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Analysis of Reservoir Water Discharge at Solar Power Plant Tanjung Raja Village as a Basis for Pico Hydro Power Plant Planning in Paddy-Field Area

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ABSTRACT

Energy is an important aspect of life as a whole. The fossil-based energy sources have dwindled over time, in line with population growth and economic growth. One approach to meeting the energy demand is to use renewable energy. According to Presidential Regulation Number 22 of 2017 on National Energy General Plan (RUEN) targets, the share of New and Renewable Energy in total national energy in 2025 will be 25%. The construction of a Hydro Power Plant is expected to reach 3.000 MW by 2025. According to NREEC statistical data from 2016, the potential for constructing a Hydro Power Plant in South Sumatera is approximately 448 MW. This paper investigates the possibility and potential of building Hydro Power Plant from the reservoir of the irrigation water system generated by a Solar Power Plant in Tanjung Raja Village, Muara Enim District, South Sumatra. The water discharge magnitude is measured, and the potential of electricity generated from the discharge is presented. The experimental data shows that water discharge from the reservoir can generate maximum electricity of 806,6488 watts with a discharge rate of 0.0653 m^3/s, and power is 36,7245 watts, with a discharge of 0,0030 m^3/s. The average electricity potential is approximately 375.6782 watts, with a discharge average of 0.0304 m^3/s. Therefore, the experimental data shows the possibility of hybridizing the Solar Power Plant with Hydro Power Plant, which will be beneficial for the residential area in Tanjung Raja Village, Muara Enim.

1. Introduction

Indonesia's energy demand is rising in tandem with the country's population and economic growth. The amount of fossil-based energy sources available has been decreasing over time. Renewable energy is one option for meeting energy demand. Renewable energy refers to renewable and limitless energy sources such as solar energy, wind energy, biomass, geothermal energy, and hydro energy [1]-[5]. Unfortunately, renewable energy implementation is currently limited to state-owned enterprises [6]-[8] and research institutions [9]-[15]. Given Indonesia's abundant renewable energy resources, this situation is appalling.

Indonesia has incredible potential in water sources; by utilizing water resources abundantly; hence, electrical power can be supplied even to rural areas [16]-[28]. According to Presidential Regulation

Number 22 of 2017 on National Energy General Plan (RUEN) targets, the share of New and Renewable Energy in total national energy will be 25% in 2025 [29].

Micro-Hydro Power Plant (MHPP) construction is aimed at 3.000 MW by 2025 (Directorate-General for New, Renewable Energy, and Energy Conservation (NREEC), 2016) [29]. According to NREEC statistical data from 2016, the potential for constructing an MHPP in South Sumatera is approximately 448 MW [29].

In Indonesia, hydro power plants are a promising source of renewable energy. Hydro Power Plant development can be divided into six categories: large hydro, medium hydro, small hydro, mini hydro, micro hydro and pico hydro. A Pico-Hydro Power Plant capacity is no more than 5 kW, which harnesses the flow rate to produce electrical power [16]-[28]. This micro scale power plant is most suitable for residential areas with a limited source of body water, such as a brook, creek, or even a small river.

This study presents the survey and measurement data needed for the Hydro Power Plant construction plant. The data is analyzed to show the expected electrical power generated by the water flow. The water discharge is the output of an Solar Power Plant-powered irrigation system. The Hydro Power Plant considered in this study is expected to provide backup electrical power for the residential area surrounding the paddy field in Tanjung Raja Village.

This research also contributes to the Governor of South Sumatra's paddy field electricity program launched in 2020. The districts of Oku Timur and Muara Enim have already begun to implement this program. Tanjung Raja Village in Muara Enim Regency is currently implementing an electricity program for paddy fields, which begins with constructing a Solar Power Plant (SPP) to power irrigation pumps capable of transporting water long distances [30]-[35]. The Enim River and the PLTS reservoir in Tanjung Raja Village are only about 900 meters apart. This water discharge output from the Solar Power Plant reservoir will be used in the construction of the Hydro Power Plant. The electricity generated by the Hydro Power Plant is expected to support farming activities such as driving the dynamo of the rice harvesting machine. The electricity generated by the Hydro Power Plant can also be used to power the lamp that illuminates the paddy fields.

The problem that will be addressed in this study is how much power is generated by water discharge from a reservoir with a low head. The research objective is to investigate the power generated by water discharge from a reservoir with a low-head source. This study presents the selection of turbines for water discharge conditions in Tanjung Raja village, South Sumatera [36]-[38].

