Eduvest – Journal of Universal Studies
Volume 4 Number 05, May, 2024
p- ISSN 2775-3735- e-ISSN 2775-3727

NEW DESIGN OF A MICRO-HYDRO POWER PLANT (MHPP) SYSTEM IN THE 3T REGION AS ALTERNATIVE SOLUTION UNIT TURBINE USING COMPUTATIONAL FLUID DYNAMICS (CFD) SIMULATION

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ABSTRACT

This research aims to select the most suitable type of water turbine for the micro-hydro power plant (PLTMH) site in the Anggi District, Pegunungan Arfak Regency, West Papua Province. The study also aims to design the most optimal and effective turbine in terms of technical aspects and generator system reliability. This objective is directed towards providing recommendations for the development of the second unit of PLTMH Anggi in a more comprehensive manner rather than relying solely on expert recommendations without thorough analysis. The data used in this research was obtained from field surveys and secondary data sources. The initial step in selecting the turbine type involves manual turbine design calculations, taking into consideration parameters such as water flow, head height, and hydraulic efficiency. Based on these calculation results, the "Francis" turbine type was chosen as the preferred option, differing from the existing Propeller Tubular Type-S turbine installed in Unit 1. The selected turbine, "Francis," was then modeled using computational fluid dynamics (CFD) simulations with the Ansys Fluent software. These simulations provide computer-generated data on hydrodynamic characteristics, pressure distribution, and flow velocity around the turbine under various operational conditions. This research has significant implications for improving the efficiency and reliability of the micro-hydro power plant system for the optimal power and efficiency development of Unit 2.

KEYWORDS *ANSYS, Computation Fluid Dynamics, Francis, Optimization, Turbine Hydro*

How to cite:	Pirzada, S.J et al. (2024). New Design of A Micro-Hydro Power Plant (MHPP) System In The 3t Region As Al-ternative Solution Unit Turbine Using Computational Fluid Dynamics (CFD) Simulation. *Journal Eduvest*. *4* (5): 3895-3911
E-ISSN:	2775-3727
Published by:	https://greenpublisher.id/

INTRODUCTION

The management of energy resources, including their provision, utilization, and exploitation, must be carried out in a just, sustainable, rational, optimal, and integrated manner to add value to the economy of the nation and the Unitary State of the Republic of Indonesia. The continuous provision, utilization, and exploitation of energy to enhance the welfare of the people should be in harmony, coordination, and balance with environmental functions. Energy management aims to achieve energy management independence, ensure the availability of domestic energy from both domestic and international sources, secure a domestic energy source, and ensure the efficient use of energy Indonesia. Government Regulation of Indonesia. (Energy Law, 2007).

Energy is one of the sectors focused on in efforts to achieve the NZE program. This large amount of energy demand in the building sector is not only increasing global energy scarcity but also impacting climate change. Various countries have issued new regulations regarding the provision of electricity tailored to the NZE program. (Ullah, 2021).

Indonesia's commitment to transitioning to carbon neutrality is emphasized by replacing the operations of conventional power plants that use coal, such as steam power plants and diesel power plants, with solar/hsd fuel. These power plants will be phased out and replaced with power plants based on renewable energy (Presidential decree, 2022).

Currently, many areas still lack access to energy, both for electricity and non-electricity, requiring efforts from the government and local authorities to meet the needs of the population, especially those in remote or isolated areas, outer islands, and border areas. According to potential village data collected by the Central Statistics Agency (BPS), around 3% of villages in Indonesia are still not electrified. Rural electrification using renewable energy is the best option for many locations far from the national grid. Many renewable energy projects have been implemented for rural areas, such as micro-hydro power plants (PLTMH). (Didik et al., 2018).

The objective of this research is to identify a turbine simulation with a convergent model. This research applies a CFD simulation reference approach, and the prediction model is developed using ANSYS Fluent CFD modeling.

