The 2nd International Conference on Multidisciplinary Engineering (2nd ICOMDEN 2024)

The 2nd International Conference on Multidisciplinary Engineering: 00063 (2024) **https://doi.org/10.29103/icomden.v2.xxxx**
Volume 2, 2024
eISSN: xxxx-xxxx
Research Original Article

Prototype of Off-Grid MHP-PV Hybrid Power Plant

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Abstract
Micro Hydro Power Plants (MHP) and Solar Power Plants (PV) are very potential renewable energy solutions to meet electricity needs in remote areas and areas with minimal access to the national electricity grid. This article discusses the development of a hybrid system prototype that combines MHP and PV in an off-grid configuration to improve the reliability and availability of electricity in areas not covered by the main grid. Through a hybrid approach, this system is able to utilize the advantages of each energy source, such as the continuity of power from water flow and solar energy as an additional resource. This study includes technical design, performance simulation, and efficiency analysis of the prototype.
Keywords: MHP, PV, hybrid, off-grid, renewable energy

Introduction
The need for electrical energy continues to increase along with the times, but there are still many areas, especially remote areas, that are not served by the national electricity grid. In facing this challenge, renewable energy, such as MHP and PV, are important alternatives because of their abundant availability and environmentally friendly impacts. MHP utilizes water flow from rivers or irrigation to generate electricity, while PV utilizes solar radiation. Both technologies have their own advantages and disadvantages; MHP can operate continuously as long as there is sufficient water flow, while PV depends on the intensity of sunlight and time [1], [2].

However, the challenge in using each technology alone is the dependence on natural conditions that are not always stable. Therefore, a hybrid system that combines MHP and PV offers a more efficient and reliable solution by utilizing both energy sources alternately or simultaneously as needed [3], [4].

The purpose of this article is to review and develop a prototype of a MHP-PV hybrid power plant in an off-grid configuration. This system is expected to be able to provide electricity sustainably to communities in remote areas that are not reached by the conventional electricity grid [5].

Literature Review
The demand for energy in remote areas that are not covered by the main electricity grid continues to increase as these regions strive for development and improved living standards. Traditional energy solutions are often inefficient and costly in isolated locations, making renewable energy sources a more attractive option. According to [6], solar power presents a particularly viable solution in tropical regions due to its abundance and low operational costs. Nevertheless, solar photovoltaic (PV) systems depend heavily on weather conditions and the availability of sunlight, which limits their reliability when used independently. Therefore, hybrid systems, which combine multiple renewable energy sources, are increasingly being seen as the key to providing stable and continuous energy in such areas [7].

Solar energy, while abundant in tropical regions, faces challenges due to its intermittent nature. During overcast days or at night, the output from solar PV systems drops significantly, making it difficult to rely on solar power alone for a consistent energy supply. Hybrid systems, which combine solar power with other renewable sources, help address this limitation. Argue that hybrid systems improve the stability and reliability of the electricity supply by balancing the weaknesses of each energy source. In particular, micro hydro power plants (MHP) offer a complementary solution to solar PV, especially in regions with access to rivers or streams, providing consistent energy throughout the day when solar power may not be available.

Micro hydro power plants are an efficient and environmentally friendly technology that harnesses water flow to generate electricity on a small scale. This makes them particularly suitable for rural areas with access to water resources [8]. emphasize that MHP systems are a practical and economical solution for communities with consistent water flow, such as those near rivers. Micro hydro plants can operate continuously, providing a reliable base load of electricity, particularly when solar PV systems are not producing energy. However, like solar power, micro hydro systems have limitations, as their performance is directly linked to the availability and consistency of water flow.

One significant challenge of MHP systems is their vulnerability to seasonal changes. In the dry season, the water flow in rivers and streams can decrease significantly, reducing the energy production capacity of micro hydro power plants. [9] noted that during periods of low rainfall, the performance of micro hydro systems can be drastically affected, leading to a reduction in the overall energy supply. This seasonal variability can pose challenges for communities that rely on micro hydro power as their primary source of electricity. To mitigate this, hybrid systems combining MHP with solar PV can offer a more reliable energy supply year-round, with solar panels providing electricity during dry periods when water flow is insufficient for optimal MHP operation.

Hybrid energy systems combining micro hydro power and solar PV have proven to be an effective solution for providing energy security in remote areas. By utilizing both water flow and solar radiation, these systems balance the limitations of each source, ensuring a continuous supply of electricity. [6] highlighted, the abundant solar resources in tropical regions make solar PV an essential component of hybrid systems. Meanwhile, MHP complements solar power by providing steady electricity during the night or periods of low sunlight. The implementation of hybrid systems in rural and remote areas not only enhances energy reliability but also promotes sustainable development by reducing dependency on fossil fuels and lowering carbon emissions.

