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Design Planning of Micro-hydro Power Plant in Hink River

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Abstract

Micro-hydro power plant is a type of renewable power plant that is environment friendly, easy to be operated and low operation cost. Hink River is a river in Manokwari, Indonesia. The result of initial survey shows that the river has hydraulic potency about 29.5 kW. According to the result, a micro-hydro power plant has been planned to this location. The power plant will use 25.2 kW of the hydraulic potency based on flow rate 0.3 m^3/s and head height 8.6 m. Turbine for the power plant is cross flow turbine type T-14 D-300 and the turbine will be coupled with a 3 phases synchronous generator to produce electrical energy about 17.32 kW. The energy will be transferred via 3 phase distribution lines to some villages around the power plant in radius of 4 km. According to economic analysis, payback period of this power plant is about 17.32 years at benefit factor 1.94; therefore the power plant has feasibility to be built.

Keywords: micro-hydro; power plant; Hink river;

1. Introduction

On contrary to electronic technology that is going to nano-technology, the usage of electrical energy starts to giga-watt. This contradiction also happens in Indonesia. The consumption of electrical energy is increasing by the

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time. PLN, as an Indonesian government company that handles electrical energy production, has responsibility to fulfill the essential power of the people in the country.

As an island in Indonesia that has biggest rain forest, Papua Island has many districts and villages separated by cities and forest. This condition gives limitation of accessibility and high investment of power lines. Therefore, not all area in Papua Island can be served by PLN and standalone power plant will be the best solution to solve the problem in Papua.

Hink River is a river in district Hink, Manokwari, Indonesia. Located in between of 1°13’ 10.7” S and 133° 56’ 05.5” E. The district can be reached from Manokwari local transportation. Hink River has good water supply to be used as micro-hydro power plant. This paper will explain the design planning of a micro-hydro power plant in Hink River and also its power lines distribution.

Nomenclature

PLN	Electrical Company of Indonesian government
S	South Latitude
E	East Longitude
Wh	Watt hour
kWh	Kilowatt hour
MW	Megawatt
km	Kilometre
m	Meter
m/s	Meter per second

2. Micro-hydro System

Hydropower is based on the principle that flowing and falling water has a certain amount of kinetic energy potential associated with it. Hydropower comes from converting the energy in flowing water, by means of a water wheel or a turbine, into useful mechanical energy. This energy can then be converted into electricity through means of an electric generator. The energy from the flowing/falling water can also be used directly by suitable machines to avoid the efficiency loses of the generator. Recently, small-scale hydropower systems receive a great deal of public interest as a promising, renewable source of electrical power for homes, farms, and remote communities. Micro-hydro systems refer specifically to systems generating power on the scale of 5 kW to 100 kW[1].

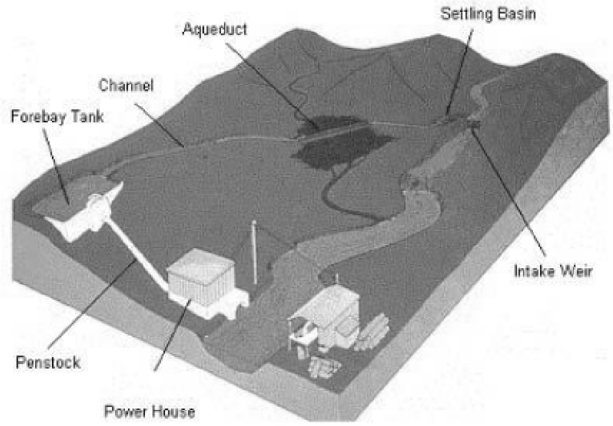

Fig. 1. General components of micro-hydro power plant[1]

The micro-hydro system includes a water turbine that converts the energy of flowing water into mechanical energy. This mechanical energy drives a generator which produces electrical power. The efficiency of the overall system, given the pipe friction loses and turbine deficiencies, is generally on the range of 50% of theoretical power associated with the energy of the flowing water. Micro-hydro has been in use for many years in many applications. The turbine varies from site to site according to the given pressure head and design flow at each site [1].