Literature review

Research by Dewi et al. (2019) an approach based on the need of electrical energy in Indonesia is continuously increasing. Currently, Indonesia has 75000 MW potency of hydropower. However, only 7573 MW were utilized. Hydro energy is one of solutions for the problem of energy needs and Indonesian government target. In this paper, a basic design of Francis turbine for one mini hydropower plants in Indonesia is presented. The Francis turbine is designed for Malabar mini hydropower plant which has head of 100.8 m and flowrate of 1.5 m^3/s with power-generated of 1.43 MW. In order to obtain the performance target, the calculations, models, and simulations were performed by Computation Fluid Dynamic software to determine the performance of the Francis turbine design. The results showed the obtained maximum hydraulic efficiency of 88.24% on flowrate of 1.52 m3/s with power generated of 1.43 MW.

Research by Pepa et al. (2017) presents research, the penstock or spiral case of a hydraulic turbine are the effect of sudden flow variation that occur during transient processes of type opening / closing or load rejection of the hydro unit. The consequence of the pressure rise in the spiral case and penstock is the water hammer phenomenon, whose effects can be devastating in some cases, up to breaking pipes and calamities produced in the area. This paper aims to analyze the method of calculation of the maximum pressure values that might occur in load rejection situations to a hydraulic turbine, in spiral case and in penstock, conditioned by the limiting of the values of the over speed and measures of limiting the increase in pressure in conjunction with limiting the increase in speed in these specific processes. The results of analytical calculation overlaid on the experimental measurements performed during the performance tests of the hydro unit lead to the conclusion that the calculation algorithm proposed has been chosen correctly and the 2-stage closing law of the wicket gate promoted in this case is effective in such situations.

Research by Sun et al. (2021), regarding the principal objective of this paper is to present the numerical investigation into load rejection towards a high-head model Francis turbine based on the structured overset mesh, which provides greater flexibility over the standard mesh techniques and adequate mesh quality during the movement of the guide vanes. The numerical results show good agreement with experimental measurements. The formation and evolution process of the vortex rope in the draft tube are elaborated by the velocity invariant Q and the swirl number S reaching its maximum value due to the formation of processing vortex rope. Evidence is presented which shows that significant influence of the rotor-stator interaction is captured, and the pressure fluctuation amplitudes caused by the changing of angular position of guide vane are also powerful. Furthermore, the velocity profiles in axial and radial imply that an increasing recirculating flow region is developed at the center of the draft tube during the transient process. The findings presented in this paper enhance the insight into transient features of load rejection process.

Research by Trivedi & Cervantes (2017) presents, three types of curves were used to define the elbow contour geometry: logarithmic spiral format curve, circle arc format curve and denominated hyperbolic spiral curve. These curves and their combinations were used to define the elbow contour in the longitudinal plane, resulted in four draft tubes geometries. The numerical results were compared with experimental results, showing good conformity. Research by Stojkovski et al. (2021) is to understand A parametric design tool with normalized geometrical constraints was created in MATLAB, suitable for generating guide vane cascade geometries for Francis turbines. The goal is to determine the limits of these constraints, which will lead to future faster prediction of initial guide vane configurations in the turbine optimal operating region. Several geometries are developed using preliminary design data of the turbine and are investigated using CFD simulations close to the Best Efficiency Point (BEP) of the turbine. Arispe et al. (2018), Three types of curves were used to define the elbow contour geometry: logarithmic spiral format curve, circle arc format curve and denominated hyperbolic spiral curve. These curves and their combinations were used to define the elbow contour in the longitudinal plane, resulted in four draft tubes geometries.

From various references that have been gap research by the author. Despite the existing micro-hydro plant projects in Anggi District, there is a gap in the literature regarding the optimization of design parameters, especially with the shift from the previously used Propeller Type-S turbine to the recommended Francis turbine. The current research projects have primarily focused on basic design and performance evaluations, leaving room for a comprehensive optimization study. While CFD (Computational Fluid Dynamics) has been applied for Francis turbine design in various contexts, there is a gap in its specific application for micro-hydro plants in Anggi District.

The existing literature highlights the benefits of CFD in turbine design but lacks a detailed exploration of its application to optimize Francis turbine performance in the unique conditions of Anggi District. The current literature provides insights into the hydraulic efficiency of Francis turbines for micro-hydro plants. However, there is a research gap in addressing transient processes, load rejection, and the effects of sudden flow variations. A more detailed analysis of the transient behavior of the proposed Francis turbine under Anggi District conditions is needed. The existing studies have touched upon the design parameters and CFD simulations individually. However, there is a gap in research that seamlessly integrates these aspects.

