International Journal on Advanced Science Engineering Information Technology

Vol.13 (2023) No. 5
ISSN: 2088-5334

Feasibility Study on the Development of a Pico-hydro Power Plant for Village Electricity Using a Centrifugal Pump as Turbine (PAT) Prime Mover

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***Abstract*—The need for electrical energy increases yearly; this study aims to analyze the feasibility of constructing a pico-hydro power plant in remote villages that do not yet have a power grid using a centrifugal pump as a turbine. The results of the analysis of technical aspects get information that there are about 25 houses that require electrical energy. The electrical power requirement of each house is about 100 W, which is used for lighting with five energy-efficient LED lamps of 20 W each. After adding street lighting and power losses to the network of about 500 W, the total electrical power needed is around 3000 W. A pico-hydro power generation system can meet the 3000 W power with a potential power of 5 kW and an effective turbine power of 3.51 kW. The water discharge requirement for the turbine is 104 liters/s, the turbine rotational speed is 543 rpm, the generator rotation speed is 1500 rpm, the specific speed is 133, the PAT runner diameter is 8 inches, and the distance from the power plant to the resident's house is 150 m, network losses 8 V, and the household electricity voltage is 210.45 V. The results of the technical aspect analysis show that the pico-hydro power plant is considered feasible to be built. The results of this analysis are the initial stage of feasibility study activities and can be continued with analysis from other aspects such as financial, economic, social, and environmental aspects.**

***Keywords*— Pico-hydro; centrifugal pump; PAT; turbine; feasibility study.**

Manuscript received 9 Aug. 2022; revised 8 Dec. 2022; accepted 18 May 2023. Date of publication 31 Oct. 2023.

I. INTRODUCTION

Renewable energy technology innovation in recent years continues to grow [1]. Many solutions have been offered and tested to meet the community's energy needs. Still, the problem of guaranteeing the availability and quality of energy has not been maximized, so it has become a challenge, especially for rural communities [2]. Renewable energy is an important choice in meeting global energy, especially water energy [3]. Hydropower plants are divided into large-scale and small-scale (micro and pico-hydro) energy plants [4]. In their development, small-scale hydroelectric power plants are gaining popularity because of their simple design and operation, less environmental impact, easier installation, and less heavy construction requirements [5]–[7]. One of the obstacles to the development of small-scale hydroelectric power plants, especially pico-hydro, is that prime movers or water turbines are not sold freely in the market; people must order in advance so that the price per turbine unit becomes expensive [8]. The community will bear the cost of the survey and planning. As a result, the investment in pico-hydro is quite expensive [9]. A simple pico-hydro generator can be built using a pump as a turbine (PAT) because of its low cost [10]. Compared to other conventional turbine prime movers with the same impeller diameter, the PAT price is much lower [11]. Many brands and types of PAT are sold in the market, so research is needed to determine the ideal type of PAT [12], [13].

The development of pico-scale hydroelectric power plants has attracted the attention of researchers worldwide, such as in Malaysia, Rwanda, Laos, and Kenya [3]. One obstacle that hinders the development of small-scale hydropower, especially hydropower so far, is procuring the main propulsion component (turbine), which is not easy [14]. Through continuous research, the researchers have succeeded in recommending an alternative fluid engine that can function as a turbine, namely a centrifugal pump, so that it will be easier for people to get prime movers for pico-hydro power plants. In applying the pump as a turbine, the working principle of the pump is reversed; that is, water flows from above through the penstock and enters the pump's exhaust side (outlet) so that the water can drive the pump impeller. The transmission system will forward this impeller rotation to drive an electric generator [15]–[17].

Some of the advantages of centrifugal pump applications as turbines, namely pump as mass products, are pumps are easily available in the market with various head and discharge variations, various brands, types, and sizes are available, easy to assemble and install, relatively low prices and easy to obtain spare parts [18]. Pump applications can be connected directly to the generator or use a belt-pulley mechanical transmission if the PAT speed does not match the generator speed [19]. Centrifugal PAT has proven to be an effective alternative for power generation because of its wide use and stable efficiency, especially at large water discharges; on the other hand, the performance of PAT will decrease under unstable water flow [20]. Economic analysis shows that pico-hydro power plants with PAT are more profitable than conventional turbines when the power generated is lower than planned [18], [21]. The construction of the PAT volute with the Francis turbine volute is relatively the same, so the water discharge when entering the PAT and Francis turbine does not have a different character. Similarly, the triangular analysis of the water velocity at the pump is relatively the same, and the difference is the direction of the water velocity when it goes to and leaves the impeller. This finding strengthens the hypothesis that centrifugal pumps can replace conventional turbines [22].

