Design and Construction of a Portable Solar Water Pump 3000 Litter per Hour

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Abstract: The solar water pumping systems are considered as one of the most promising areas in photovoltaic applications. This study aimed to produce a prototype of a Portable Solar Water Pump (PSWP) with a flow rate of water 3000 liters per hour and determine the effect of pump head in the flow rate of water on PSWP. This research was preceded by the design and construct a prototype of the PSWP system and then performed simulations test. The experiment was carried out with variations of the pump head to find a water flow rate of 3000 Lph. The results showed that the estimate to get a flow rate of water 3000 Lph, the pump head was at 1.5 m. The pump head affects the flow rate of water. If the pump head (H) increases 1 m, the flow rate of water (A) will decrease 389.66 Lph. The regression equation model can be write Q = - 289.66 H + 3445.8, on R^2 = 79.08%, which means of 79.08% Q is effect by H, and 20.92% is affected by other variables.

1 INTRODUCTION

Water is a necessity for survival that is needed by humans for drinking and household needs. Besides that water is also needed for irrigation, construction, and electricity production. Water has a very important role in the development of any country. Quality of life in any country is very dependent on the quantity and quality of available water resources. It is estimated that an average of 100 liters of water is needed per person per day for daily survival (Theodolfi and Waangsir, 2014). Although a large amount of quality water is available, there are still many that do not meet the availability of water, especially in rural areas that still do not get electricity supply from the National Electric Company (PLN) to operate water pumps, including rural areas in Kupang Regency which have an electrification ratio still 60%. The average household that has not received electricity supply is located in remote rural areas that are difficult to reach by the PLN (Sinaga et al., 2019); (Sinaga et al., 2017).

Conventionally, electricity which is largely generated by burning fossil fuels, has been supplied from the national electricity grid, this poses a problem for supplying water to remote areas that cannot be connected directly to the network to obtain national electricity. The negative impact of burning fossil fuels on the environment is increasing, the researchers are becoming more focused on developing a standalone water pump system that can be supported by renewable energy sources. Several renewable energy sources can be used for pumping water, one of which is solar photovoltaic (PV), because it is a clean and naturally available energy source.

The use of solar electricity can support government programs to reduce greenhouse gas (GHG) emissions where the emission reduction target is contained in Law 16 of 2016 concerning Paris Approval of the United Nations Framework Convention on Climate Change. Indonesia's Nationally Determined Contribution (NDC) is a reduction in GHG emissions by 2030 by 29% on its own and 4l% if there is international cooperation because the use of solar modules will reduce the process of supplying electricity through fossil fuel power plants that cause CO2 emissions (UN-RI, 2016).

Farmers in Kupang Regency are in dire need of water pumps; however, the source of electricity is an obstacle for farmers in the villages who have no electricity. Besides the problem of providing a source of electricity, the current SWP system problem is still limited to the permanent SWP system, so it cannot be used interchangeably between farmer groups who have not been able to buy permanent SWP. The

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existence of portable SWP that it is expected to be able to flow water in farmland alternately between farmer groups and the time of use is adjusted to water needs based on the area of agricultural land owned.

The research includes designing, constructing, and simulation tests of a PSWP 3000 Lph as needed. This study aimed to produce a prototype of a Portable Solar Water Pump (PSWP) with a flow rate of water 3000 liters per hour and determine the effect of pump head in the flow rate of water on PSWP. So that this PSWP 3000 Lph can be offered to the users who need especially farmers in rural areas who do not yet have access to PLN electricity.. The uniqueness of this PSWP system is that it can be moved so that each farmer can use alternately.