An advanced study should explore how specific design parameters influence the performance outcomes obtained through CFD simulations, offering a holistic understanding for optimizing micro-hydro plant design. While the recommendation is to shift from the Propeller Type-S turbine to the Francis turbine, there is a gap in the literature regarding a comparative analysis. An advanced research project should include a comparative study of the performance, efficiency, and economic considerations between the two turbine types in the context of Anggi District. The existing literature lacks a strong connection with industry insights and practices in micro-hydro design, especially in the Anggi District.

An advanced research project should bridge this gap by incorporating feedback and experiences from industry professionals involved in micro-hydro projects, ensuring the practical relevance and feasibility of proposed designs. While the technical aspects of micro-hydro design have been addressed, there is a research gap in exploring the environmental and social impact of transitioning from Propeller Type-S to Francis turbines. Advanced research should incorporate an assessment of the broader implications, including ecological considerations and community engagement. By addressing these gaps, an advanced research project can contribute significantly to the optimization, efficiency, and practical implementation of micro-hydro plant designs using Francis turbines in the unique context of Anggi District.

The aim of this research is to solve problems in the analysis and design of Francis turbine for Anggi District, at Pegunungan Arfak Regency in West Papua Province. For this purpose, ANSYS CFX software was used for the purpose of analyzing the dynamics flow of fluid (Computational Fluid Dynamics). Also needs operators who are able to use Ansys CFX properly, which currently must be overcome by students through independent learning that should be find by themselves, one way of them is via the internet. Making a thesis like this is one way to motivate students to learn to use software independently.

RESEARCH METHOD

Research Stages

The method of selection and initial design of turbines and generators was depicted in Figure 1.

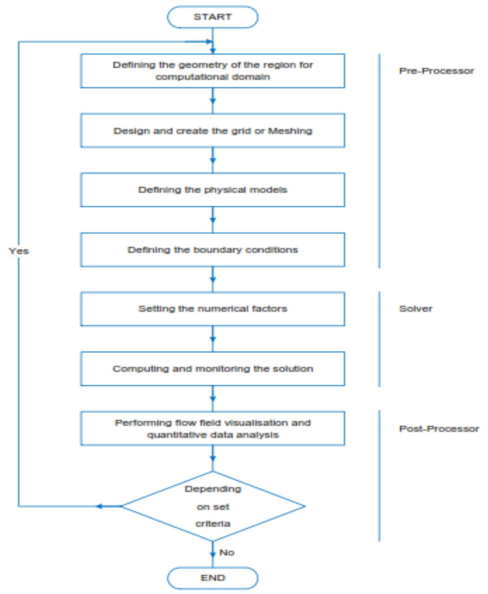

Figure. 1. A flowchart of the CFD analysis processes

The normal water surface elevation at the head pond of the Anggi micro-hydro power plant (PLTM) is +1916 meters above sea level (mdpl), and the normal elevation of the tailwater level is +1900 meters above sea level (mdl), resulting in a gross head of 16 meters for PLTM Anggi. The head loss at PLTM Anggi is listed as follows:

Table. 1. A flowchart of the CFD analysis processes

1	EL upstream		1916	msl
2	EL downstream		1900	msl
3	H gross		16	m
4	Discharge		1.353	m3/s
5	Head loss			
		entrance loss	0.17398169	m
		pipe friction	1.64569241	m
		pipe bend	0.86517699	m
		pipe reduction	0.00922161	m
		pipe bifurcation	0	m
		MIV Loss	0.06916208	
		Draftube outlet loss	0.0182361	m
6	H netto		13.2185291	m

As a result, a net head of 13.218 meters was obtained. Flow PLTM Anggi was designed to generate a power of 150 kW. With a net head of 13.218 meters and assuming a turbine efficiency of 90% and a generator efficiency of 95%, the required design flow for PLTM Anggi was achieved at the value of 1.353 m^3/s.