The challenge of the pico-hydro power plant system is to design alternative turbines that are different from conventional turbines and are suitable for application in pico-hydro plants [22]. The velocity of the water has a positive effect on the performance of the pico-hydro generator [23]. Modifying the turbine runner is one of the efforts to increase turbine efficiency [24]. One idea to increase efficiency is to modify the shape and size of the turbine impeller [25]. The number of impeller blades on the crossflow turbine affects the performance of the pico-hydro generating system [26]. One idea to increase efficiency is to modify the shape and size of the turbine impeller [27]. The number of impeller blades in the crossflow turbine affects the performance of the pico-hydro generating system [28].

PAT technology is suitable for small-scale power plants, but the challenge is that PAT does not yet have a standard specific speed interval [29]. PAT's specific speed (Ns) is generally less than 60, and to produce competitive PAT efficiency, the Ns value is recommended to range from 60 to 150 [6]. PAT is the optimal solution for pico-hydro power generation due to its low cost. The analysis results show that the pico-hydro investment is feasible if the electric power capacity exceeds 380 kWH/month [26]. The maximum efficiency of PAT can be achieved at a specific speed of 57, and the test results show that PAT can generate power from utilizing the energy potential of water flowing through the city distribution channel [30]. PAT's best efficiency point (BEP) can be achieved at speeds from 103 to 187 [31]. The PAT impeller diameter reduction increases efficiency under normal load operation [32]. Reducing the impeller diameter of a centrifugal pump as a turbine affects efficiency; a reduced diameter will reduce efficiency [26].

PAT optimization can be carried out at medium to high heads by considering the interaction between blades, water, and channel shape [13]. PAT performance is influenced by fluid viscosity; the greater the viscosity value, the higher the performance, especially the efficiency [33]. The distance between the tip of the blade and the casing is called the tip clearance, which will affect the characteristics of the centrifugal pump as a turbine. Increasing tip clearance decreases potential head and pump efficiency; 1 mm tip clearance greatly reduces performance, where efficiency is reduced by 6.26%, and the head is reduced by 10.8% [34]. PAT, from the beginning, was not designed to be a turbine, but technically, the construction of a centrifugal pump is relatively the same as the construction of a Francis turbine, so the centrifugal pump is suitable as an alternative to water turbines for pico-hydro and micro-hydro scales [35].

Centrifugal pumps as a turbine turned out to be one of the objects of observation that is quite popular among many researchers. Laboratory-scale testing conducted by the researchers aims to analyze the factors causing the low efficiency of PAT and efforts to improve it. In response to this, further research is needed, namely not only efficiency studies but also applicable studies on technical aspects and feasibility studies before pico-hydro power plants are built in the community. This study aimed to analyze the feasibility level of the technical aspects of constructing a pico-hydro power plant with a centrifugal pump as the prime mover as a turbine. This is a realistic study on renewable energy development considering the potential for pico-hydro scale energy is quite a lot, especially in villages in West Sumatra Province, Indonesia [36].

Another interesting thing to follow up on regarding this technical aspect of the feasibility study is that from the market survey that has been carried out, it is known that the investment in centrifugal pumps is much cheaper than investing in Francis turbines, as the data described in Table I. This information motivates researchers to find out the feasibility level immediately—technical aspects of constructing a pico-hydro power plant with a centrifugal pump as the prime mover.

TABLE I
CENTRIFUGAL PUMP AND FRANCIS TURBINE PRICE COMPARISON

No	Prime Mover Type	Price ($)	
		6-inch impeller	8-inch impeller
1	Centrifugal pump	614.28	857.14
2	Centrifugal blower	571.43	720.15
3	Francis turbine	1214.28	1518.24

II. MATERIAL AND METHODS

A. Types of Research

The type of research carried out is survey research to determine the feasibility level of developing a pico-hydro power plant in terms of technical aspects. The feasibility study is the initial stage of building a pico-hydro power plant, and the next stage is the design, procurement of materials, manufacture of mechanical buildings and civil buildings, testing, and analysis. The feasibility study of the technical aspect aims to determine the feasibility of developing a pico-hydro power plant by considering the technical variables at the research site. These technical variables include identifying the ideal location for the construction of a pico-hydro power plant, the potential for water discharge, the height of the fall or head, the distance from the powerhouse to the middle of the village, and the number of heads of families who will utilize electrical energy. Other technical variables are the specifications of the generator system components, starting from the dam, head race, forebay, spillway, penstock, powerhouse, tail race, and specifications of the tools and materials needed to construct pico-hydro power plants.

