Performance Analysis of Monocrystalline and Polycrystalline Solar Photovoltaic for Solar Water Pump (SWP) System in Indonesia

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Abstract: Solar Water Pumps (SWP) systems have been widely developed, especially in remote rural areas that cannot be reached by the electricity network of the State Electricity Company. The most common obstacle is that water supply through the SWP system is still relatively expensive, especially if solar panels are combined with the use of batteries. This study aims to assess the performance of the water pumping system supplied by monocrystalline and polycrystalline solar panels without using batteries. The method used in this research is the observation method by first designing and installing the SWP system using monocrystalline and polycrystalline solar panels. The results showed that in the use of monocrystalline and polycrystalline solar panels in the SWP system, the average efficiency of the solar panels was 6.87% and 6.73%, the average pump efficiency 33.85% and 32.34%, and the global efficiency 2.30%, and 2.17%.

1 INTRODUCTION

Water has a very important role in the development of any country. It is estimated that an average of 100 liters of water is required per person per day for daily survival (Theodolfi and Waangsir, 2014). However, not all rural communities have sufficient water because they cannot use water pumps sourced from the State Electricity Company (SEC). The electrification ratio in Kupang Regency is still 60%. The average household with no electrical energy supply is in remote villages that are difficult to reach by the SEC network (Sinaga R et al, 2019); (Sinaga R et al, 2017). On the other hand, the current SEC electricity network mostly uses fossil fuels to generate electricity.

The use of fossil fuels will increase greenhouse gas (GHG) emissions so that it hurts the environment, while the use of solar electricity can support government programs to reduce GHG emissions. The Indonesian government GHG emission reduction target for 2030 is 29% with own efforts and 41% if there is international cooperation (UURI, 2016).

Solar Water Pumps (SWP) require solar energy as primary energy to be converted into electrical energy through solar panels. A solar-powered water pump system contributes to a clean environment by reducing carbon emissions (does not use fossil fuels) (Aliyua et al, 2018).

The intensity of solar energy is optimal in the dry season in Kupang Regency. In the morning, afternoon, and evening, solar radiation greatly affects the energy output of solar panels (Sinaga R, 2011). The average intensity of solar radiation in East Nusa Tenggara is 5,117 Wh/m^2/day (Rahardjo and Fitriana, 2011).

The performance of solar panels in the form of maximum power output varies with the seasons. At the end of the summer or dry season, the performance of solar panels tends to increase. Solar energy is the best choice for reducing CO2 emissions. (Sinaga R et al. 2017).

The price of solar panels has decreased, thus increasing the feasibility of using solar water pumps. (Foster and Cota, 2014). The price level for installing PV off-grid systems in Kupang also decreased to the level of 0.29-0.31 US$/kWh (Sinaga R et al. 2019). Solar energy is the main variable for operating a SWP (Nogueira et al, 2015); (Sinaga R and Beily, 2019); (Sinaga R et al, 2019).

Several aspects of solar energy for SWP have been studied in the literature. The advantage of DC water pumps over AC is energy efficiency, while AC has a longer life and high speed. Belgacem (2012). stated that the efficiency of water pumps installed in Tunisia is 20% to 30%. Wade and Short (2012).

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optimized the linear actuator design for use as a water pump system. The results show that the efficiency is 7.8%, and a supply current to the actuator of 6A.

The pump head has a significant effect on the overall efficiency of the SWP system. Benghanem et al. (2014), studied the effect of various pump heads on the overall performance of the SWP system. This study tested pump heads ranging from 50 m to 80 m. The results of the analysis show that increasing the pump head reduces the overall efficiency of the system.

Figure 1 shows a schematic diagram of a common SWP system consisting of a solar panel, a control unit, a water pump and a tank. An important parameter that also affects the performance of the SWP system is the effective and efficient design of its control system.

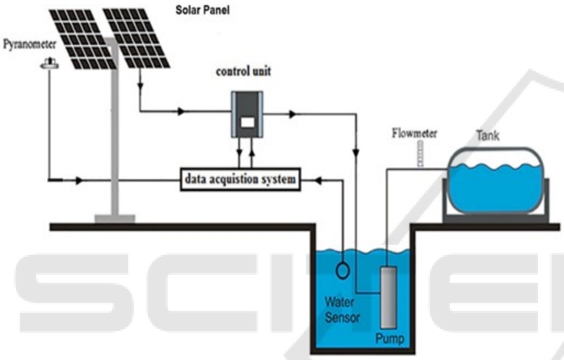

Figure 1: General schematic diagram of the SWP system (Benghanem et al, 2014).

Campana et al. (2014), recommend a control system that interacts between water supply and demand. Supply the required amount of water appropriately by managing the water supply taking into account water and groundwater responses resulting in energy optimization and water savings. Another control system recommended by Salem et al. (2010) uses a fuzzy management algorithm to control the connection period between the solar panel, battery, and water pump. The results of this study indicate that by using the fuzzy management algorithm control system, there is an increase in the use of water pumps for more than 5 hours.