Based on the Figure 2, the hydrological analysis conducted in the previous study, the availability of discharge to operate the Anggi micro-hydro power plant (PLTM) turbine at a design capacity of 150 kW is available throughout the year. PLTM Anggi is located at coordinates 133°53'40.5" E and 01°17'18.7" S precisely on the Enggimun River, Hungku Village, Anggi District, Pegunungan Arfak Regency, West Papua Province. Referring to the procedure established by the United States Bureau of Reclamation (USBR) to determine the turbine type, it is done by calculating the Trial Specific Speed. Trial Specific Speed is calculated using the formula:

$$n_s = \frac{2334}{\sqrt{H}} = 641.96\, rpm$$

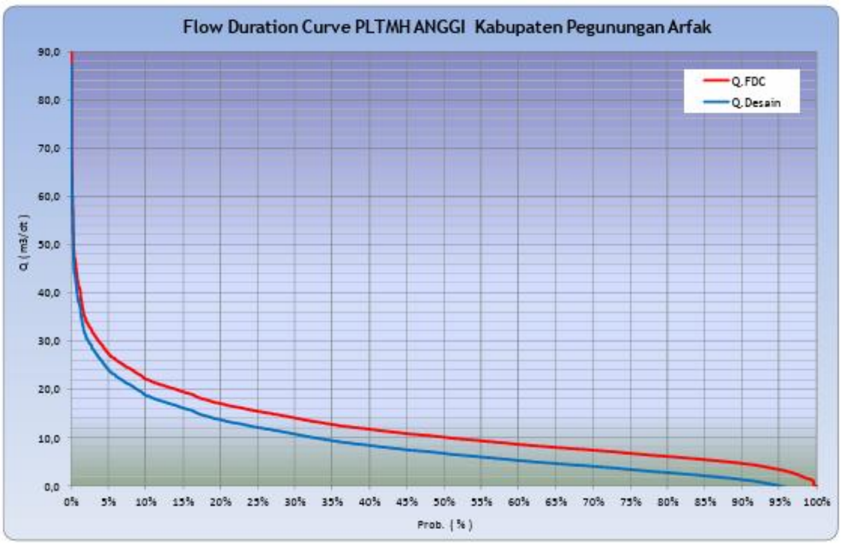

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Fig. 2. Flow duration curve.

With the turbine designed output at 150 kW, the turbine rotation can be calculated as follows:

$$n = \frac{n_s * H^{\frac{5}{4}}}{\sqrt{N}} = 1104\, rpm$$

If the turbine will be directly coupled to the generator, the iteration process will be carried out at rotations of 3000 rpm, 1500 rpm, 1000 rpm, 750 rpm, and so on (for a generator with a frequency of 50 Hz). For the ease of the construction process, it has been agreed upon by the civil and mechanical designers that the minimum suction head requirement is 4 meters. After conducting iterations, the operating rotation is selected at 500 rpm (12 poles, 50 Hz). Based on this operating rotation, the specific speed can be calculated as follows:

$$n_s = \frac{n\sqrt{N}}{H^{\frac{5}{4}}} = 290.67$$

To test the results of the specific speed turbine calculation, it is necessary to calculate the magnitude of the suction head obtained when using a turbine with a specific speed of 290.67. At (ns) = 290.67, σ can be calculated from the equation,

$$\sigma = \frac{n_s^{1.64}}{50327} = 0.218$$

The micro-hydro power plant (PLTMH) is located at an altitude of 1900 meters above sea level, so the atmospheric pressure at that location is 77390 Pa. With this value, the suction head is obtained as follows:

$$H_s \leq \frac{1}{g}\left[\frac{P_A - P_V}{\rho} - \sigma Y\right]$$

$$H_s \leq 4.77\ m$$

The position of the turbine center shaft is above the tailrace surface at a distance of 4.77 m. The suction head height of this turbine has already met the agreed-upon required suction head, which is a minimum of 4 m. The following Table 2 shows specific turbine types within a certain range of specific speed.