B. Research Sites

The research site is located in Mamping Village, which is adjacent to Manggis Village in Pakan Rabaa Timur District, South Solok Regency, West Sumatera Province, Indonesia, at the position of 101.06^{O} EL coordinates and 1.509^{O} Sl as shown in Figure 1. The power plant is located on the edge of the Langse River, a tributary that flows through Mamping Village, which the community uses to irrigate rice fields, bathe, and wash, as shown in Figure 2. The water flow of the Langse River is quite heavy during the dry season, the discharge is 150 liters/s, and the bottom slope of the channel is about 10^{0}. Clean water is very supportive as a water turbine-driving fluid. The location of the pico-hydro power plant will utilize the location of the water wheel, which has been damaged for four years and has not been operating. The existing equipment around the power plant site is a dam and a 90 m head race. The area around the power plant location is in the form of hills, most of which are forests and rice fields; the rest is in fields and residential villages.

Fig. 1 Research location in Indonesia

C. Data Analysis Techniques

1) Turbine Potential and Generating Power: The potential power (P_p) and turbine rise power (P_t) can be determined through equations (1) and equation (2) [37].

$$Pp = \rho \times g \times Q \times Ht / 102 \quad (1)$$

$$Pt = Pp \times \eta g \times \eta i \quad (2)$$

where ρ is the density of water, $\rho = 1000$ kg/m^3, g is the Earth's gravitational acceleration, $g = 9.81$ m/s^2, Q is the flow of water entering the turbine (m^3/s), H_t is the effective turbine head (m), 102 is the unit conversion number that 1 kW = 102 kgf.m/s, η_g is generator efficiency, and η_i is transmission efficiency, in this case, it is planned that the transmission used to transfer power and rotation from the turbine to the generator is a single-stage belt-pulley transmission.

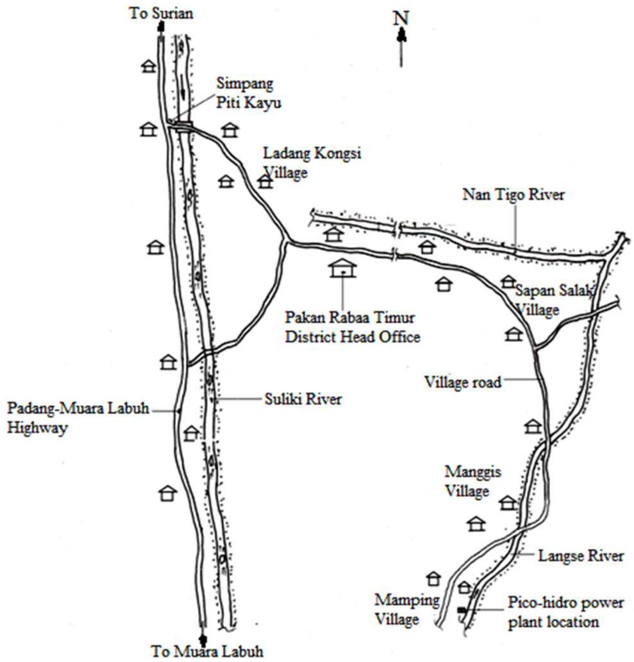

Fig. 2 Location of pico-hydro power plant

2) Penstock Diameter: The function of the penstock is to drain water from the tranquilizer to the PAT; the diameter of the penstock can be determined by equation (3-6) [38].

$$Vp = (0,3968/nc) \times Dp2/3 \times S1/2 \quad (3)$$

$$Q/Ap = (0,3968/nc) \times Dp2/3 \times S1/2 \quad (4)$$

$$Q = (0,3968/nc) \times Dp2/3 \times S1/2 \times 0,785 \times Dp2 \quad (5)$$

$$Dp = Q / [(0,3968/nc) \times S1/2 \times 0,785]0,375 \quad (6)$$

where n_c is the coefficient of manning, its value depends on the material of the pipe, and S is the slope of the hydraulic gradient, in the form of an equation written:

$$S = Hl / Lp.$$

3) Effective Turbine Head: The actual head or gross head (H) is the difference between the pool's water level and the tail race's water level. The total pressure loss due to friction and pipe installation equipment is called head loss (H_l). Then the effective head of the turbine is the difference between the actual head and the total head losses as described in equation (7) [38].

$$Ht = H - Hl \quad (7)$$

The total head losses (H_l) can be known by equation (8) [37].

$$Hl = \{ \sum c + (f \times Lp/Dp) \} \times \{Vp2 / (2 \times g)\} \quad (8)$$

where c is the sum of the resistance coefficient values in the pipe, f is the friction factor that can be known from the combination of the value of /d with the Reynolds number (R_e) on the Moody diagram, is the surface roughness value in the pipe, R_e is the Reynolds number which can be known by equation (9) [38].

$$Re = Vp \times Dp/\upsilon \quad (9)$$

Where υ is the kinematic viscosity of water, $\upsilon = 1.01 \times 10^{-6}$ m^2/s.