The basic formula for calculating the electrical power produced by a Micro Hydro Power Plant (MHP) is:

$$P = \eta \times \rho \times g \times Q \times H \quad (1)$$

Wherea:

P = Power generated (in watts or W)

η = Total system efficiency (including turbine, generator and other components) (usually between 0.5 to 0.7)

ρ = Water density (usually 1000 kg/m^3)

g = Gravitas (9, 81 m/s^2)

Q = Water debit (m^3/s)

H = Effective water fall height or head (in meters)

Solar power plants, which rely on solar radiation as an energy source, offer great potential for widespread use in areas with sufficient sunlight. Stated that solar power plants are often used in off-grid applications, but face limitations because they cannot function at night or when the weather is cloudy. Therefore, energy storage batteries or hybrid systems are needed to balance the energy supply [10].

The formula for calculating the electrical power produced by a Solar Power Plant (PV) is as follows:

$$P = A \times G \times \eta \quad (2)$$

Where:

P = Power generated (in watts or W)

A = Total area of solar panels (in m^2)

G = Solar radiation intensity (in W/m^2, usually around 1000 W/m^2 under standard conditions)

η = Solar panel efficiency (usually ranges from 15% to 22%, or 0.15 to 0.22)

The study explains that polycrystalline panels generally have an efficiency of between 15% to 18% due to their structure consisting of many crystals, making them less efficient than monocrystalline panels [11], [12]. Research discussing the advantages and disadvantages of polycrystalline solar panels, emphasizes that although their efficiency is lower than monocrystalline, their lower production costs make them an economical choice for a variety of applications [13].

Hybrid systems that combine MHP and PV offer greater flexibility by utilizing the strengths of both systems. [14] found that the MHP -PV hybrid system provides advantages in terms of continuity of electricity supply. During the day, PV can meet the main electricity needs, while MHP functions as a backup or vice versa at night. The use of both energy sources alternately increases system reliability [15].

A study showed that hybrid systems have higher efficiency compared to single energy systems. They noted that with good energy management, the combination of MHP and PV can reduce dependence on one type of energy. This hybrid system is able to provide electricity continuously in areas with varying energy needs [16].

Energy storage is an important part of the success of a hybrid system. Highlighted the importance of lithium-ion batteries for energy storage in a hybrid MHP-PV system, which is able to store excess power generated during peak periods for use when demand is higher or energy supply is reduced [17].

The use of renewable energy not only focuses on technical aspects, but also considers sustainable economic models. Noted that the initial investment in a hybrid system may be higher, but the benefits in reducing operational costs and reducing long-term carbon emissions are more profitable. This system has the potential to accelerate electrification targets in remote areas.

Technical integration between MHP and PV mini-grid requires an effective power management system. Revealed that the main challenges in a hybrid system are regulating the power flow between the two systems and integrating inverter technology to ensure operational stability. Environmental disturbances such as changes in river water discharge are also challenges for MHP performance.

Several field studies in Indonesia show that the hybrid MHP-PV system has been successfully implemented in several remote areas. Reported that the hybrid system was successfully implemented in villages that were difficult to access from the main electricity network. This system is able to provide electricity around the clock with minimal infrastructure [18].

Innovations in hybrid technology continue to develop, with a focus on improving system efficiency and control. Suggest the use of energy management software to optimize power distribution, which allows automatic adjustment between MHP and PV according to changing energy needs.

Materials & Methods

The development of this MHP-PV hybrid prototype involved several stages from design to implementation. The stages carried out are as follows:

System Design: Develop initial models of MHP and PV that will be combined in one hybrid system. This design includes key components such as a micro hydro turbine, solar panels, inverter, load controller and energy storage battery. As shown in table 1. Meanwhile, the block diagram of the tool is shown in figure 1 and figure 2 shows the equivalent circuit of the system.