Table 2. Specific Speed Table

Ns	Turbine Type
4 -35	Pelton wheel with 1 nozzle
17 - 50	Pelton wheel with 2 nozzle
24 - 70	Pelton wheel with 4 nozzle
80 - 120	Francis Turbine, low speed
120 - 220	Francis Turbine, normal
220 - 350	Francis Turbine, high speed
350 - 430	Francis Turbine, express
300 - 1000	Propeller and Kaplan Turbine

The operational rotation of the Anggi micro-hydro power plant (PLTMH) turbine is 500 rpm, resulting in a specific speed of 290.67. Therefore, the suitable turbine is the high-speed Francis turbine.

Turbine Design Data The turbine selection process determined that the appropriate turbine to be installed in PLTM Anggi is the high-speed Francis turbine. The main dimensions of the Francis turbine for PLTM Anggi are designed following the standard procedure for determining the main dimensions of the turbine, referencing the procedure established by the United States Bureau of Reclamation (USBR). The basic design data for the PLTM Anggi turbine are as listed in Table 3.

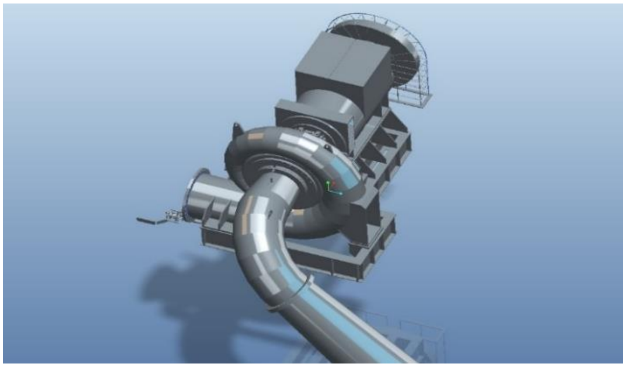
Table 3. Turbine design data

Turbine Design Data			
No	**Parameter**	**Nilai Desain**	**Unit**

1	Gross Head	16	m
2	Netto Head	13.218	m
3	Debit	1.353	m3/s
4	Trial Specific speed	641.961947	
5	Trial speed	1104.29	rpm
6	Design speed	500	rpm
7	Design specific speed	290.6	
8	Elevation of Tailrace	1900.0	mdpl
9	Atmospheric pressure	77390.0	Pa
10	Suction head	4.77	m
11	Diameter of the runner outlet	0.569	m
12	Diameter of the runner inlet	0.535	m
13	Number of runner blades	17	pcs
14	Number of guide vanes	20	pcs
15	Height of guide vanes	0.18	m
16	Number of stay vanes	20	pcs
17	Height of stay vanes	0.19	m
18	Angle of guide vanes	28	dergres
19	Angle of stay vanes	28	dergres

RESULT AND DISCUSSION

After determining the main dimensions of the turbine, the process of creating a conceptual 3D model of the Anggi micro-hydro power plant (PLTM) turbine can



be carried out. There are several methods for modeling turbines, including the top-down method, bottom-up method, skeleton method, and basic method. In modeling the Anggi PLTMH turbine, the top-down method is used, where the modeling process begins by creating an assembly model and then detailing it into machine components. This method has the advantage of ease in the assembly.

Fig. 3. 3D modeling of new design

Process and early detection of interference between machine component parts due to modeling the model for the Francis turbine of the Anggi micro-hydro power plant (PLTMH) is divided into three fluid volumes, namely:

- Spiral case, stay vane, and guide vane volume, which is the fluid volume encompassing the spiral casing, stay vane, and guide vane.
- Runner volume, which is the fluid volume encompassing the runner, Spiral casing, stay vane, and guide vane.
- Draft tube volume, which is the fluid volume encompassing the draft tube.

