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Mechanical System Design of the MicroHydro Power Plant in Solok West Sumatera

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Abstract

This study aims to design a microhydro power plant part of a mechanical system, starting with a potential of technically feasible water resources for the hydropower potential in Rangkiang Luluih Solok, West Sumatera, Indonesia. This area is geographically located at coordinates around 100°52'15.6"east longitude and 0°57'9.7" south latitude. The potential of a micro hydro power plant in Solok District, Tigo Lurah District, Rangkian Luluih from the measurements obtained a gross head of 100 m, with a net head of 97.70 m and a measured discharge of 1 $m^3 s^{-1}$. The scope of mechanical work includes the selection of mechanical equipment and design of supporting equipment. The selection and design were aimed at producing technical specifications and basic dimensions. Design data was derived from the result of the conducted field survey and optimization consisting of the result of hydrologic analysis and the result of scheme and energy optimization. The basic criteria of design were based on the following: selected microhydro scheme, condition of planned microhydro location, head and energy to be generated. From the calculation, the results of the type of turbine analysis are Francis, total turbine 2 units, unit 537 kW.

Keywords: Mechanical design; Microhydro power plant; Solok West Sumatera

Introduction

One of the renewable energy sources in Indonesia is hydropower. The potential for hydropower in Indonesia is around 75000 MW spread over 1315 locations. Hydropower is a huge potential energy source, but its use is still far below its potential. From this potential it is estimated that 34000 MW can be developed for power plant centers with a large enough capacity, which is 100 MW and above. West Sumatera Province has the potential of microhydro power plants that can be developed and spread in Pesisir Selatan District, Solok, Solok Selatan, Tanah Datar, Pariaman, Agam, and Pasaman [1]. Solok Regency is one of the districts that have a lot of energy sources from hydropower. Administrative map of the Solok Regency of West Sumatera Province and the survey location described in Fig. 1. Solok Regency there are around 80 rivers flowing in Solok sub-districts. The riverflow provides benefits to be developed as a micro-hydro power plant system [1].

Based on the description above, the researcher intends to conduct research on the potential and design of turbine design in accordance with the existing potential in Solok, West Sumatera, Indonesia. south latitude. The research is located in administrative area of Village of Rangkiang Luluih, District of TigoLurah, Regency of Solok, West Sumatera Province. Rangkiang Luluih Village is located about 60 km towards southeast of Solok City the capital of Solok Regency. This area is geographically located at coordinates around 100°52'15.6" east longitude and 0°57'9.7". TigoLurah District is bordered by Sawahlunto/Sijunjung Regencies at north and west, PayungSekaki District at east, Hiliran Gumanti District at south.TigoLurah District is located at undulating area, with the elevation around + 709 m to + 930 m above mean sea level. The annual rainfall is about 2767 mm. The district consists of 4 villages, namely Rangkiang Luluih (93 km^2), Garabak Data (149 km^2), Tanjung Balik Sumiso (175.10 km^2), Batu Bajanjang (139.40 km^2), Simanau (46 km^2). Geological condition of the weir is located at the Rangkiang Luluih which flows from South West to North East. The width of river is around 15m composed mainly of boulder of granite, some sand and gravel [2]. The left and right abutment have steep slope with 40° and 50°. Soil conditions are similar at the left and right abutments are based on silty clay and silty sand containing boulder of granite. There is no indication mass movement at the slope. Waterway is located at the slope of hilly area on the right side of river. The slope degree varies from 30° – 70° are formed by soil and boulder of granite. The sandy clay soil is stable on the slope area with no indication of landslide. In addition to, boulder of granite shown big size are located mainly on the all area. There are some cross drain that generally filled by boulder of granite. The area of head pond is located at the slope with around 30° – 45°. The soil is clayey and sandy soil with stable condition.