4) Runner Round and Diameter: The number of working revolutions of the runner (working speed) depends on the effective fall height and runner diameter. Turbine runner rotation speed (N) can be determined by equation (10) [40].

$$N = 60 \times (Vr / 3.14) \times Dr \quad (10)$$

Where D_r is the outer diameter of the runner, and V_r is the velocity around the runner, which can be found by equation (11)[38].

$$Vr = 0.5 \times Vn \quad (11)$$

5) Turbine-Specific Speed: The specific speed (N_s) of a turbine is the runner rotation which can produce an effective turbine power of 1 HP for every 1 m fall height, which can be found by equation (12) [38]

$$Ns = N \times Pt1/2 \ / Ht5/4 \quad (12)$$

III. Results And Discussion

A. Electrical Power Needs

All residents in Kampung Mamping work as rice and field farmers with a fairly modest level of welfare. The electrical power requirement of each farming family is around 100 W, which is used for lighting with five LED energy-saving bulbs of 20 W each. In Kampung Mamping, 25 houses are concentrated in one location, facilitating electric current distribution. Thus, it is expected. The entire house can meet its electricity needs. After adding street lighting and power losses in the network, estimated at around 500 W, the total electrical power required is around 3000 W. A pico hydropower generation system can meet the 3000 W power with a potential power of 5 kW.

B. Discharge and Water Source

The water source of the Langse River, as shown in Figure 3, comes from water seepage around the forest in the East Pakan Rabaa sub-district.

Fig. 3 Langse River flow

Because the water source of the Langse River comes from the seepage of the mountain forest springs, which is quite dense, the water flow is quite stable, the water is clear, and in the dry season, it is not so reduced while in the rainy season, it does not cause flooding. The measurements in early January 2022 revealed that the Langse River water discharge was around 300 liters/s. In the dry season, the water discharge is about half, about 150 liters/s. The required water discharge is around 104 liters/s, still below the minimum flow rate, so the water requirement for pico-hydro power plants is quite safe.

C. Lay-out Pico-Hydro Power Plant

The first step in constructing a pico-hydro power plant is selecting the ideal location. The ideal location is a location that has the best head or height potential, power plant buildings that are safe from the risk of landslides, and a location that is not far from residential areas. The next step is to measure and design the lay-out of the pico-hydro power plant system, as the results are shown in the lay-out in Figure 4. After the position of the powerhouse, forebay, head race, and dam is determined, the next step is to agree with the land owner regarding the status of the land, which will be used to construct a pico-hydro power plant.

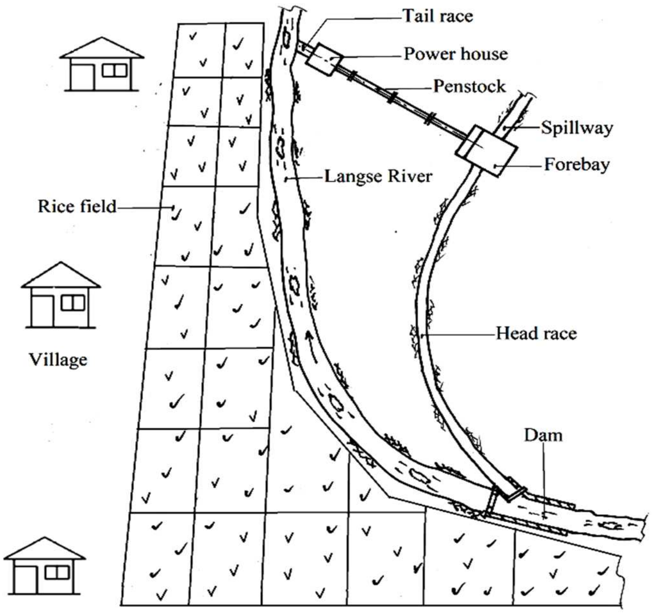

Fig. 4 Lay-out of the pico-hydro power plant system

D. Actual Head

The head race, which will be used to drain water from the dam to the forebay, will utilize the existing soil excavation channels used by the community to drain water into the residents' rice fields. The head race is expected to be able to drain water with a larger discharge, so the current excavation channel is widened and deepened. The head race is built around the waist of a 90 m long hill, while the Langse River flows below it. The position and path of the head race are shown in Figure 5. Forebay will be built at the end of the head race, equipped with a turbine inlet channel, spillway, and a water filter holder. Another civil building to be built is a powerhouse equipped with a tail race under the floor. The position of the powerhouse is about 8.5 m from the position of the tranquilizer.