The design configuration of the SWP system has been used, including the configuration of DC, AC, and battery storage systems (Chandel et al, 2015); (Susanto et al, 2018). Tukiman et al. (2013), have tested the SWP system using a water pump 550W 220V AC. The test results show that at an altitude of 8 m, the water discharge reaches 3,000 liters/hour. Priambodo et al. (2019), tested the SWP system using a 45W12V DC water pump. The results show that at the height of 4 m, the water discharge reaches 1,912 liters/hour. Sinaga R et al. (2020) have researched DC SWP using a battery storage system supplied by monocrystalline solar panels. This SWP system is considered relatively expensive.

This research is a development of previous research, especially in the design of the SWP system. The novelty of this research is the design of the SWP system with power supply through monocrystalline and polycrystalline solar panels using the same capacity to supply submersible water pumps, so that a more efficient SWP system can be found to be recommended to users, especially farmers in remote villages. This SWP system is safer against electric shock because it uses a DC system.

2 METHOD

2.1 Tools and Materials

The tools used in this study include 1) Digital multimeter to measure voltage, 2) AC/DC digital clamp meter to measure current, 3) Digital solar power meter to measure solar radiation, 4) Clinometer to measure the tilt angle of the Solar Panel, 5) Water flow meter, to measure the volume of water pumped.

The materials needed consist of 1) 2-units of monocrystalline solar panels consisting of 100 Wp and 50 Wp 2) 2-units of polycrystalline solar panels consisting of 100 Wp and 50 Wp, 3) 1-unit DC Submersible Water Pump 12 Volt, 4) 1-unit Automatic Voltage Regulator (AVR) DC, 5) 1-unit panel box with protection coponent and switching, 6) 1-unit metal structure for water tower 2.5 m, 7) 1-unit water reservoir and 1-unit the water tank, 8) PVC pipe, joints pipe, and pipe glue, 9) Ball valve, 10) cables.

2.2 Data Collection Technique

The volume (V) of water pumped is measured using a digital water flow meter. The difference between the results of the current hour water volume measurement and the previous hour reading is the water flow rate (Q).

Solar radiation (SR) is measured using a solar power meter. The solar energy produced is the multiplication of solar radiation with the surface area of the solar panels per hour. The solar panel energy output is obtained by measuring the average voltage and current of the solar panels per hour using a digital multimeter and clamp meter. Meanwhile, the energy consumed by the water pump is obtained by measuring the average current and voltage per hour on the water pump. The assembly scheme of the SWP systems is presented in Figure 2.

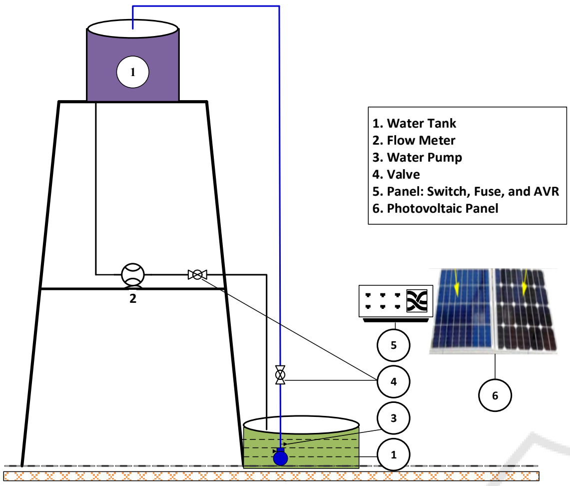

Figure 2: Schematic assembly of the SWP systems.

2.3 Data Analysis Method

The data analysis method uses regression and descriptive analysis to determine: 1) Curve of the characteristics of solar radiation and the volume of water pumped, 2) the effect of water flow rate and energy consumed, 3) the effect of available energy and consumed energy. Meanwhile, for the average efficiency of each solar panel, it is obtained using equation (1) (Nogueira et al, 2015):

$$\eta pv = \frac{Ec}{Ae}\ 100 \qquad (1)$$

Where ηpv is solar panel efficiency (%), Ec is the energy consumed, and Ae is the available energy. Pump efficiency is calculated using equation (3):

$$\eta p = \frac{Q\ Mh\ 736}{75\ U\ I}\ 100 \qquad (2)$$

Where ηp is pump efficiency (%), Q is water flow rate (m^3L^{-1}); Mh i the manometric height (m), U is the water pump voltage (V), and I is the pump current (A). The manometric height for the reservoir geometric height of 2.5 m has a suction loss of 0.40 m and a discharge loss of 3.93 m, which is added up to a manometric height of 6.83 m.

