developing a hybrid system that combines solar and wind energy to power a chili grinding machine represents an innovative approach to addressing the energy efficiency and sustainability challenges in the chili processing industry. Such a hybrid system can reduce dependency on fossil fuels, lower operational costs, and contribute to reducing carbon emissions. Furthermore, this technology could particularly benefit rural communities where access to reliable electricity remains limited.

Thus, this study aims to design and develop a chili grinding machine powered by a hybrid system of wind and solar energy. The innovation is expected to provide a practical, efficient, and eco-friendly solution for chili processing, support rural economic development, and align with government initiatives to promote the utilization of renewable energy technologies.

2. LITERATURE STUDY

Several previous studies have been conducted, one of which is titled "Analysis of the Multi-level Hybrid Vertical Savonius and Darrieus H-rotor Wind Turbine." This study examined Savonius and Darrieus wind turbines using numerical analysis and experimentation. At a wind speed of around 4.5 m/s, the Darrieus turbine generated more power than Savonius, producing 26.24 W compared to 5.24 W. However, the Savonius turbine excelled in rotational speed, reaching 429.92 rpm, while Darrieus only achieved 358.28 rpm. When the two models were combined into a hybrid Darrieus-Savonius turbine, the results showed an increase in rotational speed to 482.7 rpm [3].

Another study titled "Design of a Solar Power Plant for Households" is also relevant. The main objective of this study was to measure the output of solar panels used as a power source for household electricity since nearly all household appliances like lights, washing machines, and water heaters require electricity. Installing solar panels in households aims to reduce the use of electricity from increasingly scarce and expensive fossil energy sources. The measurements showed that these solar panels produced an average open-circuit voltage (Voc) of 20.40 V and a current of 6.54 A with an efficiency of 15.12%. However, this study noted significant power losses due to shading, high temperatures, and sunlight intensity. The panel could generate 570 Wh of energy for 11 hours of usage [4].

Indonesia has abundant natural resources in terms of flora and fauna. Various types of plants can be cultivated in the country thanks to its fertile soil conditions. One of the prominent commodities frequently cultivated is the chili plant (Capsicum), which can grow well in both highland and lowland areas.

Figure 1. Chili Plants

The chili plant is very well-known among Indonesians, as nearly all traditional dishes from various regions use chili as one of their main ingredients. Chili has a spicy flavor that creates a hot sensation on the tongue, caused by its capsaicin content. The chili plant has good economic prospects but is susceptible to diseases that often lead to price fluctuations. To minimize losses, farmers often process harvested chili by drying or grinding it into seasoning, so it can be marketed not only in fresh form [5].

Chili Grinder

A chili grinding machine is used to crush and grind chili or other wet spices. Typically, grinding is done using a blender; however, blenders have certain limitations, such as requiring added water and having a small grinding capacity. In contrast, a chili grinding machine can process larger amounts of chili in a single grind. This machine uses a small grinder to crush the chili, and the level of fineness depends on the machine's rotational speed. This tool is highly useful for culinary entrepreneurs like restaurants and food stalls and is an innovation that can simplify the cooking process [6].

Figure 2. Manual Chili Grinder

Hybrid Power Plant

A hybrid power plant (HPP) is a power plant that uses energy from more than one source. One example is a combination of solar power plants (PLTS) utilizing PV (photovoltaic) and wind power plants (PLTB). The advantage of a hybrid power plant is that if one of the energy sources encounters a disruption, it can be supported by the other power source. For instance, during cloudy weather, photovoltaic systems may not function effectively. However, with a wind turbine in place, it can compensate for the photovoltaic's shortfall [7].

PV (Photovoltaic)

Photovoltaic (PV) technology is used to convert sunlight into direct current (DC) electricity by utilizing semiconductor components. This process involves two different semiconductor plates connected at a junction. These conductive materials are made of different types of silicon, referred to as p-n. The p-layer has more holes for electrons, while the n-layer has an excess of electrons. The solar panel functions by capturing photon energy from sunlight, which generates heat at the p-n layer, causing electrons to move from the n-layer to the p-layer. An electric field is created between these layers due to the movement of electrons, producing direct current (DC) electricity [8].

