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Design of Solar-Powered Water Pump System for Medium Service Level of Quality Drinking Water in Southwest Aceh District, Indonesia

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Abstract— **Drinking water is a basic human need for survival. To meet the need for drinking water, some areas do not have good drinking water sources. Based on the World Health Organization (WHO) criteria, one area that only has a basic level of drinking water based on the World Health Organization (WHO) criteria is Dusun I Seunaloh, Blangpidie District, Southwest Aceh Regency, Indonesia. A solar-powered water pump system was designed to increase the level of drinking water services from the basic service level to the medium service level. A solar-powered water pump system is a technology that uses photovoltaic to drive pumps. The water pump design using solar power as an energy source is renewable energy, supports SDGs, and does not burden electricity costs of Dusun I Seunaloh. The specific research objective is to design a water pump based on solar energy with an estimated demand for the next 20 years. The design analysis carried out includes predicting population, solar radiation, pump power requirements, and energy requirements from photovoltaic. This analysis shows that the need for drinking water in the area is 27,828.96 liters/day. Supplying drinking water for 557 residents requires pump power of 1,750 W.**

Keywords—Drinking water; photovoltaic; pump; radiation

I. INTRODUCTION

Water is the most important compound for the life of the universe, especially humans. By drinking water, humans can avoid dehydration, constipation, and kidney stones. Water provides various benefits for human survival. The first benefit of water for daily human life is to meet the body's needs, namely through drinking water. Human drinking water needs an average of eight glasses or about 3.7 liters for adult men and 2.7 liters for adult women [1]. Many people need more water than this number for their bodies. All body organs need water to work, such as kidneys, brain, bones, muscles, and blood. Another need for water is for washing. Humans wash a variety of life equipment, including clothes, cutlery, food ingredients. Even for things like washing vehicles, mopping the house, and so on. Southwest Aceh Regency has a drinking water problem.

Based on the Qanun of Southwest Aceh Regency No. 3 of 2018 concerning the Mid-Term Development Plan of Southwest Aceh Regency for 2017-2022 [2], one of the objectives is to record the percentage of households using protected water sources and the percentage of households using water sources that are at risk of being polluted. Based on these data, the percentage of households using unprotected sources in 2014 was 11.7%. It is also stated that the percentage of households using protected water sources was 65.32%, while the remaining 22.98% was not explained. Unprotected drinking water is unprotected springs, unprotected wells and open wells that are less than 10 m away from sewage and garbage disposal.

Currently, the water used in several public facilities such as mosques, schools, Islamic boarding schools, and health centers in Southwest Aceh Regency is supplied from shallow wells and rivers. Their quality cannot be guaranteed clean, so other alternatives are needed. Another possible alternative is to drill a well. A pump is needed to pump water from the borehole to the storage tank. This requires electrical energy to drive the water pump. This, of course, results in a high burden of electricity costs that must be paid because water facilities are used regularly. Therefore, it is necessary to find a way out to avoid the high burden of electricity costs.

An alternative to reduce operational costs is by using Solar-Powered Water Pump Systems. Solar-Powered Water Pump Systems is a water pump powered by the Photovoltaic (PV) module. With the use of PV, the surrounding community does not need to pay electricity bills. This pump system generally does not use batteries and works as long as there is sunlight. However, the procurement of this solar water pump requires high investment because this pump is still a foreign product. This is where the local government needs to lend a hand to help provide these pumps. This is a public interest, and the local government is responsible for providing the access.

The goals and benefits of solar-powered water pump systems, in general, are to develop energy independence programs that can educate the public in utilizing renewable energy. In addition, the development of solar-powered water pump systems also supports the government in meeting the targets of the Sustainable Development Goals (SDGs). One of the program's targets is that by 2030 the Indonesian people get access to universal and decent drinking water that is safe and affordable for all. Specifically, this study aims to provide a solar-powered water pump system design for the fulfillment of moderate service level drinking water, around 50 liters/person/day, in accordance with WHO criteria.

II. METHODOLOGY

A. Location Selection

The indicator that influences the choice of location for the solar-powered water pump system design is the level of drinking water demand for the general public. Based on these indicators, the solar-powered water pump system planning location is set on land in Dusun I, Seunaloh, Blangpidie District Southwest Aceh Regency, Indonesia at the coordinates of 03.74925° N and 96.83629° E. Based on geoelectric resistivity data, the depth of the aquifer layer at this location is 27.6 meters [3].