The Solar Water Pump (SWP) requires solar energy as primary energy to be converted into electrical energy through solar modules. The results of the study prove that in Kupang District the intensity of sunlight is very optimum in the dry season. In the morning, afternoon, and evening sunlight radiation is very influential on the energy output of solar panels (Sinaga, 2011). Changes in the intensity of sunlight and the angle of incidence of sunlight greatly affect the voltage received by solar panels. The intensity of solar radiation on average in East Nusa Tenggara is 5,117 Wh / m2 / day, which has the potential to generate electricity (Rahardjo and I. Fitriana. 2015)

The performance of solar modules in the form of maximum power output varies with the seasons. At the end of the summer or the dry season, solar panel performance tends to increase. Based on a review of cost-efficient, effective, and environmentally friendly criteria in reducing CO2 emissions, the best choice for supplying small-scale electrical energy is to use the solar modules and with the power supply using solar modules capable of moving water pumps (Sinaga et al., 2017)

Photovoltaic (PV) modules utilize solar energy directly to produce electricity which can be used to power electrically operated water pumps. Over the past few years, researchers have focused on developing efficient solar-powered water pumping systems. This system has proven reliable even in bad weather conditions, and a recent search revealed that the largest PV system installed in the world is the Tengger Desert Solar Park in China with an installed capacity of 1500 MW. Many aspects of solar water pumping systems have been investigated, such as overall efficiency, the efficiency of individual components, economic viability, and optimization of their size. In economic terms, problems related to the use of fossil fuels such as availability, transportation costs, prices, and effects on the environment while the price of solar modules is declining due to advancements in Photovoltaic (PV) technology thereby adding to the increased feasibility of using solar water pump systems (Foster and Cota, 2014). The results of the study of Sinaga et al. 2019 in Kupang show that the price level of the installation of an off-grid PV system is at the level of 0.29-0.31 US $ / kWh.

The Solar Water Pump (SWP) system has been a real focus of interest for researchers for decades along with increasing awareness about the energy crisis. There are various design possibilities for developing SWP. However, the most common are those involving solar modules (Aliyua et al., 2017). Picture 1 shows a schematic diagram of a general SWP system consisting of a power collection system, a power conditioning unit, a water pump, and a reservoir. Water pumps installed at the source of water and pumping from the source to the reservoir which is higher than the ground level. The difference in height from the water pump to the inlet reservoir is known as the pump head. This pomp head (H) is an important parameter in designing SWP.

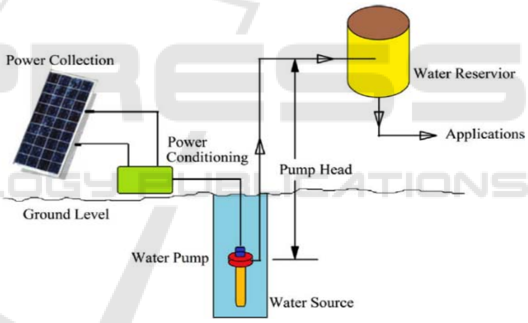

Figure 1: Schematic diagram of a solar water pump system (Aliyua et al., 2017).

Solar energy collection systems an important role in the performance of SWP system (Nogueira et al., 2015); (Sinaga and Beily, 2019); (Sinaga et al., 2019). Several aspects of solar energy collection systems have been studied in the literature which has a direct effect on the overall efficiency of SWP. The advantages of DC water pumps compared to AC include portability and energy saving, while AC has a longer life and high speed. Although the performance of commercially operated water pumps is commercially available, some researchers study the performance of water pumps. The researcher has evaluated the performance of submersible centrifugal pumps for solar water pumping and reports subsystem efficiencies ranging from 20% to 30% for water pumps installed in four different locations in Tunisia

(Belgacem, 2012). Two-person of the researcher also do research about optimized linear actuator design for use as a water pump system (Wade and Short, 2012). This research presented a design that utilizes current from the solar module to flow through copper windings so as to induce a magnetic flux in the metal core made of iron which causes it to move upward. This research also report an acceptable agreement between optimized results and experimental data. Research results show that the efficiency estimated at 7.8% with a 6A supply current to the actuator.