3. METHOD

A structured research flow is required for this project to ensure all processes run smoothly without any steps being overlooked. The research flow is outlined below.

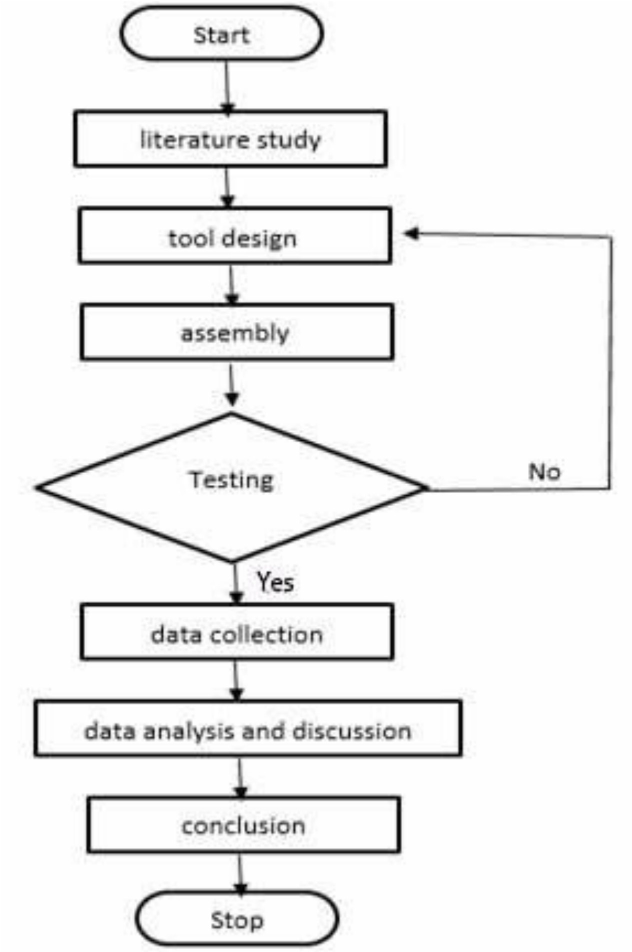


Figure 3. Research flowchart

Based on the flowchart in Figure 3, the stages of the research can be explained as follows:

a. Start
Begin the research phase.

b. Literature Review
Conduct a literature review to study various reference sources related to the research being conducted.

c. Tool Design and Development
Design the tool before conducting the research tests. Once the design is understood, the next step is to develop the tool according to the known references.

d. Provision of Tools and Materials
Prepare the tools and materials required for tool development.

e. Tool Testing
Once the tool is completed, the next step is to test it, to ensure it meets the planned specifications.

f. Data Collection
At this stage, data is collected once the tool has successfully been tested.

g. Data Analysis
Data analysis is performed to process the data into useful information, allowing the characteristics of the data to be understood and used as a solution to the research problem.

h. Report Writing
After tool testing, data analysis, and data collection, report writing is conducted, where the data is processed into the results of the research.

i. End
The research flowchart system is complete.

3.1 Tool Design

Tools Used for Testing

Several tools will be used for testing and data collection.

Table 1 Testing Tools.

No	Tool	Function
1	*Avometer*	Tool used to check voltage and electric current
2	*Anemometer*	Tool used to measure wind speed
3	*Tachometer*	Tool used to check the rotational speed of an object
4	Notebook and Pen	Tools used for writing and recording data
5	*Lux meter*	Tool used to check sunlight intensity

Design and Drafting

Designing is to facilitate the manufacture of tools, reduce the possibility of failure, and facilitate the preparation of tools and materials. Below is a block diagram of the tool manufacturing flow.