A. Renewable Energy

Renewable energy is defined as energy derived from natural sources that are constantly replenished on a human timescale. Natural sources include solar, wind, wave, tidal, biomass, and geothermal are renewable energy sources that can be converted into electricity or gasoline. Each renewable energy source is unique in its way. Renewable energy sources are the local wisdom, where there is a potential disparity of renewable energy sources in each area that can be used [1]-[13].

B. Pico-Hydro Power Plant

Pico-Hydro Power Plant is a scaled-down installed power generation of less capacity that uses power or flow as its propulsion, such as creeks, irrigation aqueducts, and waterfalls that use the head. The principles of Hydro Power Plant are seizing the potential energy of the head and the amount of water discharge supplied to the penstock. The electricity produced is dynamic to the height of the waterfall. The higher the waterfall, the more massive the kinetic energy potential is available to generate electricity. The water output will actuate the turbine, resulting in kinetic energy, and the turbine will be connected to the generator, allowing the generator to produce electricity [17].

Based on the output, Hydro Power Plant is distinguished to 6 sorts [36]:

- Large-hydro: more than 100 MW
- Medium-hydro: between 15 – 100 MW
- Small-hydro: between 1 – 15 MW
- Mini-hydro: more than 100 kW, but less than 1 MW
- Micro-hydro: between 5 kW – 100 kW
- Pico-hydro: the power output is less than 5 kW

Pico Hydro Power Plant has several advantages compared to other power plants, such as no Green House Gas Emissions, requiring only a small portion of the water flow, and operating as a run-of-river system. The run-of-water system means the water flows through the generator is routed to the river; hence, having a minor or even no impact on the ecology. This way of generating electricity can meet the electricity needs of developing countries.

C. *The Culvert Discharge*

The culvert discharge is the volume of fluid flowing through the cross-sectional area per unit time. The culvert discharge is calculated to discover the water quantity flowed in a volume of fluid per time [17].

D. *Screw Turbine*

Screw Turbine is one of the turbines which is deployed on Micro-Hydro Power Plant or Pico-Hydro Power Plant. Screw Turbine was derived from ancient concepts by Mathematician and Physicist Archimedes (287 – 212 SM). Besides known by turbine screw, this turbine also is known as Archimedes screw. Mayrhofer stated that screw turbine is more compatible deployed on the low-head or the elevation difference between upstream and downstream low rate even zeros [16]. Screw turbine is one of the turbines produced to the area which has the low-head. In the use of screw turbine, vantage points depend on the circumstances of the head in the field.

Another advantage of this screw turbine than other turbines is the ability of this turbine that can be operated on dirty water, the cost of manufacturing and maintenance which is in-expensive, and fish-friendly [38].

2. Method

A. *Research Site*

This study is located on the reservoir that serves as an irrigation source for the paddy fields in Tanjung Raja Village, Muara Enim District, Muara Enim Sub-District, South Sumatera, as shown in Fig. 1. The water source reservoir required for irrigation is from the Enim River, and the stream water is routed to the reservoir over a distance of 900 meters using a pump powered by a solar power plant.

Figure 1. Research site at Tanjung Raja Village

B. Structural Design Approaches

The design of the Hydro Power Plant considered in this study is illustrated in Fig. 2. Water from the reservoir is routed 10 meters away via a 6 inch PVC pipe. A screw turbine is attached to the pipe's end, which will drive a generator to generate electricity.

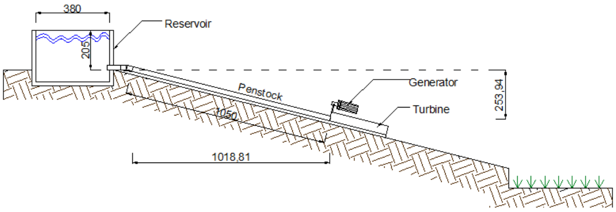

Figure 2. The scheme manufacture of pico-hydro

The measurement and retrieval data were conducted to the variety of the valve-opening, whereby the valve ¼ open, the valve ½ open, the valve ¾ open and the valve full open. Variations in reservoir valve openings will result in variations in water flow, which will rotate the turbine. It is expected to know the minimum and maximum discharges to get the minimum and maximum power generated.