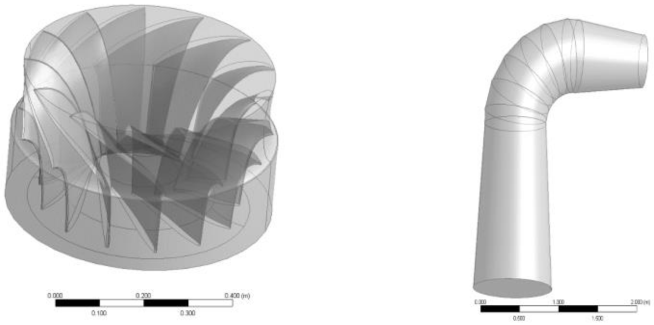


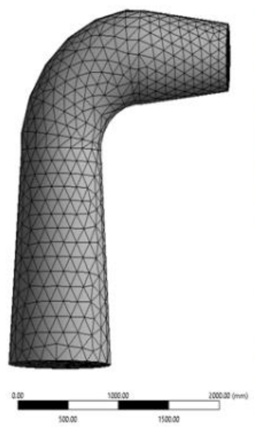
Fig. 4. Meshing process of turbine

Figure 4 shows the division of the fluid volumes above, there will be three corresponding domains to be defined in the simulation:

- Spiral Case Volume
- Runner Volume
- Volume Draft Tube
- Mesh Generation

After the domains have been defined, the process continues with the generation of a mesh in each domain. The recapitulation of the mesh generation results can be seen in the following image.

1. Input material to be simulated

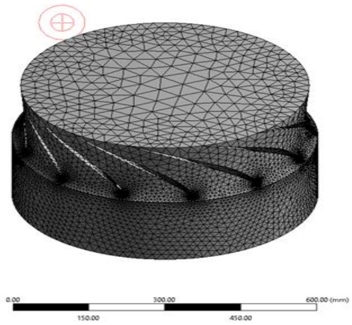


Model (D3) > Geometry > Parts	
Object Name	DRAFTUBE
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Reference Frame	Lagrangian
Material	
Fluid/Solid	Defined By Geometry (Solid)
Bounding Box	
Length X	2988. mm
Length Y	2162.1 mm
Length Z	1012.2 mm
Properties	
Volume	2.0899e+009 mm³
Centroid X	1051.1 mm
Centroid Y	1659.5 mm
Centroid Z	-2.3027e-006 mm
Statistics	
Nodes	1669
Elements	7328
Mesh Metric	None

Fig 5 Recap of the mesh generation result

2. Determining the domain, in this simulation, the Anggi Micro Hydro Turbine is divided into 3 domains, namely:
   - Spiral case domain consists of the fluid volume encompassing the spiral casing, stay ring, and guide vane, defined as a stationary domain.
   - Runner domain is the fluid volume encompassing the runner, defined as a rotating domain rotating at 500 rpm.
   - Draft tube domain is the fluid volume inside the draft tube, defined as a stationary domain.
   - Determining interface domains, in this case, there are 2 interface domains defined as frozen rotor.
   - Determination of boundary conditions.

The boundary conditions used in the simulation of the Anggi Micro Hydro Francis turbine are as follows:



Model (A3) > Geometry > Parts

Object Name	*RUNNER*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Reference Frame	Lagrangian
Material	
Fluid/Solid	Defined By Geometry (Solid)
Bounding Box	
Length X	604.8 mm
Length Y	346.68 mm
Length Z	604.8 mm
Properties	
Volume	7.7929e+007 mm³
Centroid X	-2.2263e-003 mm
Centroid Y	89.786 mm
Centroid Z	-6.2423e-005 mm
Statistics	
Nodes	624749
Elements	3446520
Mesh Metric	None

Fig 1 Defined Geometry

Solution (Solver)

At this stage, before calculations are performed, there are several steps that must be taken, namely:

- Determining solver settings, including setting convergence criteria, the maximum number of iterations, and other required parameters.
- Configuring resources for computations, such as serial or parallel computation, setting the number of computers or CPU cores to be used for parallel calculations, and so on.
- Determining the level of calculation precision; typically, there are two types of precision: single precision and double precision. The choice of precision type will affect the duration, number of iterations, and output of the calculation.
- Initialization calculation settings, where iterations can be performed from the beginning or from the existing previous iteration.

In solving fluid flow problems, CFD engines typically address the issues using the Reynolds-Averaged Navier-Stokes (RANS) equation approach.