Fig. 5 Head race, forebay, and spillway constructed at the waist of the hill

The difference between the water level in the forebay and the water level in the tail race results in an actual head of about H = 7.5 m, as shown in Figure 6. At the same time, the pico-hydro power plant design produces the power plant system specifications, as shown in Table II.

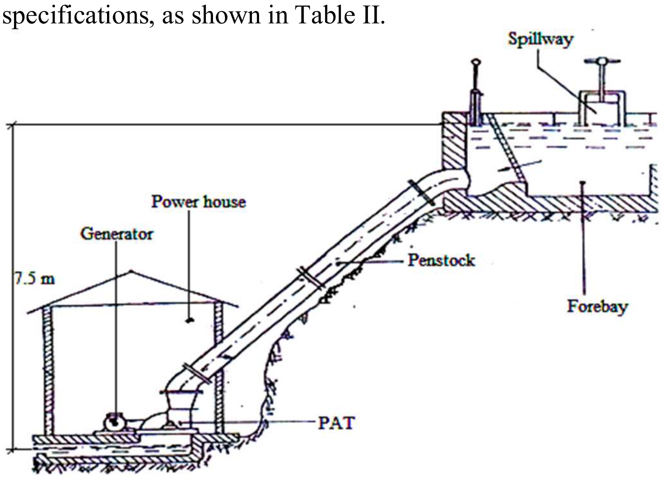

Fig. 6 The actual head position is 7.5 m in the pico-hydro power system

TABLE II
SPECIFICATIONS OF GENERATING SYSTEM COMPONENTS

No	Specifications	Dimensions
1	Potential power (P_p)	5 kW
2	Turbine effective power (P_t)	3.51 kW
3	Turbine rotation speed (N)	543 rpm
4	Specific speed (N_s)	133
5	Actual head (H)	7.5 m
6	Turbine head (H_t)	6.6 m
7	Turbine discharge (Q)	104 liters/s
8	Penstock diameter (D_p)	10 inches
9	Penstock length (L_p)	10.9 m
10	Diameter of PAT runner (D_r)	8 inches

E. Selection of Centrifugal Pumps as the Prime Mover of Piko-Hydro Power Plant

The process of selecting the prime mover of the turbine begins with determining the turbine rotation (N), turbine power (P_t), and turbine head (H_t). It continues with determining the specific speed of the turbine, which can be analyzed by equation (13). Based on that specific speed, the ideal type of prime mover can be determined as described in Table III [37]. The specific speed of the planned turbine is ns = 133, so the suitable turbine is the Francis turbine or the Crossflow turbine. The Francis turbine has a relatively similar construction to a centrifugal pump, as described in Figure 7.

TABLE III
SPECIFIC SPEED OF THE CONVENTIONAL TURBINE

No	Turbine Type	Specific Speed (N_s)
1	Pelton and water wheel	10 - 35
2	Francis	60 - 300
3	Crossflow	70 - 180
4	Kaplan and propeller	300 - 1000