1) *Pipe Cross-Sectional Area:* A 6inch pipe with the circle cross-section can be counted with the area of a circle formulation.

$$A = \frac{1}{4}\pi d^2 \tag{1}$$

where:

A = Cross-Sectional Area (m^2)

d = Pipe Diameter (m)

2) *Water Velocity Count:* On this research, the data of water velocity using current-meter was obtained to 44 data. The measurement and retrieval data were conducted to the variety of the valve-opening, whereby the valve ¼ open, the valve ½ open, the valve ¾ open and the valve full open.

Table 1. Water Velocity with the Reservoir Valve ¼ Open and Reservoir Valve ½ Open

No.	Valve ¼ open	Name of unit	Valve ½ open	Name of unit
1	2.2970	m/s	4.1330	m/s
2	2.3970	m/s	4.1960	m/s
3	2.4240	m/s	4.3910	m/s
4	2.6010	m/s	4.3960	m/s

5	2.6500	m/s	4.4300	m/s
6	2.6680	m/s	4.6070	m/s
7	2.7740	m/s	4.7840	m/s
8	2.8760	m/s	4.8170	m/s
9	2.9370	m/s	4.8920	m/s
10	2.9500	m/s	4.8960	m/s
11	2.9540	m/s	4.9130	m/s

Table I shows water velocity with the reservoir valve ¼ open, the minimum water velocity is 2.2970 m/s and the maximum water velocity is 2.9540 m/s. Water velocity with the reservoir valve ½ open, the minimum water velocity is 4.1330 m/s and the maximum water velocity is 4.9130 m/s.

Table 2. Water Velocity with the Reservoir Valve ¾ Open and Reservoir Valve Full Open

No.	Valve ¾ open	Name of unit	Valve Full open	Name of unit
1	6.0990	m/s	6.0660	m/s
2	6.1650	m/s	6.1320	m/s
3	6.3670	m/s	6.2880	m/s
4	6.5690	m/s	6.3670	m/s
5	6.6940	m/s	6.6080	m/s
6	6.7890	m/s	6.8490	m/s
7	6.8060	m/s	7.0880	m/s
8	6.9680	m/s	7.1210	m/s
9	7.1300	m/s	7.1390	m/s
10	7.1480	m/s	7.2080	m/s
11	7.2680	m/s	7.2610	m/s

3) *Culvert Discharge (Water Discharge):* The discharge (Q) is counted to discover the amount of water that flowed in volume per unit time [2].

$$Q = A.v \tag{2}$$

where:

Q = water discharge in volume per unit time

A = cross-sectional area

v = water velocity using current-meter

C. *Potential of Electrical Power Count*

The amount of hydropower available from the water source is determined by the amount of head and water discharge. Head refers to the altitude difference between the levees and the water output from the turbine relative to the water reservoir. [19].

Theoretically, the potential of the electrical power that can be generated by the water flow is calculated by [20]:

$$P = \rho.Q.g.H \tag{3}$$

where:

P = Electrical Power (watt)

ρ = Water Density (kg/m^3)

Q = Water Discharge (m^3/s)

g = Gravity Velocity (m/s^2)

H = Head (m)

If the power potential is calculated using the minimum of the frontier, the output of the resurrected power potential obtained is given by [37]:

$$P = \rho . Q . g . H . \eta_p . \eta_t . \eta_g \qquad (4)$$

where:

η_p = the minimum frontier of power potential (0,9)

η_t = the minimum frontier of turbine (0,7)

η_g = the minimum frontier of generator (0,8)

3. Result and Discussion

A. *The Analysis of Water Discharge*

The amount of required water discharge can be calculated by:

$$Q = A . v \qquad (5)$$

Water velocity (v) is measured using a current meter 11 times for each type of reservoir valve-opening. The water velocity of the penstock affects the water discharge, which in turn affects the output characteristic of the Pico Hydro Power Plant.

The measurement and retrieval data that was conducted to the variety of the valve-opening of ¼ open, ½ open, ¾ open and full open, hence it will be obtained to the variety of cross-sectional area which caused the variety of the water discharge drove the turbine and is expected to find out the minimum and maximum discharge to obtain the minimum and maximum power output. The results of the measurement of water velocity and the calculations of water discharge are given in Table 3 to Table 6.