Materials and Methods

Many types of the turbine design methodology start from a potential study including measurement of discharge and head. Surveys and observations carefully with GPS in determining the side of water availability, water discharge, head, and geological conditions of the system plan location. Furthermore, as a basis in designing a hydroelectric power system, the potential amount of electrical energy generation can be calculated using the obtained data. The literature on turbines is also the basis for designing the mechanical system of the power plant that will be installed later. Water turbines are the main tool for converting water energy into round-shaped mechanical energy. There are many types of water turbines that can be used in Hydro Power Plants according to the potential hydraulic energy characteristics available. Types of water turbine generally used include Pelton Turbine, Francis Turbine, Crossflow Turbine and Kaplan/Propeller Turbine. Each turbine type has operational characteristic and operational area at a certain condition, so that selection of appropriate type turbine should be based on head, generating design discharge and specific rotation (*ns*) [3 – 5]

(a) (b)

Fig. 1 Map of the Solok Regency, West Sumatera: (a) Sumatera Island; (b) Solok Regency.

Fig. 2 Location micro hydro power plant design.

Specific speed as shown in equation (1) is the speed of the turbine model (turbine with the same shape but different in scale), which works on 1 unit of height and falls with 1 unit of discharge and produces 1 unit of power.

$$n_s = \frac{n.\sqrt{P_1}}{H^{5/4}} \tag{1}$$

n = turbine rotation (rpm), n_s = specific speed (rpm), P = power (kW), H = head (m). If it is known that the height of the effective water fall and the maximum discharge can be known, the power out. If the speed of the type is known, it can be calculated the rotational speed (n), based on the equation (2):

$$n = \frac{n_s.H^{5/4}}{\sqrt{P_1}} \tag{2}$$

The picture above shows the type of turbine table used based on its specific speed range. Turbines with higher specific speeds are more economical because turbines with higher speeds are usually more compact turbine units, but this high speed must also be accompanied by good construction, turbine material strength, and generator or load capability. Microhydro Power Plant is designed because of the potential that can be generated due to the difference in height on the river by *H* in meter, the power that can be generated due to the difference in height *H* can be formulated as follows [4]:

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

Were, P = power generated (W), ρ = water density = 1000 kg m^{-3}, g = gravity = 9.80 m s^{-2}, Q = discharge (m^3 s^{-1}), H = head (m), and η = efficiency (%).

Table 1 Turbine type based on the head range.

Turbine Type	Head range (m)
Kaplan and Propeller	$2 < H_n < 40$
Francis	$25 < H_n < 350$
Pelton	$50 < H_n < 1300$
Crossflow	$5 < H_n < 200$
Turgo	$50 < H_n < 250$

Table 2 Specific speeds for various turbine types.

Turbine Type	Specific Speed (rpm)
Pelton	10 – 35
ImpulsTurgo	35 – 60
Crossflow	20 – 80
Francis	60 – 300
Propeller& Kaplan	300 – 1000
Bulb	> 1000

Table 1 explains the theory of selecting turbine types based on head range. As an example, for head larger than 2 m to less than 40 m using Kaplan and Propeller turbines. Table 2 is a theory of the choice of turbine type based on specific speed (rpm). As an example, for specific values of Speed from 10 to 35 rpm using Pelton turbines.

Results and Discussion

From measurement, the discharge 1.11 m^3 s^{-1} has been obtained, with net head is 108.32 m. Operational pattern of Microhydro Power Plant run of river must take into account the value of discharge/river flow in the year to the design discharge/design discharge of the turbine. To prevent turbine to operate at low efficiency and by taking into account the optimization outcome, the number of turbine to be used is 2 (two) units, with total design discharge of 1.11 m^3 s^{-1} or 0.56 m^3 $s^{-1}$for each turbine unit for net head 108.32 m. The turbine output power is as follows form equation 3: Pturbin1 = 9.81 × 0.56 × 108.32 × 0.91 = 537 kW per unit. The conclusion of this research is the potential and energy that can be raised are shown in Table 3. Types of water turbine generally used include Pelton Turbine, Francis Turbine, Crossflow Turbine and Kaplan/Propeller Turbine.

Each turbine type has operational characteristic and operational area at a certain condition, so that selection of appropriate type of turbine should be based on head and by taking into account of net head in Rangkiang microhydro power plant of 108.32 m [6]. Turbine types of Francis, Pelton, Turgo and Crossflow can be used, with reference table 2 or Fig. 2 Crossflow turbine with capacity above 500 kW.