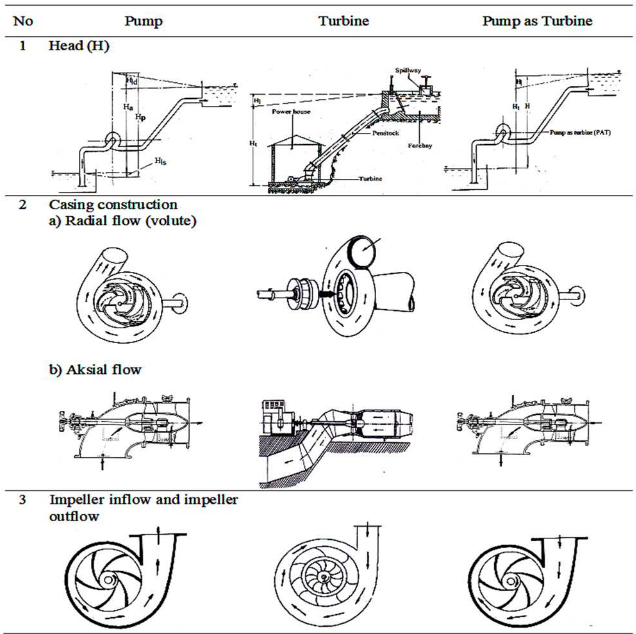

Fig. 7 Comparison of pump characteristics, Francis turbine, and PAT

Fig. 8 10-inch centrifugal pump as the prime mover of the pico-hydro power plant

The centrifugal pump construction is easier to adjust when it is used as a water turbine. There is no extreme modification treatment, but with the installation of a V-belt transmission, the centrifugal pump can directly function as a water turbine. In addition, the construction of the centrifugal pump is quite sturdy and compact because it is made solid through the casting process. Another advantage, centrifugal pumps are easily available in the market in various brands and sizes, and the price is relatively low. From these findings, it is recommended that centrifugal pumps are feasible to be developed in rural areas as a solution-alternative fluid engine to replace conventional turbines. Furthermore, in this feasibility study, a 10-inch centrifugal pump was chosen as the prime mover of the Pico hydropower plant, as described in Figure 8, and the full specifications are shown in Table IV.

TABLE IV
RECOMMENDED CENTRIFUGAL PUMP SPECIFICATIONS

No	Component specifications	Dimensions
1	Type	ST-5
2	Power	5 kW
3	Inlet pipe diameter	300 mm
4	Impeller diameter	8 inches
5	Weight	78 kg
6	Length × heigh	600 mm × 420 mm

F. Pico-Hydro Power Plant Construction Schedule

The time needed to construct a pico-hydro power plant until electricity enters people's homes is about four months. The first two months are used for site surveys, procurement of tools and materials, manufacturing mechanical building components in workshops, and constructing civil buildings at power plant sites. The next two months are used for transporting turbine components to the generator site, installing and assembling turbine components at the generator site, installing distribution network cables, installing electrical installations in people's homes, testing, analysis, socialization, and coaching. A detailed description of these activities is shown in Table V.

TABLE V
IMPLEMENTATION SCHEDULE FOR THE CONSTRUCTION OF A PICO-HYDRO POWER PLANT

No	Activity	Month			
		1	2	3	4
1	Meeting/discussion with the people of Kampung Mamping about the plans and preparations for the construction of a pico-hydro power plant.	▨			
2	Survey to determine the location of the power plant in the vicinity of the Langse River.	▨			
3	Pico-hydro power plant planning (design documents and large drawings).	▨			
4	Procurement of tools and materials.	▨			
5	Operations at the workshop and at the plant site:				
	a. Preparation/cleaning around the location of the pico-hydro power plant.	▨			
	b. Implementation of mechanical work: pico-hydro power plant prime mover assembly and transmission and painting system		▨		
	c. Implementation of civil works: manufacture of dams, control doors, head race, forebay, spillway, tail race, power house and others.		▨	▨	
	d. Installation/assembly of PAT on the pico-hydro power plant system.			▨	
	e. Testing the performance of PAT prime mover efficiency, transmission efficiency, generating system efficiency, and electricity quality.			▨	
	f. Repairs / improvements.			▨	
	g. Final testing/evaluation.			▨	
	h. Analysis of test results.				▨
6	Technical socialization of the operation, maintenance, and management of pico-hydro power plants to the public				▨
7	Supervision				▨

G. Materials Used

As shown in Table VI, the materials used to build a pico-hydro power plant consist of materials for mechanical, civil, and electrical buildings. The mechanical components include a centrifugal pump, turbine/generator frame, elbow, gate valve, reducer, and draft tube, as shown in Figure 9.

H. Required Tools

Workshop tools and measuring tools needed for mechanical work, such as making filters, sluice gates, rapid pipes, transmission systems, and frames, are shown in Table VII.

Fig. 9 Mechanical components of them from left to right: centrifugal pump, turbine/generator frame, elbow, gate valve, reducer, and draft tube

I. Generator Selection

The electrical equipment of the pico-hydro power plant system consists of a generator, control system, and distribution cable. The generator converts the turbine shaft's mechanical energy into electrical energy. The single-phase synchronous/alternating current (AC) generator is used. The selection of this single-phase generator is based on considering that the houses are in one location, so the distribution of electric power becomes easier. The selected generator has a planned capacity of 5 kW and a voltage of 220 V. The rotational speed of the generator can be known from the following equation (13) [37].

$$Ngt = 120 \times fr / Zk \quad (13)$$

Where n_{gt}: generator rotation speed (rpm), f_r: electrical frequency = 50 Hz, for generators circulating in Indonesia. Z_k: number of poles; in this case, each generator has a different number of poles, namely 2, 4, 6, 8, 10 and 12. The equation above explains that Z_k is variable, so the relationship between the number of poles and the rotational speed of the generator is shown in Table VIII [37].