B. Total population

The population of Dusun I Seunaloh was obtained from direct interviews with local residents. The population of this area is 82 families, and most of them work as farmers.

To anticipate the demand for drinking water in the future, solar-powered water pump systems need to be designed according to the average age of the pump, which can work up to 20 years [4][5]. This design is also in line with the International Electrotechnical Commission (IEC) International Standard 62253. To meet these standards, the population is projected for the next 20 years. The geometric method is used with the following equation for the projection of the population growth rate for the next 20 years [6].

$$P_t = P_1(1+r)^z \tag{1}$$

where:

P_t = total population in year t
P_1 = population in base year
r = population growth rate
z = projection period

C. Drinking-Water Needs

This study's analysis of drinking water needs refers to the World Health Organization (WHO) guidebook for drinking water quality guidelines [7]. The manual describes several levels of service and the amount of water collected in obtaining access to drinking water, as shown in table 1. Currently, the residents of Dusun I, Seunaloh, meet the criteria for basic access service levels. In this study, the design of a solar-powered water pump system for the level of service access was moderate. The community in the Dusun I Seunaloh could access drinking water of around 50/liter/day.

D. Solar Radiation

Solar radiation data is a very important input in solar-powered water pump system design. Radiation data on the solar-powered water pump system in this study were obtained from the National Aeronautics and Space Administration (NASA) (Atmospheric Science Data Center, 2016). The data obtained is the monthly accumulation of solar radiation data at coordinates 03.74925° north latitude and 96.83629° east longitude in kW/m^2/day units.

TABLE I. SERVICE LEVEL AND QUANTITY OF WATER COLLECTED [7]

Service level	Distance/time	Likely volumes of water collected
No access	More than 1 km / more than 30 min round-trip	Very low: 5 liters per capita per day
Basic access	Within 1 km / within 30 min round-trip	Approximately 20 liters per capita per day on average
Intermediate access	Water provided on-plot through at least one tap (yard level)	Approximately 50 liters per capita per day on average
Optimal access	Supply of water through multiple taps within the house	100–200 liters per capita per day on average

E. Pump Power Requirement

A pump is a machine that is used to explain the energy of moving fluids by using other energy, namely shaft energy. The term pump is commonly used for liquid fluids (liquid), while for fluids in the form of gases (compressible fluids), the word compressor is more commonly used. Basically, a compressor is also a pump, where the components and working principle are the same. To analyze the power requirements needed by the shaft on the solar-powered water pump systems pump, the following equation is used [8]:

$$P_{shaft} = \frac{Q.\rho.g.H}{3{,}6.10^6.\eta_{pump}} \tag{2}$$

where:

P = pump power (kW)
Q = flow capacity (m^3/hour)
ρ = Density of fluid (kg/m^3)
H = Total head (m)
η_{pump} = pump efficiency

For this solar-powered water pump systems design, the above equation is used with the provisions of ρ, which is a water density of 1000 kg/m^3. Power P is theoretical power in practice. There are pump shaft power losses and electric motor losses.

$$P_{motor} = \frac{P_{shaft}}{\eta_{motor}} \tag{3}$$

Total Dynamic Head (TDH) is the total water level that must be pumped by calculating the friction losses in the pipe and the connection between the pipe connections. TDH is calculated using the following equation [9]:

$$TDH = Vertical\ lift + Pressure\ head + Friction\ losses \tag{4}$$

The vertical lift is the vertical distance between the surface of the water source (well) and the surface of the tank. The pressure head is the pressure at the point of delivery of water in the tank. Friction losses are losses that occur due to friction when water flows in the pipe. To calculate friction losses, the Hazen-Williams equation is used as follows [10]:

$$\frac{H_L}{L} = \frac{10{,}67Q^{1{,}852}}{C^{1{,}852}D^{4{,}8704}} \tag{5}$$

where:

H_L = head loss (m)
L = length of pipe (m)
Q = volume of flow of water(m^3/s)

C = Hazen-Williams roughness constant
D = internal diameter of the pipe (m)

To analyze the pump power requirements of the Solar-Powered Water Pump Systems, Lorentz Compass software is used. The type of pump in this research is a submersible centrifugal pump. Centrifugal pumps have an efficiency of 60-80% [11]. While the motor usually has a maximum efficiency of 75% [12].