Table 3 Potential data and power generated.

No.	Description	Value
1	Head	108.32 m
2	Discharge	1.11 $m^3 s^{-1}$
3	Potential power	980 kW
4	Efficiency	91%
5	Total power perunit	537 kW

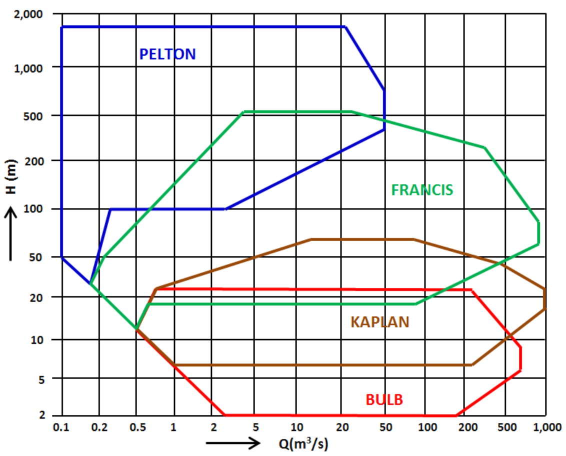

Fig. 3 Turbine selection graph [7].

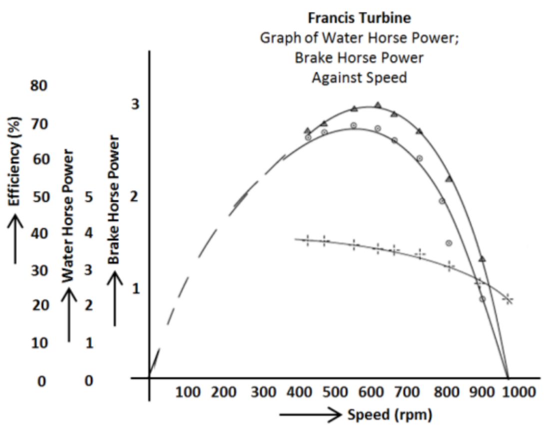

Fig. 4 Graph of Equation of velocity of specific turbine [8].

Based on the discharge and head in the above graph, type of turbine used to be use includes Francis, Turgo impulse or Pelton turbine. Based on the specific rotation, the appropriate turbine type is Francis turbine type (Fig. 3 and Fig. 4). By taking into account the head parameter, discharge and specific rotation velocity, Francis turbine type met the operational area limitation of such three parameters, Francis turbine type with spiral casing was selected for this system.

Other considerations in the selection of such turbine type are as follows: the efficiency of Francis turbine type is relatively high for low load condition which usually occurs during the day, most microhydro power plant in Indonesia use Francis turbine type, the operation and maintenance are easier because it is relatively well-known and the maintenance of Francis turbine type is relatively easier. Then knowing the rotation of the turbine.

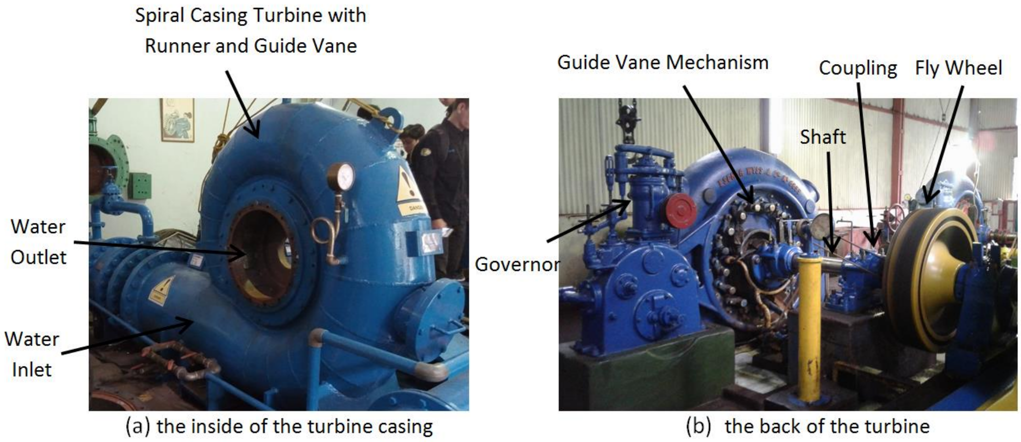

Fig. 5 Francis turbine.