The pump head has a significant effect on the overall efficiency of SWP. In this case Benghanem, et al. (2014), studied the effects of various pump heads on the overall performance of the pump system. They tested pump heads ranging from 50 to 80 m. The analysis shows that increasing the pump head reduces the overall efficiency of the system. A decrease in efficiency at a higher pump head can make the whole system economically unfeasible.

An important parameter that also influences the performance of the water pump system is an effective and efficient design of the control system. The researcher Campana et al. (2014), proposed a control system that interacts between water supply and demand. Water and groundwater responses need to be considered in supplying of water needed to produce energy optimization and water savings

Another control system proposed by Sallem et al. (2010), uses of fuzzy management algorithms to control the connection period between solar modules, batteries, and water pumps. The results of this study indicate that with the use of a fuzzy management algorithm control system, there has been an increase in the use of water pumps for more than 5 hours.

The design configuration of the SWP system has been used, among others, the configuration of the DC system and AC with a battery storage system (Chandel et al., 2015); (Susanto et al.,2018). The results of the study SWP AC with a battery storage system by Tukiman et al. (2013) showed that for the use of a 550 Watt AC pump, 220 Volt at the head of 8 m, resulting in a water discharge of 3000 liters/hour. While the results of the study SWP DC systems by Priambodo et al. (2019), using a 45 Watt 12 Volt DC pump, at the head of 4 m, produces a flow rate of water up to 1912 liters/hour.

This research is developing of previous research, especially in the design of the SWP system. The novelty of the research is the SWP system in the special needs of 3000 litters per hour which can be moved. PSWP can be used by each farmer group as needed and is safer against electric shock because it uses a DC system.

2 METHODS

This research was preceded by the design and construct a prototype of the PSWP system and then performed simulations test. The experiment was carried out with variations of the pump head to find a water flow rate of 3000 Lph. The research process is presented in Figure 2.

2.1 Selection of Parameters Water Pumping Systems

The formulation for determining the water pump power capacity is presented in equation (1) (Tukiman et al., 2013):

$$P = \frac{QH\rho}{Fc.\eta} \quad (1)$$

Where: P: Water pump power (Watt), Q: flow rate of water (m^3/hour), H: Total pump head, η: Efficiency (%), ρ : water density (Kg/m^3), Fc: Power unit conversion factor.

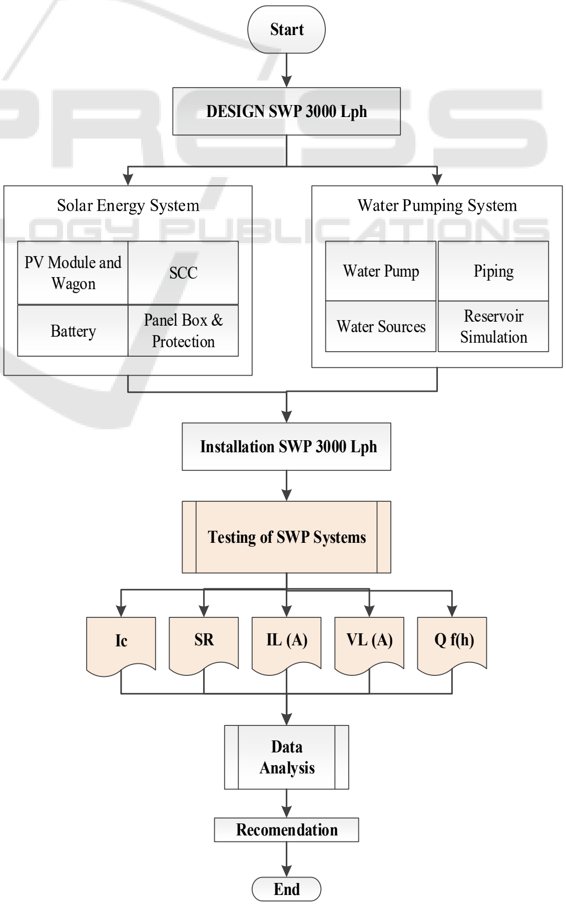

Figure 2: The research process.