Fig. 1 shows a typical system and details components generally found at a micro-hydro facility. Water flow in upstream will be diverted in intake weir and it will flow into the channel. The channel transports the water to forebay tank before going to penstock pipe. In the tank, debris will be filtered and prevented from being drown to the turbine by means of penstock. Power convertion is done inside the power house, and turbine will transfer mechanic energy to generator, then generator produces electric energy.

Once power estimates have been made, one can select the appropriate turbine for the site. In general, there are two types of turbines to choose from (though there are more, and hybrids are common): impulse turbines and reaction turbines. Impulse turbines are most common for high head, low flow sites, while reaction turbines are most common with low head, high flow sites. The two most common types of impulse turbines are the Turgo and the Pelton. In the Turgo, a jet of water from the nozzle strikes the turbine runners at an angle. Significant power can be generated with relatively little head. Like the Turgo, Pelton turbines are particularly suited to low flow, high head sites. Water jets from the nozzle strike along the circumference of the turbine blades. Nozzle selection is also important in microhydro systems. Nozzle size is limited by the size of the turbine runners (blades), flow rates, and penstock diameter. Many turbines on today's market are capable of utilizing more than one nozzle. In these situations, it is common to use nozzles with different diameters that can be turned on or off depending on the time of year and the flow rates. Nozzle diameter greatly impacts the jet flow rate of the system and should be matched with the stream flow rates [1].

3. Methodology

3.1. Hydro Potency

Hydro energy potency in Indonesia can reach 75000 MW and only 8% or about 3700 MW has been used in hydro and mycrohydro power plant. The development of hydro power plants depends much on geographic location, rainfall and chatchement area. This condition has involved the variation of power plant capacity. Indonesian government has an action to upgrade the micro-hydro capacity until 2846 MW in year 2025 [2].

3.2. Measuring Flow and Head

Flow is the quantity of water moving past a given point over a set time period which is expressed as volume in gallons per minute (gpm) or cubic meters per second (m^3/s), and head is the vertical distance that water descends in altitude as a result of gravity.

Water flow can be measured by some simple methods. Bucket method and area and speed method are two methods commonly used in measuring flow rate. Bucket method can be used in measuring flow rate especially in measuring flow rate in low flow streams or in a small river. The method is used to count the time needed to fulfill a bucket and flow rate is calculated by dividing water volume in the bucket with time consuming. On the other hand, area and speed method is used in streams with a higher flow. Water flow can be measured by constructing a weir of known dimensions and measuring the time necessary for the pooled water to rise to a known height. An object can be placed and timed to float from the upstream to the downstream line. Flow rate is the product of water volume, water movement and friction coefficient (0.6 for rocky stream bottoms).

In case where it is hard to construct a weir, the area and speed method can be used. This method will calculate the cross section area (S) as the product of width and average deep of the river. Then, flow rate can be found by multiplaying cross section area with water speed flow. Flow rate (Q) is equal to average speed of water flow (V_{avg}) and the cross section area of the media (S). This method can be formulated as follows [3].

$$Q = V_{avg} \, x \, S \text{ (L/s)} \tag{1}$$

3.3. Hydro Power

The theoretical power produced by a micro-hydro system depends entirely on the flow rate of the water, vertical height (or head) that the water falls and the acceleration of water due to gravity through following equation [1-10].

$$P_T = \rho\, g\, Q\, H \quad (2)$$

$$P_T = c\, Q\, H \quad (3)$$

Where P_T is theoretical power in units of watts, ρ is density of water that equal to 1000 kg/m^3, Q is the flow rate in m^3/sec, H is the head in meters and g is gravity in 9.81 m/s^2. Because water density and gravity are constant, the equation can be simplified as in eq. 3 with c is the product of both contant parameter.