TABLE VI
MATERIALS USED TO BUILD A PICO-HYDRO POWER PLANT

No	Name of Material	Use
1	Angle bar, 65×65×6mm, L= 6 m	Making control doors on dams and water filters
2	C profile steel, 75×45×15mm,L=6 m	Making turbine frames
3	Steel pipe, d=12 inches,t=4 mm,L=6m	Making penstock
4	Plain bar, d=10mm, L=12 m	Make a water filter
5	Steel electrodes, 2.6×350 mm	Metal joints in the welding process
6	Riverstone and sand	Build a dam, head race, forebay, spillway, powerhouse, and tail race foundation.

No	Name of Material	Use
7	Portland Cement, 50 kg/bag	Civil building component fastener
8	Wooden board	Making a powerhouse wall
9	Wood, 5 cm×7 cm, L= 4 m	Making the frame for the walls and roof of the powerhouse
10	Spandex roof, t= 0.2 mm, 80 cm×120 cm	Powerhouse roof
11	Paints	Painting mechanical components and power housing
12	Metal nails	Installing metal roof
13	Nog	Installing the wooden board
14	Wood size, 20cm×20 cm, L= 4 m	Distribution cable support pole
15	Caustic cable 7 turns, d=1.5 mm	Distributing electric current from the powerhouse to the village residents
16	Synchronous generator, P = 5 kW	Converting mechanical energy into electrical energy
17	Centrifugal pump, d = 10 inches	Converting the potential energy of fluid into mechanical energy
18	Single stage belt-pulley transmission, d_1= 16 inches, d_2= 4 inches, 2 grooves	Transferring power and rotational speed from turbine to generator
19	Gate valve, d= 8 inches	Regulating the flow of water entering the turbine

In this plan, the ST-5 type generator with 1500 rpm rotation and 5 kW power was chosen, as shown in Figure 10, considering that this type of generator is more widely sold in the market. Meanwhile, the planned PAT rotation is Nt = 532 rpm, so using a single-stage belt-pulley transmission with a 3:1 ratio makes it easy to transfer power and PAT rotation to the generator. The diameter of the drive pulley on the turbine shaft is 15 inches, so the diameter of the pulley driven on the generator shaft is 5 inches.

TABLE VII
TOOLS USED FOR MECHANICAL WORK

No	Tool Name	Function
1	Electric welding machine	Assembling turbine components
2	Drilling machine	Making bolt holes
3	Tap/snai machine	Making inner thread and outer thread
4	Grinding machine	Smooth surface
5	LPG-oxygen gas arc welding	Cutting and shaping turbine components
6	Benchwork equipment: caliper, vise, file, hand saw, hammer, etc.	Supports the function of machines in the process of holding, leveling, filing, and bending
7	Tachometer	Measuring the rotational speed of the turbine shaft and generator shaft
8	AVOmeter	Measuring the resistance, voltage, and amperage of the generator
9	Torque meter	Measuring the torque generated by the turbine

TABLE VIII
THE RELATIONSHIP BETWEEN THE NUMBER OF POLES AND THE ROTATIONAL SPEED OF THE GENERATOR

No	Number of Poles (Pieces)	Generator Rotation Speed (rpm)
1	2	2000
2	4	1500
3	6	1000
4	8	750
5	10	600

Fig. 10 ST-5 type synchronous generator

J. Distribution Cable

The distribution of electrical power from the powerhouse to the residents' houses uses a 220 V low-voltage distribution cable without a step-up transformer. The electrical cable used is a caustic cable with 7 turns of wire rods with a diameter of 1.5 mm from an insulated aluminium mixture so that it is safe to use in rural areas. Voltage losses that occur along the distribution cable can be analyzed by equation (14) [37].