Figure 5 is basic features of Francis turbine. Water from the penstock enters the spiral casing, which transfers it to the runner with uniformly decreasing cross-section to maintain constant flow velocity. In between the runner and the spiral casing, two sets of vanes are distributed in circular rings. The first set of vanes are called stay vanes, which transfers water to guide vanes and provides structural support to spiral casing [9 – 10].

Turbine rotation is based on head, specific turbine velocity and total poles of generator. The head and specific velocity are two important parameters in the basic planning of the generator turbine, while total generator poles constitute parameter for corrected turbine velocity if the turbine schemes used is direct couple. *ns* value needs to be calculated using some equations to obtain moderate values. Specific Speed (n_s) value in the design turbine determines the dimension and cavitation of turbine. Based on such specific rotation, the turbine may operate at the rotation rate of 1000 rpm. The selection of actual turbine rotation rate should take into account the following matter. Each turbine type has different operational area, including the operational area of the rotation to be produced by the turbine. Maximum rotation produced by the turbine is highly dependable on the head and design discharge of the plant. And the maximum rate of the turbine is calculated based on its Specific rotation (n_s) constituting the functions of water head. Based on the selected turbine rotation 100 rpm for turbine power 510 kW, head 108.32 m, the actual specific rotation rate (actual n_s) is 66.30. High turbine rotation will give impact on the decreased age of bearing, so that the selection of low turbine rotation will increase the availability of turbine operation. For the horizontal axle Francis turbine type, the bearing generally used is radial bearing, where this bearing type has less contact area for its contact component of bearing bullets/balls and line, accordingly the voltage of bearing bullet material is fairly large. Based on such matter, high rotation at the bearing may cause more frequency contact between the bearing bullet and the line thereof. This leads to the short age of the bearing. Configuration of correlation between turbine axle and generator may be in the form of direct couple or increaser/reducer.

For the microhydro power plant scheme, where the turbine is able to produce 1000 rpm rotation, the selected configuration should be direct couple. The purpose of this selection is to enable easy maintenance and reduce the investment cost of turbine-generator. Based on the above description, the operational rotation of Francis turbine with spiral casing and the generator thereof with horizontal-direct couple axle configuration is 1000 rpm. With such rotation, the specific rotation of the turbine is 66.30. Based on the specific rotation calculated as above, the dimension of Francis turbine can be calculated using formula F. de Siervo and F. de Leva [11].

Draft tube in part of Fig. 5 is a component used to drain water out of the turbine runner. In Francis turbine, the dimension of draft tube depends on turbine specific speed, and the draft tube must be laid below the minimum tail race water level. Draft tube must be placed below the minimum water level of tailrace and have a certain bend to prevent water evaporation. Based on the calculation results of the basic design of Rangkiang MHP, the summary of all design parameters is as follows at table 4.

Table 4 Results of the calculation of the design of mechanical systems and generators.

Parameter	**Description**
Turbinetype	Francis,horizontalaxis,spiralcasing
Totalturbine-generator	2 units
Turbinepower	537 kW(perunit)
Turbineefficiency	0.91%
Generatorpower	510 kW(perunit)
Generatorefficiency	0.95%
Effectiveheight	108.32 m
Rateddischarge (Qrated)	0.55 $m^3 s^{-1}$ (perunit)
Specificspeed	66.30 rpm
Rotationvelocity	1000 rpm
Diameterrunner	0.42 m
Suctionheight	1.46 m
Runnerweight	55.23 kg
Turbineweight	2.17 kg

Conclusion

Potential of microhydro power plants in Solok District, Tigo Lurah District, Rangkiang Luluih Besar has been evaluated. This area is geographically located at coordinates around 100°52'15.6" east longitude and 0°57'9.7" south latitude. This potential if developed will become a renewable energy source that provides benefits for development in Solok Regency. Power potential. From the calculation, the results of the type of turbine analysis are Francis, total turbine 2 units, unit 537 kW.

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