The theoretical power is rough calculation of hydro power in a river. There are some losses that reduce power while conversion process. Therefore, electrical power produced by a micro-hydro should be multiplied with total efficiencies of the system, including efficiencies of penstock η_p, generator η_g, and turbine η_t. Then, the output of electrical power can be fomulated as follows [3-11].

$$P_g = \rho\, g\, Q\, H\, \eta_o \quad (4)$$

Where P_g is the generated power in units of watts and ηo is overall efficiencies in percent that will be in between 50-70% [9]. Normally, head is decreased after the instalation of the micro-hydro equipment, and then generated power will be lower than theoritical power.

3.4. Economic Analysis

Economic analysis of a micro-hydro power plant is important to evaluate the eligibility of the plant. The analysis includes cost, benefit and benefit cost ratio, and payback period to build the plant.

a. Cost

Cost in developing a micro-hydro power plant will be investment and operational cost. Investment cost is the cost to build the plant, including cost for civil, electrical and mechanical, and distribution line works, for taxes, contingencies cost and engineering cost. The last two costs are indirect cost and others are direct cost for the work. Contingencies cost is the cost for over predicting payment while engineering cost is the cost for engineering activity including survey, detail design, supervision, etc.

Operation cost is the cost for operating the power plant. This cost can be the cost for bank interest, operators, management, and maintenance. Deviation of civil buildings, distribution wires, and electrical mechanical equipments are the other operation costs of a micro-hydro power plant. By using flat system of annual cash flow, the deviation of equipments for 25 and 30 years operation in 3% of interest rate is determined about 0.0274 and 0.0210 [12].

b. Benefit

Daily benefit of micro-hydro power plant operation will be the product of power production and fixed price of the power. By multiplying daily benefit within 30 days, it will give monthly benefit value. Annual benefit is 12 times higher than monthly benefit.

Benefit cost ratio (BCR) is sometimes the simple way to evaluate feasibility of an investment. BCR is a comparison between benefit and cost of an investment. The investment is feasible if BCR is equal to or higher than 1; on the other hand, it is not feasible for the BCR value lower than 1 [12].

c. Payback Period

Payback period is the time period for paying back all of the cost. The payback period is calculated by counting the number of years taken to recover the cash invested in a project. The investment is feasible if the payback period is lower than investment period [12].

4. Result and Discussion

4.1. Social Condition

The development of microhydro power plant took place in the capital of the Hink district. The district is 40 km away from Manokwari city and it lais from 1° 13' 10.7" S to 133° 56' 05.5" E at position 2100 m high from sea level. The district is a district of 29th distict in Manokwari regency and it can be reached by land vehicle.

There are five villages in the capital of Hink district located close each other and furthermost the distance is about 3 km. Official resource has mention that 650 people live in the villages and it has been provided in table 1.

Table 1. Population data of Hink district.

Name of village	Family head	Population	House
Demunti	25	141	12
Menyememut	23	81	20
Mbeigau	29	89	25
Leihak	50	154	44
Kisab	39	185	16
Total	166	650	117

It can be seen from the table that in a house can contain more than a family head. This is caused by the local tradition that men can marry in very young and they can live in the house with their big family. Local people work as farmer, but the harvest is only for self consumption since there is no local market.

4.2. Potency of Hink River

A survey had been done to investigate hydrolic potency of the Hink River in earth coordinate of 1° 14' 08.9" S and 133° 57' 14.2" E. The potency could be determined by measuring the flow rate of the river and the measurement was done by using the method of speed and area. Digital current meter was used to measure water speed flow and the result was multiplied by the cross section area of the river. The multiplication gave flow rate of the river about 0.3 to 0.4 m^3/s.