Table 3. Velocity Measurement and Water Discharge Calculations with the Reservoir Valve ¼ Open

No.	Velocity (m/s)	Cross-Sectional Pipe Area (m^2)	Cross-Sectional Wet Area (m^2)	Discharge (m^3/s)
1	2.2970	0.0180	0.0013	0.0030
2	2.3970	0.0180	0.0013	0.0031
3	2.4240	0.0180	0.0013	0.0031
4	2.6010	0.0180	0.0013	0.0034
5	2.6500	0.0180	0.0013	0.0034
6	2.6680	0.0180	0.0013	0.0035
7	2.7740	0.0180	0.0013	0.0036
8	2.8760	0.0180	0.0013	0.0037
9	2.9370	0.0180	0.0013	0.0038
10	2.9500	0.0180	0.0013	0.0038
11	2.9540	0.0180	0.0013	0.0038

Table 3 shows that having the water velocity data using the reservoir valve ¼ open is sequenced from the minimum to maximum have obtained the minimum value of the water discharge is 0.0030 m^3/s and the maximum is 0.0038 m^3/s.

Table 4. Velocity Measurement and Water Discharge Calculations with the Reservoir Valve ½ Open

No.	**Velocity (m/s)**	**Cross-Sectional Pipe Area (m^2)**	**Cross-Sectional Wet Area (m^2)**	**Discharge (m^3/s)**
1	4.1330	0.0180	0.0035	0.0145
2	4.1960	0.0180	0.0035	0.0147
3	4.3910	0.0180	0.0035	0.0154
4	4.3960	0.0180	0.0035	0.0154
5	4.4300	0.0180	0.0035	0.0156
6	4.6070	0.0180	0.0035	0.0162
7	4.7840	0.0180	0.0035	0.0168
8	4.8170	0.0180	0.0035	0.0169
9	4.8920	0.0180	0.0035	0.0172
10	4.8960	0.0180	0.0035	0.0172
11	4.9130	0.0180	0.0035	0.0173

Table 4 shows that having the water velocity data using the reservoir valve ½ open is sequenced from the minimum to maximum have obtained the minimum value of the water discharge is 0.0145 m^3/s and the maximum is 0.0173 m^3/s. The difference in wet cross-sectional area is caused by variations in reservoir valve openings.

Table 5. Velocity Measurement and Water Discharge Calculations with the Reservoir Valve ¾ Open

No.	**Velocity (m/s)**	**Cross-Sectional Pipe Area (m^2)**	**Cross-Sectional Wet Area (m^2)**	**Discharge (m^3/s)**
1	6.0990	0.0180	0.0062	0.0376
2	6.1650	0.0180	0.0062	0.0380
3	6.3670	0.0180	0.0062	0.0393
4	6.5690	0.0180	0.0062	0.0405
5	6.6940	0.0180	0.0062	0.0413
6	6.7890	0.0180	0.0062	0.0419
7	6.8060	0.0180	0.0062	0.0420
8	6.9680	0.0180	0.0062	0.0430
9	7.1300	0.0180	0.0062	0.0440
10	7.1480	0.0180	0.0062	0.0441
11	7.2680	0.0180	0.0062	0.0448

Table 5 shows that having the water velocity data using the reservoir valve ¾ open is sequenced from the minimum to maximum have obtained the minimum value of the water discharge is 0.0376 m^3/s and the maximum is 0.0448 m^3/s.

Table 6. Velocity Measurement and Water Discharge Calculation with the Reservoir Valve Full Open

No.	**Velocity (m/s)**	**Cross-Sectional Pipe Area (m^2)**	**Cross-Sectional Wet Area (m^2)**	**Discharge (m^3/s)**
1	6.0660	0.0180	0.0090	0.0546
2	6.1320	0.0180	0.0090	0.0552
3	6.2880	0.0180	0.0090	0.0566
4	6.3670	0.0180	0.0090	0.0573
5	6.6080	0.0180	0.0090	0.0595
6	6.8490	0.0180	0.0090	0.0616
7	7.0880	0.0180	0.0090	0.0638
8	7.1210	0.0180	0.0090	0.0641
9	7.1390	0.0180	0.0090	0.0642
10	7.2080	0.0180	0.0090	0.0648
11	7.2610	0.0180	0.0090	0.0653

Table 6 shows that having the water velocity data using the reservoir valve ¾ open is sequenced from the minimum to maximum have obtained the minimum value of the water discharge that is 0.0546 m^3/s and the maximum is 0.0653 m^3/s.

As can be seen in Tables 3 through 6, the reservoir valve opening affected the cross-sectional wet area of the penstock. The more significant the reservoir valve opened, the larger the cross-sectional wet area, which affects the water discharge, which is also increasing.