To produce a flow rate of water up to 3 m^3/hour or 3000 Liters per hour (Lph) it takes a water pump capacity (Pp) 163 Watt, but the water pump on the market (Ppm) is 180 Watt, the water pump capacity needed to produce a water discharge of 3000 Lph is 180 Watt. The results of the calculation of the power capacity required water pump are presented in Table 1.

Table 1: Calculation of the power capacity of water pump.

Load Type	Q	H	ρ	Fc	η	Pp	Ppm
	(m^3/hour)	(m)	(Kg/m^3)			(Watt)	(Watt)
Submersible pump	3	15	1	367	75%	163	180

2.2 Selection of Parameters Solar Energy Systems

First, it is assumed that this solar energy system uses a PV module at 100 Wp. The question is how many modules are needed to use 180 Watt water pump capacity?

The water pump energy needed to flow water from a water source to a certain time interval is formulated as in equation (2).

$$E = P \times tp \text{ (Wh)} \tag{2}$$

Where E is Energy of water pump (Wh), P is the power of water pump (Watt) and tp is the duration of the use of water pumps (Hour). While the energy of PV module (E_{PV}) is presented in equation (3).

$$E_{PV} = \frac{E}{100} \text{ (Wh/Wp)} \tag{3}$$

The power of PV module (P_{PV}) uses the formula in equation (4).

$$P_{PV} = \frac{EPV}{ti} \text{ (Watt/Wp)} \tag{4}$$

Where ti is solar module irradiation time. The number of PV modules (N_{PV}) uses can be formulated by equation (5).

$$N_{PV} = P_{PV} \times Ad \tag{5}$$

Where Ad is Autonomy Day. PV module capacity (C_{PV}) formulated by equation (6).

$$C_{PV} = N_{PV} \times 100 \text{ (Wp)} \tag{6}$$

The capacity of battery (Cb) formulated by equation (7), while the number of batteries (Nub) formulated using equation (8). Then the parameters of the solar energy system are presented in Table 2.

$$Cb = \frac{E}{DoD \times Vb} \text{ (Ah)} \tag{7}$$

$$Nub = \frac{E}{Cb \times Vb \times DoD} \tag{8}$$

Table 2: Parameters of solar energy system.

Load Type	P (W)	tp (h)	E (Wh)	E_{PV}	ti	P_{PV}
				(Wh/Wp)	h	W/Wp
Submersible pump	180	2	360	3,6	4	0,9

Ad	N_{PV}	C_{PV}	DoD	Battery		
Day	Unit	Wp	%	Cb (Ah)	Vb (Volt)	NUb
1	1	90	50%	60	12	1

2.3 Construction of PSWP

The material used of the PSWP construction consists of PV modules, submersible pumps, batteries, wagons and box panels containing controllers, protection components, push-button switches, cable terminals, cable installations. The Construction of PSWP is presented in Figure 3.

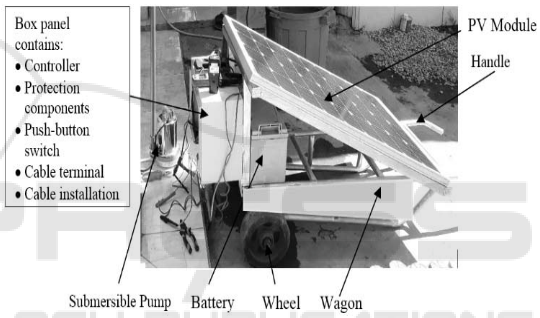

Figure 3: Construction of PSWP.

3 RESULT

PSWP test results show that solar radiation affects the battery charging current (Ic). However, the current flowing into the water pump (Ip) is not affected by solar radiation, because the electrical energy to the water pump is sourced from the battery. The battery is continuously charged as long as the PV module receives sunlight.