F. Photovoltaic Module Requirement

The efficiency of the existing photovoltaic module is around 18% [13]. In the next few years, with the application of new technologies, the efficiency of solar cells is expected to reach 22% [14]. Meanwhile, the loss factors that will affect the solar panels consist of ±5% power tolerance and ±5% dust factor. In addition, the temperature coefficient is around ±5%/ºC compared to the test temperature at 25ºC.

The average solar energy in Indonesia that can be absorbed and converted into electrical energy lasts for 4.5 to 5 hours. Therefore, to calculate how much the photovoltaic module needs we divide the power requirement by the length of time at peak energy. To facilitate the calculation, the total watt-hour/day requirement is divided by the efficiency value of the PV module to avoid losses that occur.

To maximize the reception of solar radiation on the photovoltaic module, the direction of the slope of the PV module needs to be considered. Photovoltaic modules that are fixed (not moving with the sun's movement) should be positioned facing the direction of the sun's radiation.

III. RESULTS AND DISCUSSION

A. Population Analysis

The majority of the residents of Dusun I, Seunaloh do not have access to drinking water from PDAM Gunong Kila, a public water utility company in Southwest Aceh Regency. For drinking water needs, the community transports water from wells less than 1 km away, while for washing and other cleaning needs, they use river water from the hills. According to WHO criteria, the service level of the population in the Dusun I Seunaloh is included in the basic service level, around 20/liter/person/day.

To provide access to drinking water for the residents of Dusun I Seunaloh, communal public taps are projected for the needs of the next 20 years. For the projected population growth rate for the next 20 years, it is assumed that 1 household consists of 5 people (2 parents and 3 children). So, the total residents are:

$$total\ population = Total\ household\ \times 5$$
$$total\ population = 82\ \times 5$$
$$total\ population = 410\ resident$$

Based on data from the Central Agency on Statistics (BPS) of the Republic of Indonesia in 2020, the growth rate of Southwest Aceh Regency is 1.54%. To project for the next 20 years, the prediction of the population according to equation 1 in Dusun I Seunaloh is:

$$P_t = P_1(1+r)^z$$
$$P_{20} = 410(1+1{,}54\%)^{20}$$
$$P_{20} = 556{,}58$$
$$P_{20} = 557\ residents$$

B. Drinking-Water Requirement Analysis

Based on the World Health Organization (WHO) guidebook on drinking water quality guidelines, residents should have access to drinking water at a distance of up to 1 km or 30 minutes from their home and have basic access to drinking water at around 20 liters/person/day. This research designs the needs of the residents of Dusun I Seunaloh to access at a moderate level of 50 liters/person/day through the provision of communal public taps. It means that the residents of Dusun I Seunaloh need water as much as:

$$Water\ requirement\ = total\ residents\ \times 50\ l/d$$
$$Water\ requirement\ = 557\ \times 50\ l/d$$
$$Water\ requirement\ = 27.828{,}96\ \ l/d$$

C. Solar Radiation Analysis

The solar-powered water pump systems to be built is planned to be located on community land with an elevation of 238 m above sea level with coordinates of 3,74925° north latitude and 96,83629° east longitude. From these coordinate points, the average monthly solar radiation is obtained, as shown in Figure 1.

From these data, it can be seen that the minimum amount of solar radiation occurs in November every year. Based on data from NASA, the minimum radiation at this location is 4.63 kWh/m^2. While the maximum radiation occurred in February which reached 5.47 kWh/m^2. The average monthly solar radiation at the location is shown in Figure 1. The average solar radiation per year is obtained by adding up the average solar radiation per month divided by 12 months. The average annual radiation at this location is 5.02 kWh/m^2.

D. Pump Power Requirement Analysis

The power analysis of the pump is designed for water needs of 27,828,96 liters/day. With peak sun hour equal to the average annual radiation at that location, which is 5.02 hours, it takes a discharge of 5.54 m3/hour or 0.00154 m3/s to fill the storage tank.

$$Water\ requirement\ /5{,}02\ h = \ 1{,}54\ l/s$$
$$Water\ requirement\ /5{,}02\ h = \ 5{,}54\ m^3/h$$

Based on geoelectric data, the aquifer layer at this location is 27.6 meters, and if the height of the water tower is 7 meters, the vertical lift is 34.6 m.