Once the data is sequenced from Table 3 to table 6, will be discovered that the minimum discharge is 0.0030 m^3/s, the maximum is 0.0653 m^3/s and the average discharge out of 44 data is 0.0304 m^3/s.

B. *The Analysis of The Electric Power Potential*

Water discharge affects the rotation velocity that drives the turbine, and the turbine drives the generator to produce electricity. The potential electricity generated by the flow using the minimum frontier can be calculated by:

$$P = \rho . Q . g . H . \eta_p . \eta_t . \eta_g \qquad (4)$$

where, *H* is measured-head amounted to 2,5m in the field. Tables VII to X show the results of the formula-based calculations of the electrical power potential.

Table 7. Potential of Electric Power Using Reservoir Valve ¼ Open

No.	Velocity (m/s)	Discharge (m^3/s)	Power (watt)
1	2.2970	0.0030	36.7245
2	2.3970	0.0031	38.3233
3	2.4240	0.0031	38.7550
4	2.6010	0.0034	41.5849
5	2.6500	0.0034	42.3683
6	2.6680	0.0035	42.6561
7	2.7740	0.0036	44.3508
8	2.8760	0.0037	45.9816
9	2.9370	0.0038	46.9569
10	2.9500	0.0038	47.1647
11	2.9540	0.0038	47.2287

Table 7 shows that the more massive water discharge the more massive the power-output potential, the minimum power is 36.7245 watt and the maximum is 47.2287 watt.

Table 8. Potential Of Electric Power Using Reservoir Valve ½ Open

No.	Velocity (m/s)	Discharge (m^3/s)	Power (watt)
1	4.1330	0.0145	179.3109
2	4.1960	0.0147	182.0442
3	4.3910	0.0154	190.5043
4	4.3960	0.0154	190.7212
5	4.4300	0.0156	192.1963
6	4.6070	0.0162	199.8755
7	4.7840	0.0168	207.5547
8	4.8170	0.0169	208.9864
9	4.8920	0.0172	212.2403
10	4.8960	0.0172	212.4138
11	4.9130	0.0173	213.1514

Table 8 shows the minimum power is 179.3109 watt and the maximum is 179.3109 watt.

Table 9. Potential Of Electric Power Using Reservoir Valve ¾ Open

No.	Velocity (m/s)	Discharge (m^3/s)	Power (watt)
1	6.0990	0.0376	464.3071
2	6.1650	0.0380	469.3316
3	6.3670	0.0393	484.7095
4	6.5690	0.0405	500.0874

5	6.6940	0.0413	509.6035
6	6.7890	0.0419	516.8357
7	6.8060	0.0420	518.1299
8	6.9680	0.0430	530.4627
9	7.1300	0.0440	542.7955
10	7.1480	0.0441	544.1658
11	7.2680	0.0448	553.3012

Table 9 shows the minimum power is 464.3071 watt and the maximum is 553.3012 watt.

Table 10. Potential Of Electric Power Using Reservoir Valve Full Open

No.	Velocity (m/s)	Discharge (m^3/s)	Power (watt)
1	6.0660	0.0546	673.8922
2	6.1320	0.0552	681.2244
3	6.2880	0.0566	698.5549
4	6.3670	0.0573	707.3313
5	6.6080	0.0595	734.1048
6	6.8490	0.0616	760.8783
7	7.0880	0.0638	787.4296
8	7.1210	0.0641	791.0957
9	7.1390	0.0642	793.0954
10	7.2080	0.0648	800.7608
11	7.2610	0.0653	806.6488

The effect of water discharge on power-output potential is shown in tables VII to X; the more significant the water discharge, the greater the power-output potential. After sequencing the data from table VII to table X, it is possible to determine that the minimum power is 36.7245 watts, the maximum power is 806.6488 watts, and the average power is 375.6782 watts.

4. Conclusion

This paper presents the electric potential of water discharge from irrigation reservoir pumped by the solar-powered pump. The experimental data shows that water discharge from the reservoir can generate maximum electricity of 806,6488 watts with a discharge rate of 0.0653 m^3/s, and power is 36,7245 watts, with a discharge of 0,0030 m^3/s. The average electricity potential is approximately 375.6782 watts, with a discharge average of 0.0304 m^3/s. Therefore, the experimental data shows the possibility of hybridizing the Solar Power Plant with Hydro Power Plant, which will be beneficial for the residential area in Tanjung Raja Village, Muara Enim.

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