The current absorbed by the water pump is greater than the battery charging current so that this PSWP is designed to operate within a maximum of 2 hours. The highest battery charging current (Ic) is 4.3 Amperes when the solar radiation is 981 w / m^2, while the highest water pump (Ip) current is 12.30 Amperes. The graph of Solar Radiation (SR), battery charge current (Ic), and water pump current (Ip) are presented in Figure 4.

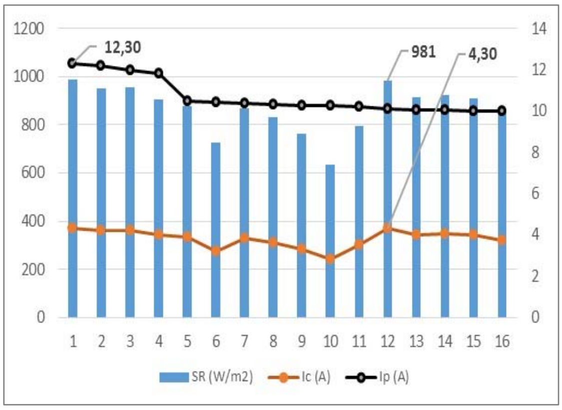

Figure 4: Graph of solar radiation (SR), battery charge current (Ic), and water pump current (Ip).

The data of the test for the pump head (H) and the flow rate of water (Q) shows, if the H increase, the Q will be decreased. The maximum of the Q at the H 0.5 m is 4,286 Lph, while the minimum of the Q at the level 1,412 Lph on the H 8 m, While the achievement of Q at the 3000 Lph is estimated to be at H 1.5 m. The graph of the H vs Q is present in Figure 5

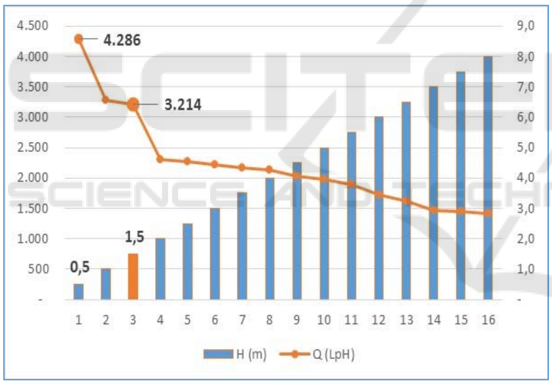

Figure 5: The graph of H vs Q.

The data of the test for the pump head (H) and the power of the water pump (Pp) shows that if the H increase, Pp will be decreased. The maximum of Pp at 125.46 Watt and the minimum of Pp at 100 Watt. The graph of H vs Pp is present in Figure 6.

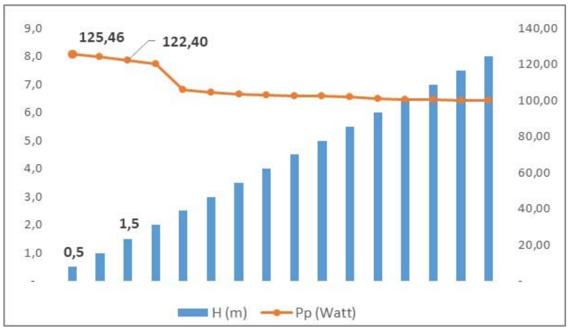

Figure 6: The graph of H vs Pp.

The battery charging current (Ic) is affected by Solar Radiation (SR). An increase in SR of 1 W / m^2, the Ic will be increased by 0.0044 Amperes. The equation regression model is Ic = 0.0044 SR with R^2 = 99.99%, which means that 99.99% Ic is affected by solar radiation and 0.01% is effect by other variables. The effect of SR on the Ic is presented in Figure 7.