$$Rv = 3.5 \times Lj \times Nk1 / (Ak \times E2) \quad (14)$$

where R_v: voltage losses along the distribution cable, L_j: length of a distribution cable to the farthest load, L_1 = 150 m, N_{k1}: total load delivered by a single phase wire N_{go} / 1 = 5 kW, E: voltage supplied = 220 V, A_k: cross-sectional area of distribution cable which the equation can find,

$$Ak = 0.785 \times (1.5\ mm)2 \times 7 = 12.5\ mm2.$$

$$Rv = \{3.5 \times 150 \times 5000/ (12.5 \times 2202)\}\ \%$$

$$Rv = 4{,}34\%$$

Thus, the electricity voltage in the furthest residential area (E_1) is,

$$E1 = 220\ V - (4.34\% \times 220\ V)$$

$$E1 = 210.45\ V$$

At a voltage of E_1 = 210.45 V, electrical equipment such as lights, TV, and radio can operate normally to satisfy people. The equipment needed for distribution cable installation is an electric pole installed every 30 m distance. The distance to be traversed by the distribution cable is 150 m, so the required number of electric poles is about 5 pieces. After the distribution cable is installed in the middle of the resident's village, the next step is the installation of electrical installations in people's homes. The installation equipment installed is a 1 Ampere MCB which is useful for limiting the use of electric current, a single switch, and an LED light bulb with a standard installation model, as shown in Figure 11.

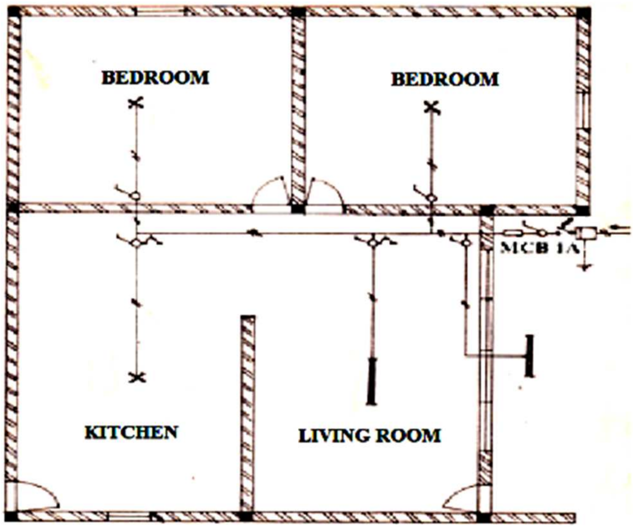

Fig. 11 Electrical installation model and power limitation in residents houses

K. Control System

The distribution of electrical power from the generator inside the powerhouse to the residents' houses requires a distribution cable equipped with measuring or switching devices and other control, protective, and safety devices installed in the powerhouse. Figure 12 shows a schematic of the control system circuit installed in the powerhouse, which consists of a single-phase main switch, a voltage meter (Voltmeter), an electric current meter (Amperemeter), Zikring (fuse), and a control lamp, each of which consists of one unit.

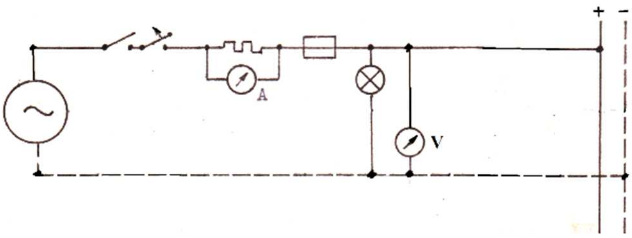

Fig. 12 Circuit schematic of control and gauge system

IV. CONCLUSIONS

Centrifugal pumps as turbines turned out to be one object of observation that is quite popular among many researchers. The results of the feasibility study analysis, especially the technical aspects, obtained information that there were about 25 houses that needed electrical energy. The electrical power requirement of each house is around 100 W, which is used for lighting with five energy-saving LED bulbs of 20 W each. After adding street lighting and power losses to the network, about 500 W, the total electrical power needed is around 3000 W. Power of 3000 W can be met by a pico-hydro power generation system with the potential power of 5 kW and an effective turbine power of 3.51 kW. Other technical data from observations in the field include the location of the generator, which has been identified beside the Langse River with an actual head of about 7.5 m and river water discharge during the dry season of around 150 liters/s. The water discharge requirement for the turbine is 104 liters/s, the turbine rotation speed is 543 rpm, the generator rotation speed is 1500 rpm, the specific speed is 133, the PAT runner diameter is 8 inches, the distance from the powerhouse to residents' houses is 150 m, network losses are 9.55 V, and the electricity voltage in people's houses 210.45 V. The results of the analysis of the technical aspects show that constructing a pico-hydro power plant is considered feasible to be carried out. The results of this analysis are the initial stage of the feasibility study activity. They can be continued to analyze from other aspects such as financial, economic, social, and environmental aspects.

ACKNOWLEDGMENT

We would like to thank the people of Mamping Village, Pakan Rabaa Timur District, South Solok Regency, West Sumatra, Indonesia, who have assisted and facilitated the site survey of the pico hydro power plant and measurements of the head and water flow of the Langse River.

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