The global efficiency of the SWP system is obtained from the efficiency of the solar panels and the efficiency of the water pump, as in equation (4):

$$\eta g = \frac{\eta pv\ \eta p}{100} \qquad (3)$$

Where ηg is global efficiency (%).

3 RESULTS

Monocrystalline 100Wp and 50Wp solar panels in parallel to get sufficient current output to run DC water pump. Likewise for polycrystalline solar panels. The placement of the solar Panel arrangement is presented in Figure 3. The structure of the tower and reservoir in the SWP test is presented in Figure 2.

Figure 3: Monocrystalline (right) and polycrystalline (left) solar panels.

SWP testing has been carried out on 26 and 27 July 2021 in Kupang Regency Indonesia. Results show of the test SWP system used monocrystalline and polycrystalline that the average volume of water produced in 3 hours reaches 4,174 liters and 3,898 liters. The water volume and solar radiation curves are presented in Figures 4 and 5.

In the monocrystalline system, every increase in Ec 1 Wh, Q will increase by 5.2069 L/h. Regression equation estimation model Q = 5.2069 Ec - 9.1113 with R^2 = 94.03%, meaning that 94.03 % Q is influenced by Ec and 5.97% is influenced by other variables. While in the polycrystalline system, every increase in Ec 1 Wh, Q will increase by 4.981 L/h. Regression equation estimation model Q = 4.981Ec - 8.9075 with R^2 = 95.10%, meaning that 95.10% Q is influenced by Ec and 4.9% is influenced by other variables. The wter flow rate and energy consumed by the monocrystalline and polycrystalline systems are presented in Figures 6 and Figure 7.

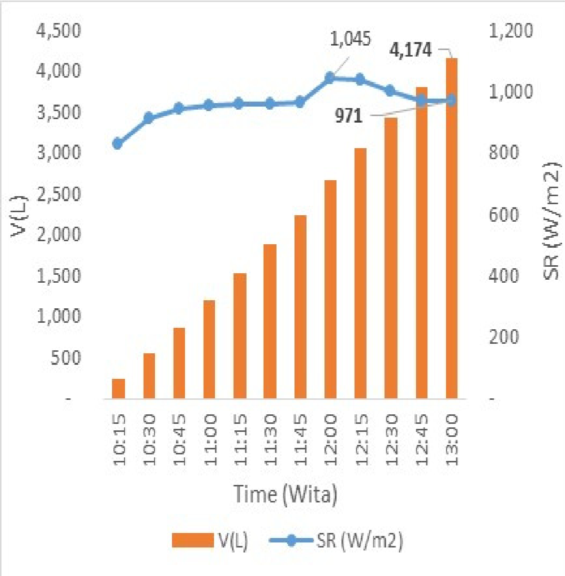

Figure 4: Volume of water and solar radiation in monocrystalline systems.

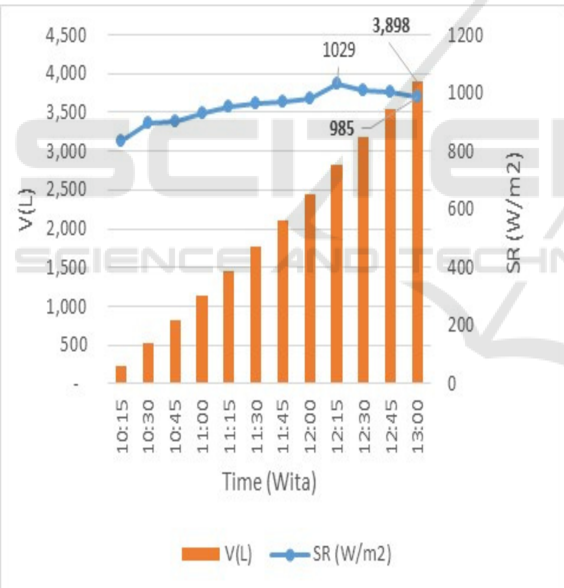

Figure 5: Volume of water and solar radiation in polycrystalline systems.

In the monocrystalline system, every 1Wh increase in Ae, then Ec will increase by 0.069 Wh. Regression equation estimation model Ec = 0.069 Ae +0.7807. R^2 = 97.82%, its mean 97.82 % Ec is influenced by Ac and 2.18% is influenced by other variables. Whereas in the polycrystalline system, every 1 Wh increase in Ae, then Ec will increase by 0.0673 Wh. The estimation model of the regression equation Ec = 0.0673Ae + 0.0132. R^2 = 99.18%, meaning that

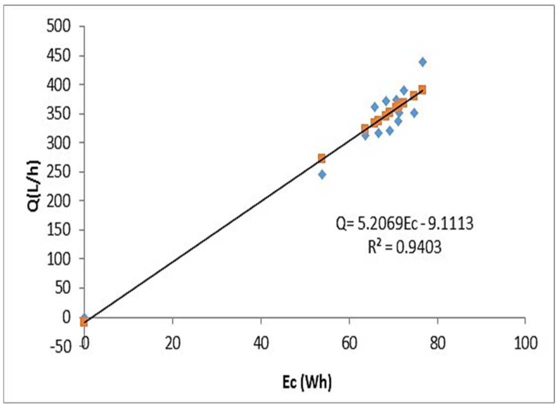

Figure 6: Water flow rate (Q) and energy consumed (Ec) by the monocrystalline system.