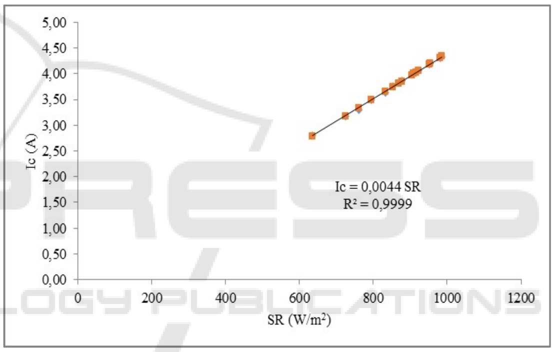

Figure 7: The effect of SR on the Ic.

The pump head affects the flow rate of water: if the pump head (H) increases 1 m, the flow rate of water (Q) will decrease 289.66 Lph. The regression equation model is Q = -289.66 H + 3445.8, with R^2 = 79.08%, meaning 79.08% Q is effected by H, and 20.92% is affected by other variables. The effect of H on Q is presented in Figure 8.

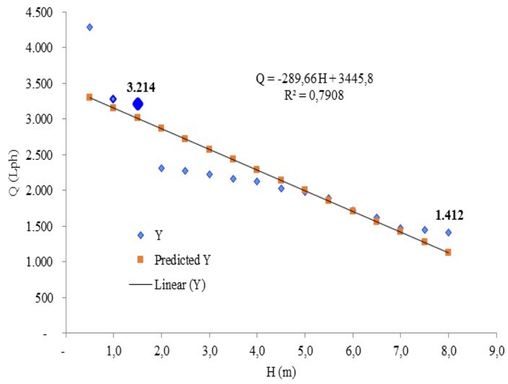

Figure 8: The Effect of H on Q.

The water flow rate (Q) is affected by the power of the pump (Pp). If the Pp increase Pp 1 Watt, then Q will increase 72.819 Lph. Regression equation estimation models can be written Q = 72.819 Pp - 5609.9, while R^2 = 80.73%, which means that 80.73% Q is effected Pp and 19.27% is affected other variables. The effect of Pp on Q is presented in Figure 9.

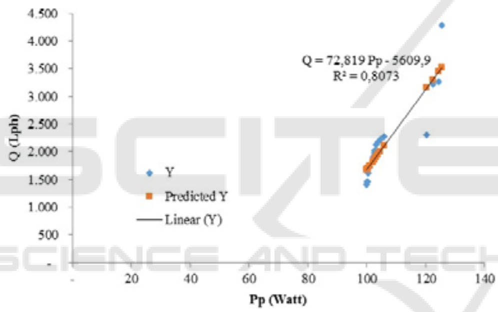

Figure 9: Effect of Pp on Q.

4 CONCLUSIONS

The results showed that the estimate to get a flow rate of water 3000 Lph, the pump head was at 1.5 m. The pump head affects the flow rate of water. If the pump head (H) increases 1 m, the flow rate of water (Q) will decrease 389.66 Lph. The regression equation model can be write Q = - 289.66 H + 3445.8, on R^2 = 79.08%, which means of 79.08% Q is effect by H, and 20.92% is affected by other variables.

The battery charging current (Ic) is affected by solar radiation (SR). If SR increases of 1 W / m^2, so Ic will be increased by 0.0044 Amperes. The equation regression model can be written Ic = 0.0044 SR on R^2 = 99.99%, which means that 99.99% of Ic is affected by solar radiation and 0.01% is effect other variables.

The water flow rate (Q) is affected by the power of the pump (Pp). If the Pp increases 1 Watt than Q will increase 72.819 Lph. Regression equation estimation models can be written Q = 72.819x - 5609.9, while R^2 = 80.73%, which means that 80.73% Q is effected Pp and 19.27% is affected other variables.

Recommendation: PSWP 100Wp-180W60Ah, can be used to produce a water flow of 3000 liters per hour at a pump head of 1.5 m. if the pump head is more than 1.5 m, the water flow obtained is less than 3000 liters per hour.

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