Fig.2 shows the map and the nature of survey location and in around this locacion intake was placed. The intake for the power plant had been chosen in around the survey location while the power house was placed about 140 m from the intake. Measured by a GPS, the height of the head was about 10 m. Therefore, the hidrolyc potency of the river with flow rate $0.3 m^3/s$ was calculated using eq.2 as follows.

$$P_T = (1000 \, {}^{kg}\!/_{m^2})(9.8 \, {}^{m}\!/_{s^2})(0.3 \, {}^{m^3}\!/_{s})(10m) \\ = 29.4kW \quad (5)$$

The potency could be reduced by efficiency of the micro-hydro power plant equipment and the head would be lower by placing the equipments into those location. According to JICA [9], overall efficiency will be 50-70%, and then the generated power is in between 14.70-20.58 kW. Therefore, the turbine and generator should be chosen higher than 20.58 kW.

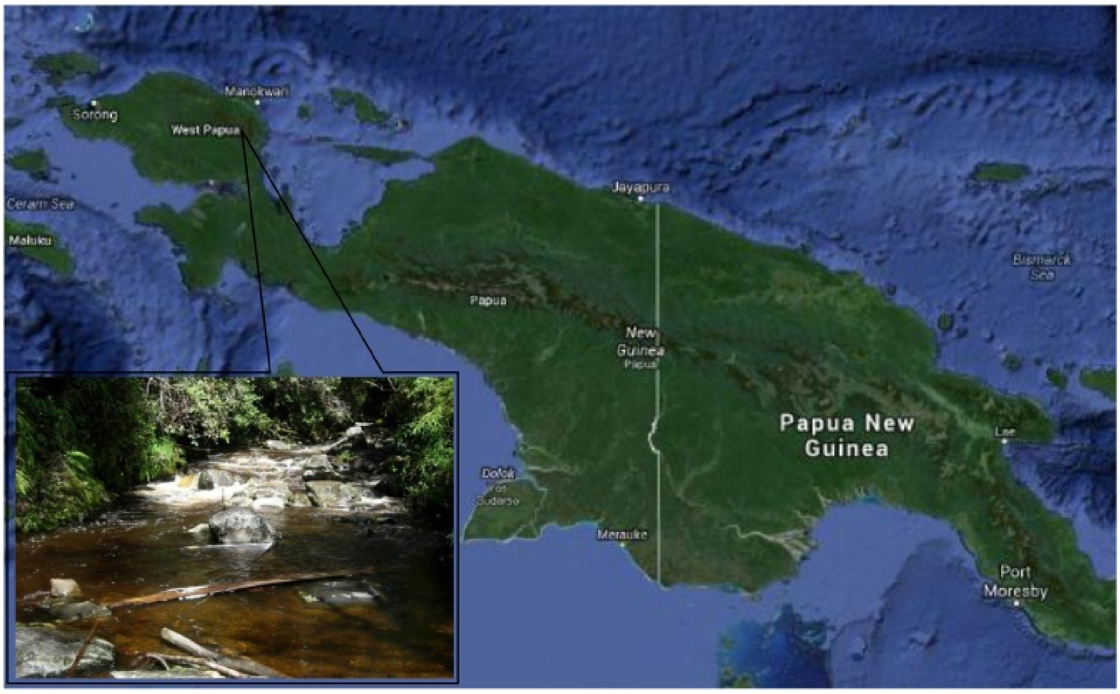

Fig. 2. Map and Location of surveying

4.3. Microhydro Power Plant Equipment

a. Civil Equipment

Waterworks of the planning micro-hydro power plant include weir, intake, forebay and tailrace. Flood gate and trash screen are the complement equipments that are placed in intake and forebay. Flood gate is used to maintain the power plant, and trashrack is used to separate trash from water before it comes to the turbine. Specification of the waterworks is given in tabel 2. Penstock used PVC pipe with diameter 16” class D about 35 unit to fix the distance from intake to power house.

Dimension planning of power house was 3x3 m and it will be semi pemanent building with set forth of gavel stone in bottom side and thick board in upper side. Slove and machine foundation will be reinforced concrete with iron cast type K-225 and the house will be roofed by corrugated iron.

Table 2. Waterworks equipment.