Post-Processing

After the iteration process meets the convergence criteria, the iteration process will be stopped, and the results of the iteration process can be obtained. A recapitulation of the simulation results of the Anggi Micro Hydro Turbine at peak performance is presented in the following table:

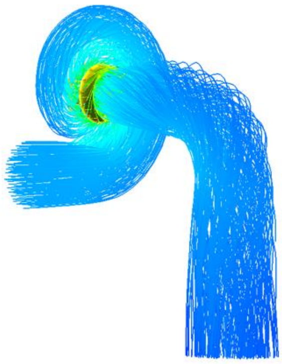


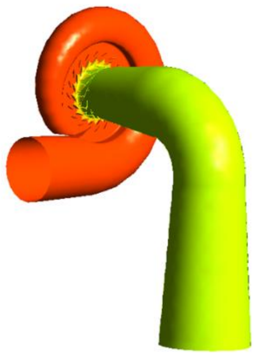
Fig 2 Streamline Design Turbine

Based on the simulation results, it is known that the design of the Anggi Micro Hydro as listed in Table 4. Turbine has an efficiency of 90.14%, and the design of the Francis runner has an efficiency of 95%. The energy loss in the spiral casing, stay vane, and guide vane is 2.77%, and the energy loss in the draft tube is 2.36%.

Table 4. Simulation Calculation Report

CFD Simulation Results				
Discharge	1.31369	m3/s		
Inlet Total Pressure	129568	Pa	13.20775	m
Casing-Runner interface Total Pressure	126021	Pa	12.84618	m
Runner-Draft Tube interface Total Pressure	4340.02	Pa	0.442408	m
Outlet Total Pressure	1313.83	Pa	0.133928	m
Head System	128254.2	Pa	13.07382	m
Head Runner	121681	Pa	12.40377	m
Torque Runner	2900.42	Pa		
Rotational Speed	52.36	rad/s	500	rpm
Power output	151.8656	kW		
Runner Efficiency	**95.00%**			
Turbine Efficiency	**90.14%**			

Peak performance is not achieved at the design flow rate (1.353 m3/s) but at 97% of the design flow rate, which is 1.3137 m^3/s. According to these simulation results, the design of the Anggi Micro Hydro Turbine is considered quite good and can proceed to the production process.

	
Fig 8 The pressure contour on the runner	Fig 9 The pressure contour on the Spiral Casing
	
Fig 10 The pressure contour on the runner	Fig 11 The pressure contour on the runner turbine

In the design of the Anggi Micro Hydro Turbine, no pressure contours were found that could potentially trigger cavitation, making this design sufficiently safe for application. However, to ensure cavitation does not occur, it is essential to verify that the elevation settings during construction are done correctly within the allowed suction head range. The control characteristics of the turbine are essentially a function of the inertia effects of the flywheel and the water column. The flywheel provides stabilization effects, while the water column's inertia has the opposite effect on speed regulation. The flywheel effect is typically expressed as the starting-up time of the unit, turbine runner, and generator, providing an inertia effect WR2, which can be formulated as follows:

$Turbin - WR^2 = 135\ kg.m^2$

$Generator - WR^2 = 130\ kg.m^2$

$T_m = 5.85\ s$

Tm is the time it takes for the turbine to accelerate from zero rotations to reach operational speed, expressed in seconds. The water column inertia, also known as the starting-up time of the water column, can be calculated using the following formula

$$T_w = \frac{\sum LV}{gh} = 9.51\ s$$

"The critical time for the Anggi Micro Hydro Power Plant (PLTM), which has a penstock with a diameter of 900 mm and a length of 570 m, is 1.16 s. The water hammer constant (allevi or water hammer number) is hw: 8.2. For a system with hw values above 2, it is recommended that the turbine closing time (Tk) be 2.5 x Tw, or approximately 23.78 s ~ 24 s.

The PID Governor constants are determined based on Stein's empirical equation, resulting in the following PID constants:

Kp: 0.6 (range 0-10)

Ki: 4.75 (range 0-1.5)

Kd: 28.5 (range 0-40)

Based on the above calculations, it is known that the Anggi Micro Hydro Turbine will have suboptimal regulation characteristics, as reflected in the PID constant Ki falling outside the recommended range. This Ki constant is related to water inertia. For the Anggi Micro Hydro Power Plant to have good regulation characteristics, it is advisable to design Tw to be less than 3s.