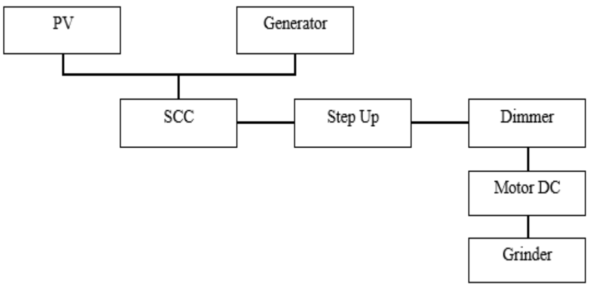


Figure 4. Block diagram of the chili grinder flow

The image below is the installation and design of a chili grinding machine based on a hybrid of wind and solar power.

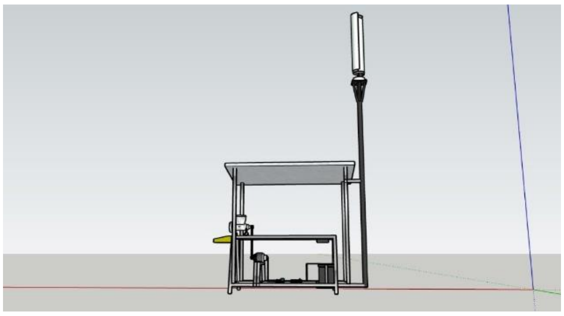


Figure 5. Chili Grinding Machine Design

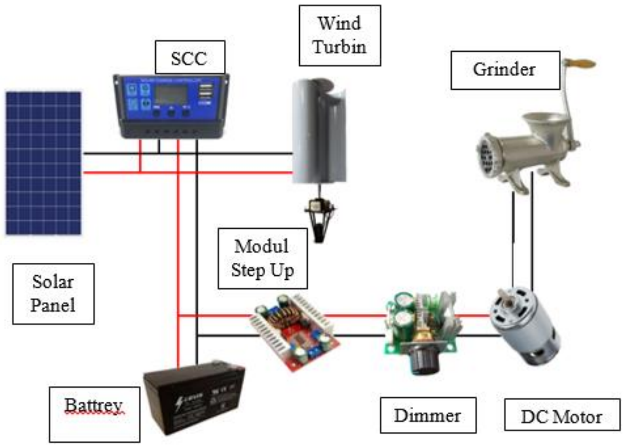


Figure 6. Overall Installation

a. **Input Power**
Pin=G×AP_{in} = G \times APin=G×A
Where:
- PinP_{in}Pin: PV Input Power (W)
- GGG: Sunlight intensity (W/m^2)
- AAA: Cross-sectional area (m^2)

b. **Photovoltaic Cross-sectional Area**
A=P×LA = P \times LA=P×L
Where:
- AAA: Cross-sectional area (m^2)
- PPP: Length of photovoltaic panel (m)
- LLL: Width of photovoltaic panel (m)

c. **Output Power**
Pout=I×VP_{out} = I \times VPout=I×V

Wind Turbine
a. **Wind Kinetic Power**
PK=21ρAv3
Where:
- PKP_KPK: Wind kinetic power (W)
- ρ\rhoρ: Air density (kg/m^3)
- AAA: Cross-sectional area (m^2)
- VVV: Wind speed (m/s)

Output Power
Pout=I×VP_{out} = I \times VPout=I×V

Hybrid Wind and Solar Power
Total Power
Ptotal=Vtotal×ItotalP_{total} = V_{total} \times I_{total}Ptotal=Vtotal×Itotal

4. RESULTS AND DISCUSSION

The testing and data collection for the wind and solar hybrid-powered chili grinding machine were conducted in a single day, on August 2, 2024, at the Nurul Jadid Islamic Boarding School in Karanganyar Village, Paiton District, Probolinggo Regency. Several tools were used for data collection in this test, totaling at least five, as detailed below:

- An avometer to measure current and voltage
- An anemometer to measure wind speed
- A tachometer to measure rotation (rpm)
- A lux meter to measure sunlight intensity
- A stopwatch to measure time

3.1 Data Collection on PV

Data collection for the PV was conducted on Friday, August 2, 2024. During this process, an avometer was used to measure the voltage and current generated by a 100 Wp PV panel, and a lux meter was used to measure the sunlight intensity for that day. Measurements were taken from 09:00 to 16:00. In addition to using the lux meter to determine sunlight intensity, the following calculation can also be used:

G=PinAG = \frac{P_{in}}{A}G=APin

Where:

- PinP_{in}Pin: PV Input Power (W)
- GGG: Sunlight intensity (W/m²)
- AAA: Cross-sectional area (m²)

The cross-sectional area is calculated by multiplying the length and width of the photovoltaic panel, as shown below:

A=P×LA = P \times LA=P×L

A=0.77 m×0.67 mA = 0.77 \, m \times 0.67 \, mA=0.77m×0.67m

A=0.52 m2A = 0.52 \, m^2A=0.52m2

Photovoltaic Discussion Results

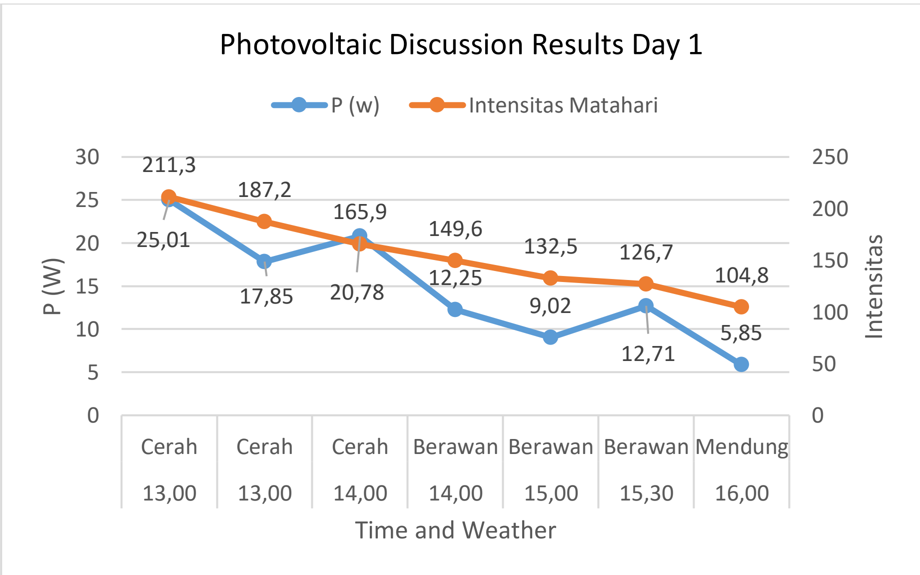


Figure 7. Photovoltaic Experiment Results Graph Day 1

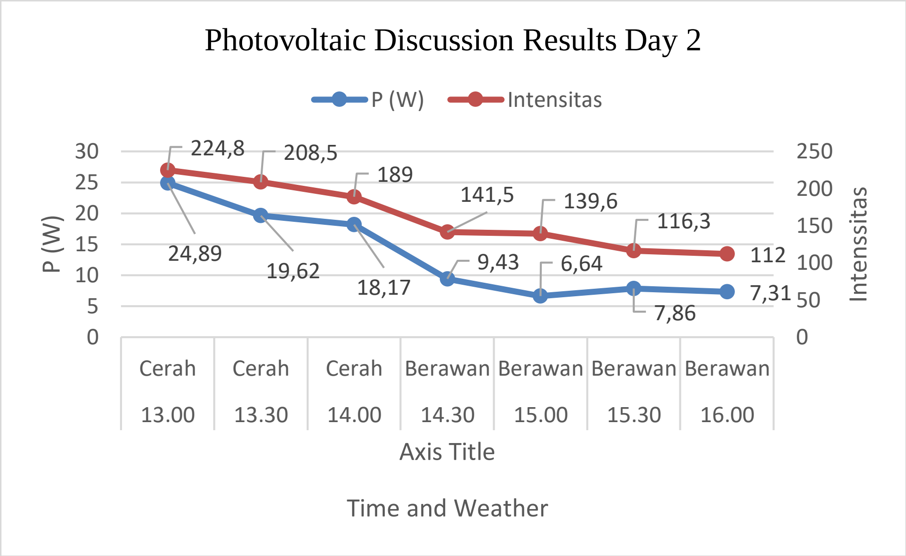


Figure 8. Photovoltaic Experiment Results Graph Day 2

Wind Turbine Discussion Results

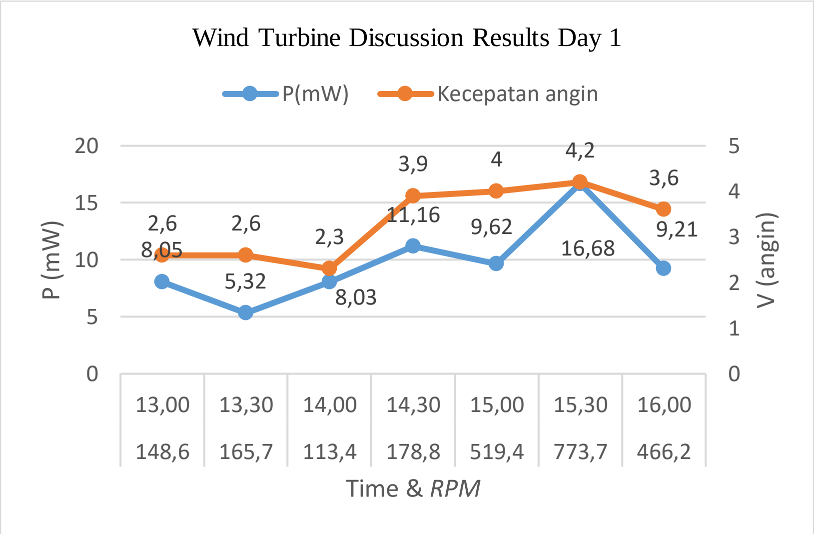
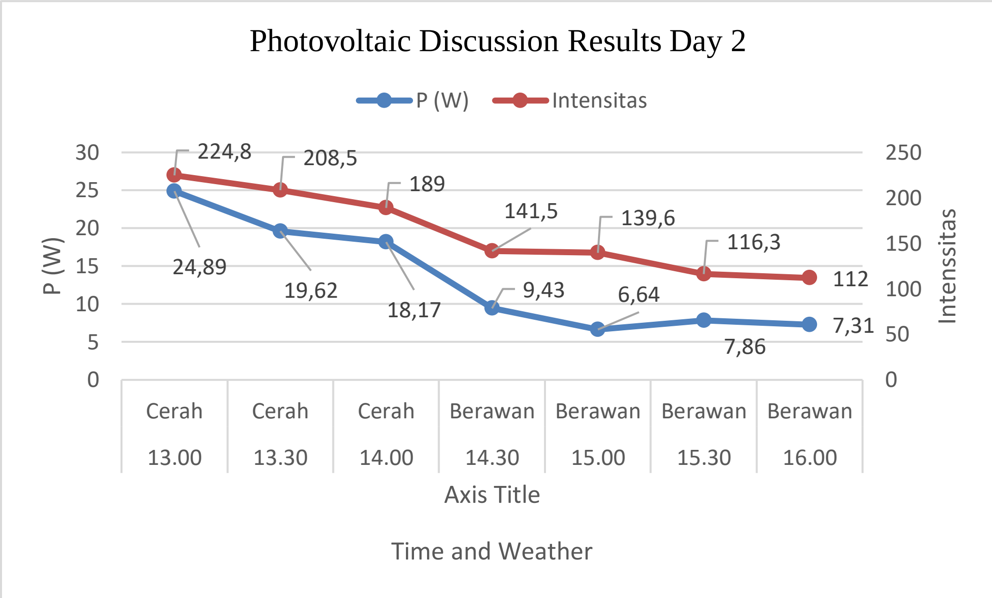