	Weir	Intake	Forebay	Tailrace
Dimension (length, widht, height)	8x1x1 m	1x1x1 m	3x2x1 m	3x0.5x0.5 m
Construction	Gravel stone	Gravel stone	Gravel stone	Gravel stone
Flood gate	-	0.75x0.75 m (sheet metal)	0.75x0.75 m (sheet metal)	-
Trashrack	-	0.75x0.75 m (cast iron 10mm)	0.75x0.75 m (cast iron 10mm)	-

b. Electrical and Mechanical Equipment

According to flow rate and head measurement, this micro-hydro power plant is planned to use cross flow turbine type T-14 D-300 with efficiency about 76%. Power axle of the turbine is 24 kW to handle 300 l/s flow rate at head 8.6 m. Mechanic energy from the turbine is transfered to generator to produce electrical energy. The generator of micro-hydro power plant is 220V/380V 3 phase synchronous generator with rating power 28kVA/22.4 kW, power factor 0.8, frequency 50 Hz and efficiency 92%.

Energy produced by the micro-hydro power plant is constant hour by hours. To anticipate the damage caused by load variation, a controller is needed to balance the load of the consumen and power produce. The function of this controller is also to protect generator and turbine from run away speed caused by load clearing. The controller is Electronic Load Controller (ELC). While load is decreased and power is excessive, ELC switches the power to ballast load.

4.4. Energy Production and Distribution

Efficiency of turbine, generator and penstock are known about 76%, 92% and 98 % respectivelly while effective head after instalation the equipments is approximatly 8.6 m. Therefore, overall efficiency and generated power are calculated as follows.

$$\eta_O = 0.98 \cdot 0.920 \cdot 0.760 \cdot 100\% \\ = 68.52\% \tag{6}$$

$$P_g = 1000 \, {}^{kg}\!/_{m^2} \cdot 9.8 \, {}^{m}\!/_{s^2} \cdot 0.3 \, {}^{m^3}\!/_{s} \cdot 8.6m \cdot 68.52\% \\ = 17.32kW \tag{7}$$

Electrical energy from the micro-hydro power plant will be distributed to seven villages by overhead distribution lines using twisted cable 3x50 mm and 1x35 mm in 4000 m long. Cable stanchion will be from wood with dimension 6 x 0.12 x 0.12 m. Distance between stanction is about 50 m and therefore it will need 80 sticks to meet 4000 m of distribution cable. Each house will tab the enery from main distribution line using twisted cable 2 x 25 mm and electrical instalation each house using NYM cable 2.5mm.

Table 3. Power usage for public facility

Name of village	Location	Lamps (Wh)	Wall plugs (Wh)	Total power (Wh)
Church	Mbeigau	1430	17600	19030
Church and office	Leihak	2860	17600	20460
Junior High School	Leihak	2860	13200	16060
Church	Kisab	1430	13200	14630
Elementary school	Kisab	3289	13200	16489
Pre school	Kisab	1573	4400	5973
District office	Kisab	3718	13200	16918
Clinic	Kisab	2574	8800	11374
District hall	Kisab	1573	8800	10373
House of district head	Kisab	1430	4400	5830
House of district vice head	Kisab	1859	4400	6259
House of school head	Kisab	1716	4400	6116
House of clinic head	Kisab	1859	4400	6259
Street lamps	All villages	14950	0	14950
Total		43121	127600	170721

Energy produce will be spread to 117 houses and each house will consume total 429 Wh for lumination about 11 watt, each in living room, bed room and kitchen. On the other hand, 1150 watt energy will be allocated to street lamp about 23 watt in 50 stanchions and those lamps will use 14950 Wh per day. Public facility buiding in the capital of Hink district is about 13 buildings including schools, churches, clinic, district office, district hall and street lamps. The electricity used for public facility is planned about 8867 watt 10 about 170721 Wh per day under assumption that lamps and wall plugs will work 13 and 22 hours respectively. Total energy distribution planning for each village is provided in table 3 and 4.