Table 1. Materials and tools

Tool Name	Amount	Specification
Water box	1 pcs	P30cm x L15cm x T15cm
Solar panels	1 pcs	polycrystalline 10Wp, 35x27x3cm
Voltmeter and Ampere meter	2 pcs	Digital 4.5-30VDC, Arus kerja 60mA, Range Tegangan 0-100VDC, Range Arus 0-10A, Display 7mm
Relay	3 pcs	Coil voltage DC 12v, 5pin, rate load 10A/250VAC, 10A/30VAC, coil power 0.36W
DC Dynamo	1 pcs	DC 12v RS550, 4.5A, kecepatan 21000RPM
Battery Regulator	1 pcs	20Ah, 12-24V, Dual USB 5V
VRLA Battery	1 pcs	12V, 7.5Ah, P151 x L65 x T95mm
Cable	20 m	NYAF 0- 220 VDC dan VAC, diameter 1.5mm, 0-20A
Cable Terminal	10 pcs	3pin, Voltage 220/250V, Current 16/24A
PCB Board	1 pcs	5x7cm, jumlah lobang 432 (18x24) diameter lobang 1mm, jarak lobang 2.54mm
Screwdriver and Pliers	1 pcs	6mm x 65mm dan 16cm
DC Water Pump	1 pcs	3amp
Indicator Lights	2 pcs	12V, diameter lampu 15mm, panjang kabel 18cm, merah dan kuning
SPDT Switch	1 pcs	3pin 250v 6A
Power Supply	1 pcs	1A
Rectifier Diode	2 pcs	3 A, V_F 1.1V,

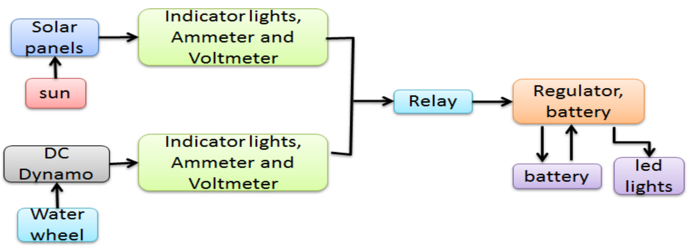

Figure 1. Blok Diagram Alat

Prototyping: After design, a physical prototype of the hybrid system is built for testing in the laboratory and field. At this stage, monitoring and measurement devices are also prepared to monitor system performance in real situations.

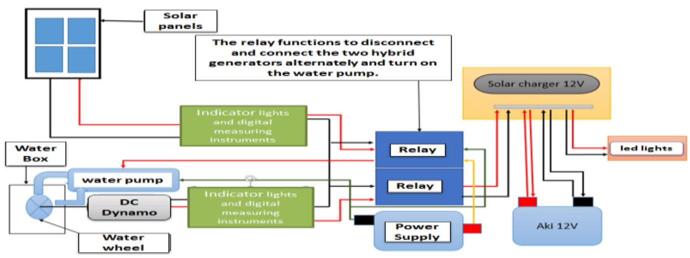

Figure 2. Equivalent circuit of MicroHydro Power Plant (MHP) and Hybrid Solar Power Plant (PV)

Figure 3. PV and MHP

Field Trials: Prototypes are tested in locations that represent actual field conditions, such as remote areas with sufficient access to water and sunlight. The data obtained from this trial was analyzed to evaluate the performance of the hybrid system and its efficiency.

Results and Discussion

Testing of the MHP equipment aims to determine how much voltage, current and power will be produced within a certain period of time 17 October 2024 as seen in figure 4. The Micro Hydro Power Plant experiment took around 30 minutes to charge the battery from 1 bar to 2 bars at 14.56 WIB.

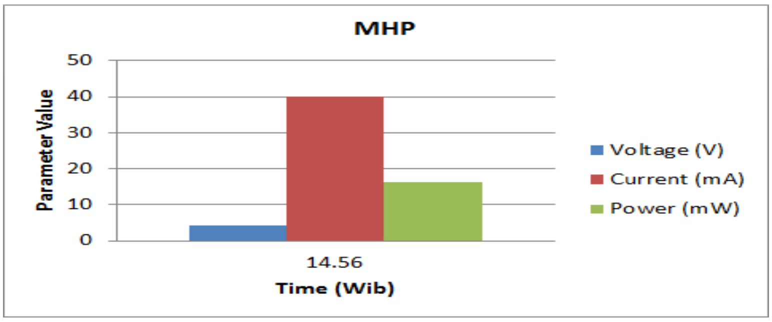

Figure 4. Graph of voltage, current and power measurements on the MHP

The following test of the PV equipment aims to determine how much voltage, current and power will be produced within a certain period of time 11 September 2024 as seen in Figure 5. The solar power plant trial takes 2 hours to fully charge the battery. At 12.00 WIT the voltage produced was 10.5 V, the current was 0.13 A, and the power was 1.3 W. At 12.30 WIT the voltage produced was 13.5 V, the current was 0.33 A, and the power was 4.4 W. At 13.30 WIT the voltage produced was 13.6 V, the current was 0.38 A and power 5.1 W. At 14.00 WIT the voltage produced is 11.5 V, current 0.15 A and power 1.7 W. So at 13.30 WIT the time is right for charging the battery.