Figure 9. Wind Turbine Experiment Results Day 1



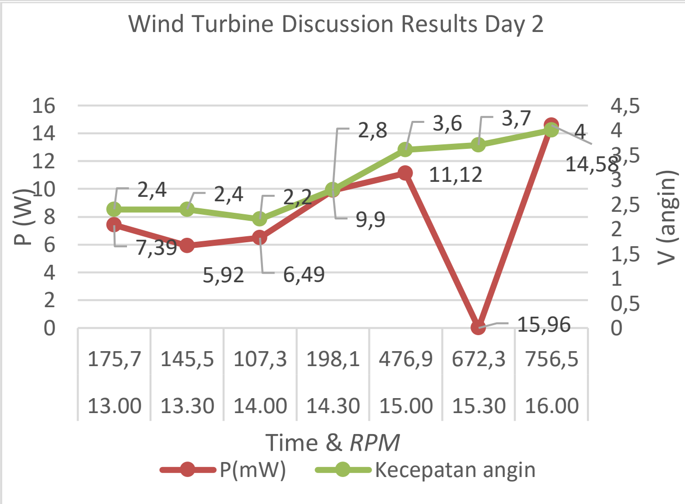


Figure 10. Wind Turbine Experiment Results Day 2

Hybrid Power Plant Discussion Results

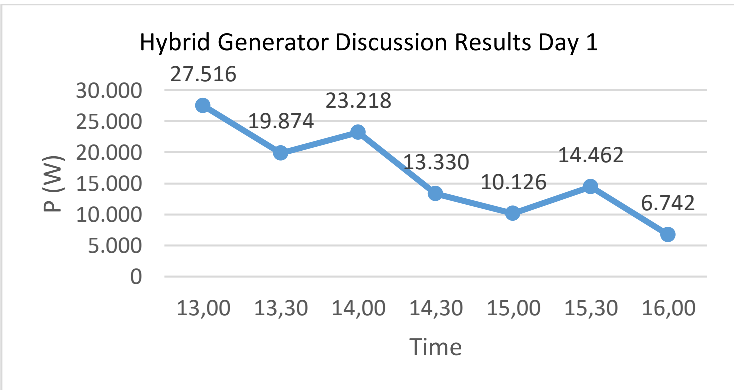


Figure 11. Hybrid Experiment Results Day 1

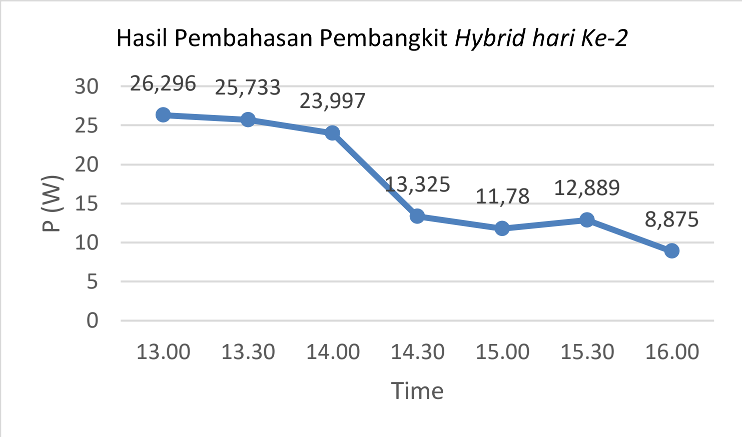


Figure 12. Hybrid Experiment Results Day 2

Overall research results

The results show that photovoltaic output reaches its peak during daylight hours, provided weather conditions are clear, with no interference from clouds or rain. Conversely, the vertical wind turbine's output is relatively low, primarily due to the less-than-ideal generator used in this research. Consequently, the current output difference between the photovoltaic system and the hybrid power system is minimal. Furthermore, the battery takes longer to reach a full charge than the time it can sustain the DC motor.

5. CONCLUSION

Based on the results of design, manufacture, testing, and data analysis, this study concludes that the hybrid wind and solar-powered chili grinding machine has adequate performance. From the test, the average power generated by the wind turbine is 6.715 mW and the photovoltaic is 14.77 W. The combination of these two energy sources is able to produce an average power of 16.466 W. However, charging the battery to full takes longer than the duration of battery use to operate the DC motor. This study shows the potential for using renewable energy in chili grinding machine applications with a hybrid approach.

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