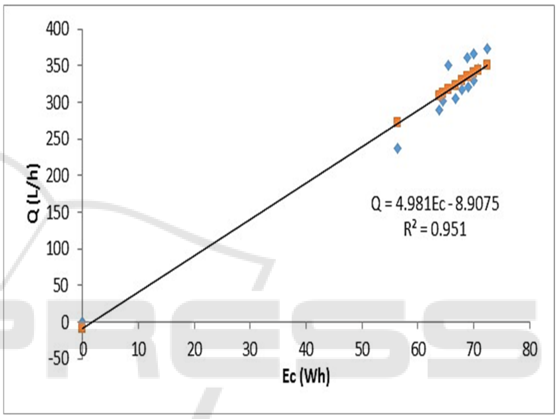

Figure 7: Water flow rate (Q) and energy consumed (Ec) by the polycrystalline system.

99.18% Ec is influenced by Ae and 0.82% is influenced by other variables. The available energy and the energy consumed are presented in Figures 8 and 9.

Based on equations (1), (2), and (3), monocrystalline and polycrystalline systems: 1) the average efficiency of solar panels is 6.87% and 6.73%. The average efficiency of the pumps is 33.85% and 32.34%. The global efficiency is 2.30% and 2.17%.

Table 1: Efficiency of each panels and temperature range.

Solar Panels	Temperature (°C)	η_{Panels} (%)	η_{Pump} (%)	η_{Global} (%)
Monocrystalline	42-62	6.87	33.85	2.30%
Polycrystalline	50-60	6.73	32.34	2.17%

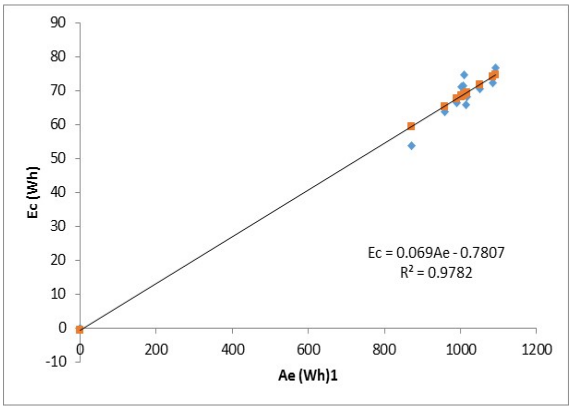

Figure 8: Energy available and energy consumed for monocrystalline system.

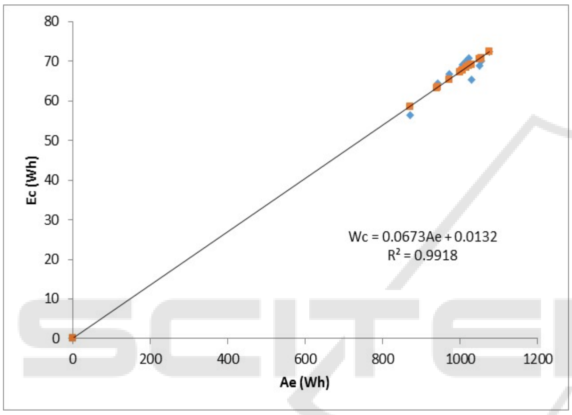

Figure 9: Energy available and energy consumed for polycrystalline system.

4 CONCLUSIONS

SWP system used monocrystalline and polycrystalline that the average volume of water produced in 3 hours reaches 4,174 liters and 3,898 liters

There is an effect of water flow rate (Q) and energy consumed (Ec). The regression equation estimation models for monocrystalline and polycrystalline systems is Q = 5.2069 Ec - 9.1113 and Q = 4.981Ec - 8.9075. There is an influence of available energy and energy consumed. The regression equation estimation models for monocrystalline and polycrystalline systems is Ec = 0.069 Ae +0.7807.and Ec = 0.0673Ae + 0.0132.

The comparison of the efficiency of the SWP system using monocrystalline and polycrystalline solar panels is as follows: The average efficiency of solar panels is 6.87% and 6.73%. The average efficiency of the pumps is 33.85% and 32.34%. The global efficiency is 2.30% and 2.17%. Thus, the more efficient use of solar panels in the SWP system is monocrystalline solar panels.

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