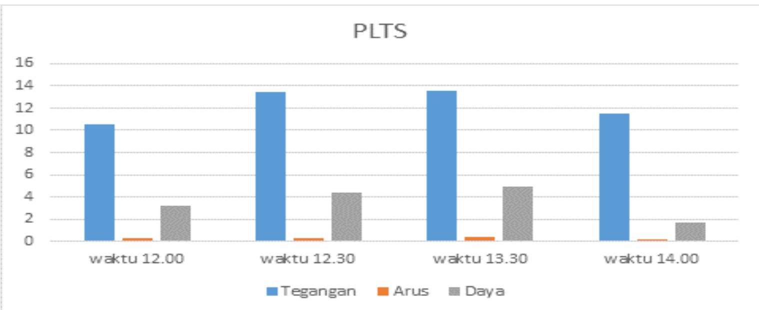

Figure 5. Graph of voltage, current and power measurements on PV

Initial testing of the prototype shows that the MHP-PV hybrid system is capable of producing energy stably in various weather conditions. During bright daylight, PV can function optimally and charge energy storage batteries for use at night or when water conditions are less favorable. On the other hand, MHP provides continuous electricity when water flow is sufficient, which is especially beneficial when solar radiation is reduced. The aim of testing this tool is to determine how much voltage, current and power will be produced within a certain time period on October 17 2024 as shown in Figure 6.

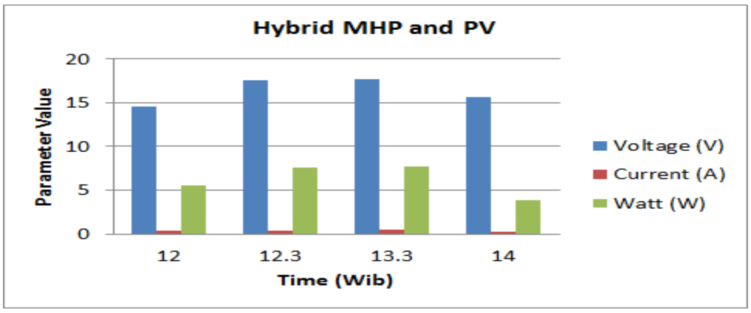

Figure 6. Graph of voltage, current and power measurements on Hybrid MHP and PV

From Figure 6, the MHP and PV hybrid experiment shows that the battery charging process takes approximately 2 hours to reach full charge. At 12.00 WIT, the resulting voltage was 14.6 V with a current of 0.39 A and a power of 56 W. At 12.30 WIT, the voltage increased to 17.6 V with a current of 0.43 A and a power of 7.6 W. At 13.30 WIT, the voltage was recorded at 17.7 V with a current of 0.44 A and a power of 7.7 W. Meanwhile, at 14.00 WIT, the voltage decreased to 15.6 V with a current of 0.25 A and a power of 3. 9 W. Therefore, the optimal time for charging the battery occurs at 13.30 WIB, when the voltage and current are in a relatively stable condition.

The energy efficiency of this system is obtained from polycrystalline solar panels with an efficiency of 18%. Meanwhile, the efficiency produced by MHP is relatively low due to the limited water fall distance and small water volume, even though the overall performance is quite good. Reducing energy waste and increasing operational time in the field have been successfully achieved. The implementation of an automatic control system allows switching resources between MHP and PV seamlessly, thereby optimizing the use of renewable energy without interruption.

This hybrid system is also equipped with an energy storage battery that can maintain electricity supply for several hours when both energy sources are not operating. This makes this prototype suitable for use in remote areas that do not have round-the-clock access to electricity.

Conclusions

The MHP -PV hybrid system prototype shows that the combination of a Micro Hydro Power Plant (MHP) and a Solar Power Plant (PV) can produce energy stably and efficiently in various weather conditions. Charging a battery with an MHP takes around 30 minutes, while a PV requires 2 hours for a full charge, with the optimal time at 13.30 WIB. The efficiency of polycrystalline solar panels reaches 18%, while MHP efficiency is still hampered by the limited volume and distance of water falling. This system is equipped with automatic control that allows seamless switching between MHP and PV, optimizing the use of renewable energy, as well as a storage battery that can maintain electricity supply for several hours. Thus, this prototype is very suitable for application in remote areas that are not reached by conventional electricity networks.

Acknowledgments

Thank you to Medan Area University for giving the author the opportunity to complete this research, which is one of the requirements for completing studies at Medan Area University.

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