Based on equation 5, the Hazen Williams equation, if a PVC pipe is used and the Hazen Williams constant 150, with a size of 3/4 inch with an inner pipe diameter of 26 mm, will result in friction losses:

$$\frac{H_L}{L} = \frac{10{,}67Q^{1{,}852}}{C^{1{,}852}D^{4{,}8704}}$$
$$H_L = 27{,}6\ m \times \frac{10{,}67 \times 0{,}00154^{1{,}852}}{150^{1{,}852} \times 0{,}26^{4{,}8704}}$$
$$H_L = 8{,}91\ m$$

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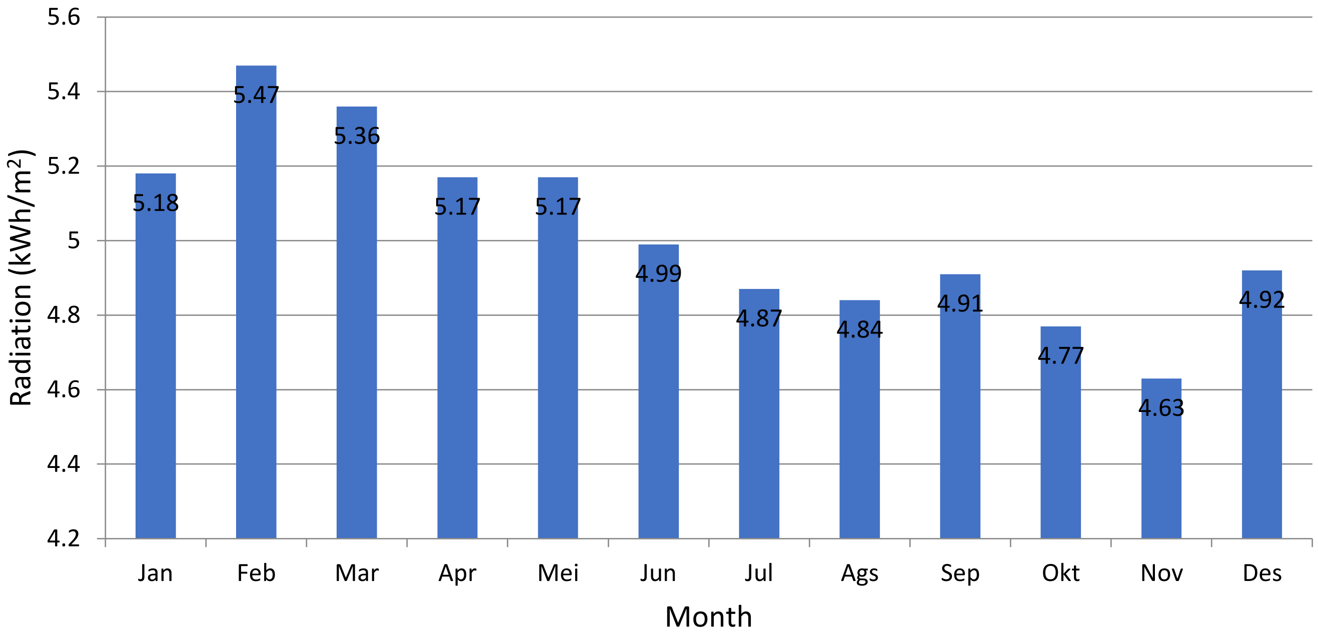

Fig. 1. Average solar radiation per month

The pump is designed in the form of a submersible pump, so it is assumed that there is no pressure head from the well to the pump. At the point of delivery of drinking water (surface of the tank), there is also no pressure head because there is no pressure on the surface of the tank. Therefore, according to equation 4, the TDH that occurs is:

$$TDH = Vertical\ lift + Pressure\ head + Friction\ losses$$

$$TDH = 34{,}6\ m + 0 + 8{,}91\ m$$

$$TDH = 43{,}51\ m$$

From the above calculation, the TDH is 43.51 m. Based on Lorentz Compass software analysis, as shown in Figure 2, it can be seen that the pump power requirement is 1.4 kW.