Table 4. Power usage for houses

Name of village	Lamps (Wh)	Wall plugs (Wh)	Total power (Wh)
Demunti	5148	4400	9548
Menyememut	9152	4400	13552
Mbeigau	11297	4400	15697
Leihak	19162	4400	23562
Kisab	6864	13200	20064
Total	51623	30800	82423

Total power needed in Hink district is about 335567 Wh per day while output of micro-hydro power plant will be 415680 Wh per day. Therefore, power safe from the process conversion is about 80113 Wh per day. The saving energy can be used for the other public facility, and roughly it is enough to illuminate 93 more houses.

4.5. Economic Analysis

Investment of the micro-hydro power plant is approximately Rp. 778224202.02, including direct cost and indirect cost. Contingencies cost is predicted about 5% of direct cost and engineering cost is about 7% of direct cost for survey, supervision cost, detail design and planning as shown in table 5.

Table 5. Investment cost

Items		Prize (Rp)
Direct cost		
1. Civil works		382388690.18
2. Electrical and Mechanical		198000000.00
3. Distribution lines		57500000.00
4. Taxes (10%)		63788869.02
	Sub total	701677559.20
Indirect cost		
1. Contingencies cost (5%)		31894434.51
2. Engineering cost (7%)		44652208.31
	Sub total	76546642.82
	Total	778224202.02

Annual generator output is about 149644.8 kWh; therefore annual benefit is about Rp. 92543126.40 at power price Rp. 720.00/kWh and monthly load benefit is chosen about Rp. 32000.00 per month kWh or in this case about Rp. 5468160.00 per month. Cost which includes deviation of civil building (30 years), deviation of electrical and mechanical (25 years), deviation of distribution lines (30 years), operation and manintenance cost, and 3% of bank interest are shown in table 6.

Profit of annual operation is the benefit minus cost and it will cost Rp. 44933537.85. Benefit factor build by the micro-hydro power plant in Hink district is about 1.94 and payback periode will be 17.32 years or about 17 years and 4 month. Electrical and mechanical equipment can reach 25 years and the building can life until 30 years. According to the criterion of benefit cost ratio and payback period, the development of micro-hydro power plant in Hink district is feasible.

Table 6. Anual cost and benefit

Items		Prize (Rp)
Benefit		
1. Annual Load benefit		5564160.00
2. Annual benefit		86978966.40
	Total benefit	92543126.40
Cost		
1. Bank interest (3%)		23346726.06
2. Deviation of civil building		8030162.49
3. Deviation of electrical and mechanical		5425200.00
4. Deviation of distribution lines		1207500.00
5. Operation and maintenance cost		9600000.00
	Total cost	47609588.55
	Profit	44933537.85

5. Conclusion

The result of water supply measurement in Hink River shows that maximum flow rate is 0.4 m3/s. With head about 10m, the hydraulic potency is equal to 29.5 kW. Design planning of micro-hydro in Hink River includes hydraulic potency, generator and turbine, power house, and overhead distribution lines. Hydraulic potency of planned micro-hydro power plant for Hink River is 0.3 m^3/s and with 8.6 m of head, the maximum potency is about 25.2 kW. Turbine cross flow type Flow T-14 D-300 is chosen to be coupled with 3 phase synchronous generators to produce electrical energy about 17.32 kW. The energy can be transferred to some villages around Hink District in about 4 km from power house using overhead distribution lines.

Electrical energy from the micro-hydro power plant is planned to be transferred to 5 villages that will consume 335567 Wh per day. Saving energy from the power plant is about 80113 Wh per day and it can be used for other public facilities or houses around the villages.

Annual benefit is Rp. 92543126.40, while annual cost can reach Rp. 47609588.55; therefore annual profit operation will be Rp. 44933537.85 and total investment of the micro-hydro is Rp. 778224202.02. Benefit cost ratio and payback period are about 1.94 and 17.32 years. Both benefit cost ratio and payback period have indicated that the micro-hydro power plant in Hink district is feasible to be built.

Environment and social impacts of developing and operating of the mycro-hydro power plant in Hink River are not studied yet. This research will continue to investigate those impacts.

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