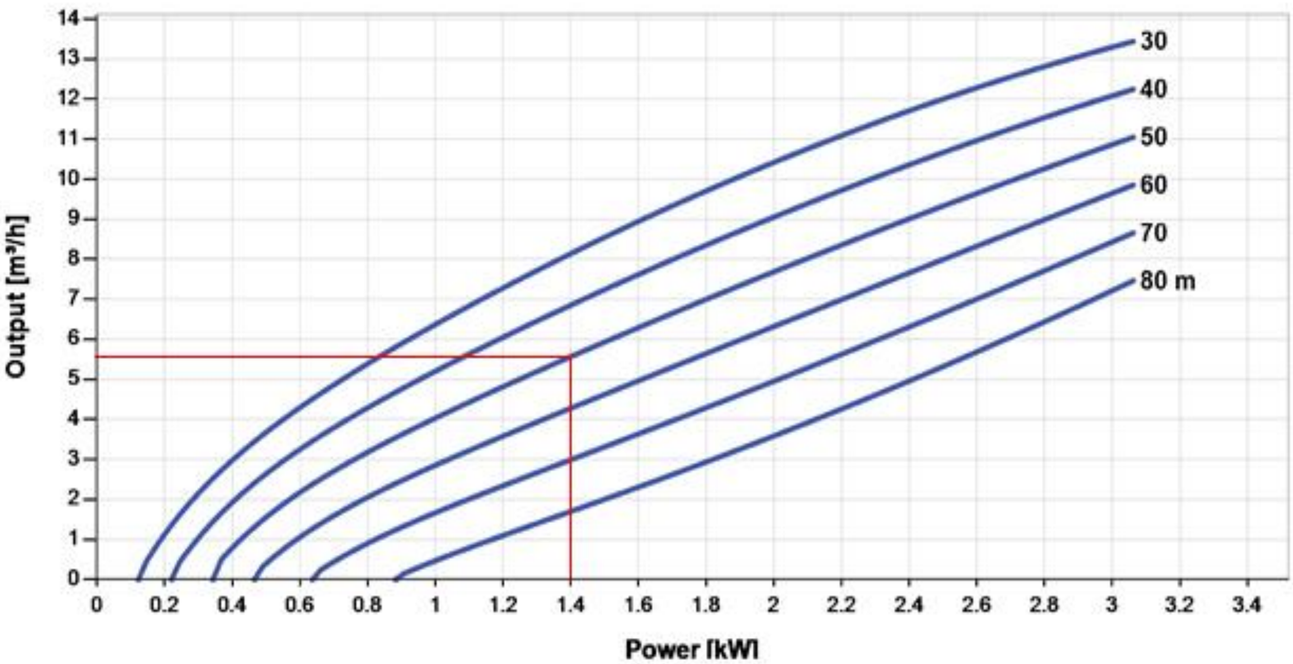

Fig. 2. Lorentz Compass analysis results

In addition to using the Lorentz Compass software, calculations are also carried out using equation 2. Based on calculations using equation 2, assuming the pump efficiency (shaft on the pump) is 70%, the following results are obtained:

$$P_{shaft} = \frac{Q.\rho.g.H}{3{,}6.10^6.\eta}$$

$$P_{shaft} = \frac{5{,}54 \times 1000 \times 9{,}81 \times 43{,}51}{3{,}6.10^6 \times 70\%}$$

$$P_{shaft} = 0{,}94\ kW$$

The power of 0.94 kW is the power required by the pump to be able to pump water of 5.54 m3/hour. This power does not include power on the motor. If the efficiency of the motor is 70%, then the power required is:

$$P_{motor} = \frac{0{,}94\ kW}{70\%} = 1{,}340\ kW$$

The power obtained from the Lorentz Compass software and calculations using equation 3 produces a power that is not much different. The power must be supplied by the PV module.

If the efficiency of the PV module is 18%, then 7,780 W of power is needed from the PV module to drive the submersible pump. The power generated by the PV module needs to be calculated for additional power of about 25%. This needs to be done because of external factors such as heat, dust, and age, which can affect the ability to produce energy to work for 20 years. With the addition of 25% power, a PV module with a power of 9,725 W is needed. However, PV module products sold in the market usually include the maximum power generated per PV module. Considering the maximum power generated per PV module, after adding 25% power to avoid external factors, 1750 W of power is needed from the PV module. If a PV module with a maximum power of 355 W is used, then 5 units of PV modules are needed to drive the pump of solar-powered water pump systems.

IV. CONCLUSION

The need for drinking water for the residents of Dusun I Seunaloh, Blangpidie District, Southwest Aceh Regency can be done by providing solar-powered pumps. This need can be met with a PV module power of 1750 W and deliver 5.54 m3/hour of water. With this amount of water, the need for drinking water of 50/liter/person/day can be achieved so that it can meet the WHO medium level of service criteria. The power needed to deliver the drinking water is 1,750 W. In addition, the implementation of solar-powered water pump systems can protect the environment from pollution while the residents in the Dusun I Seunaloh do not have to pay electricity bills.

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