The normal recommendation for turbine closure is 24 s. With this closing time, the pressure rise due to the water hammer effect can be calculated as follows:

$$\Delta h = \frac{2Q \sum L/A}{g t_c} = 10.47\ m$$

The pressure rise that occurs during normal closure is 10.47 m or equivalent to 65.5%. Equipment in the power plant typically has a test pressure of 150% of the nominal pressure, so with normal closure, the pressure rise exceeds the specifications of the equipment installed at the Anggi Micro Hydro Power Plant. To reduce the water hammer effect, slower closure is needed, but it will certainly affect other turbine parameters such as speed rise, which will be discussed in the next subsection.

Speed rise during load rejection requires special attention. Speed rise is the increase in speed from the operational speed when the turbine is suddenly disconnected from the grid load while operating under governor control. Turbines and generators are designed to withstand runaway speed, but at high speeds, vibrations usually occur in the machine, sometimes causing shear pin breakage in the guide vane regulating mechanism. To reduce vibrations, speed rise should not exceed 60%, but it is advisable for speed rise to be between 35% - 45%.

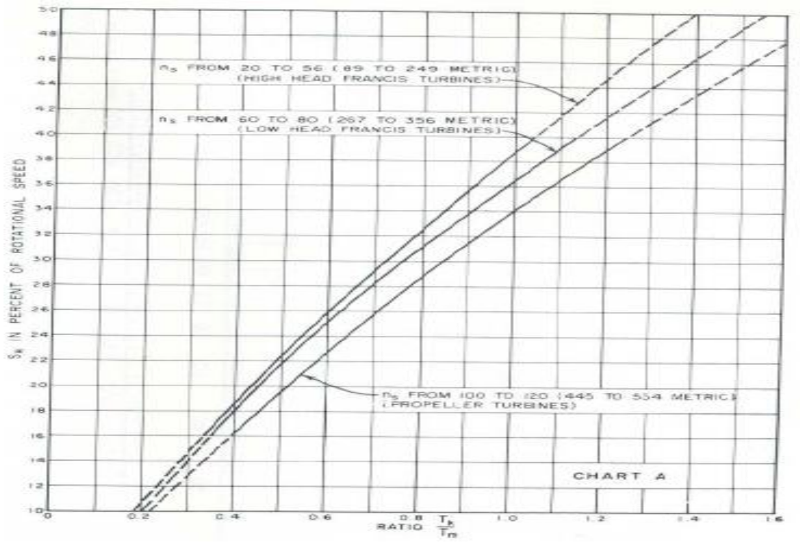


Fig 12 Turbine Speed Rise

Based on the previous calculation, Tk was obtained as 24 s. With this closing time, the Tk/Tm ratio is 1.64, and the Sr (speed rise based on the graph above) is 58.7% of the nominal speed. The closing time for the guide vane (Tf) can be determined using the following formula:

$$T_f = T_k - 0.25 = 23.75\ s$$

The starting-up time of the water column based on the previous calculation is 9.51 seconds.

$$K = \frac{T_w}{T_f} = 0.4$$

The actual speed rise that will occur can be calculated using the following formula:

$$SR' = SR(1 + k) = 82.245\%$$

The high-speed rise that occurs indicates that the Anggi Micro Hydro Turbine will experience runaway speed during load rejection at 100% turbine output when closed with normal closing time.

If the closing time is accelerated, a significant water hammer effect will occur, but if it is slowed down, the turbine will experience runaway speed phenomena. Therefore, for the Anggi Micro Hydro Turbine, a pressure regulator needs to be added, whether in the form of a surge tank or a pressure relief valve, so that the inertia effect of water in the penstock can be significantly reduced. The turbine can then be closed more quickly without causing a significant water hammer effect.

Runaway speed is the speed reached by the turbine when, at full load, the generator is disconnected from the grid load, and the governor is unable to control the turbine. Each manufacturer will produce turbines with different runaway speeds even when operating at the same operating parameters, due to differences in the design of the turbine runner and generator. Based on field tests, the runaway speed will not exceed the following value.

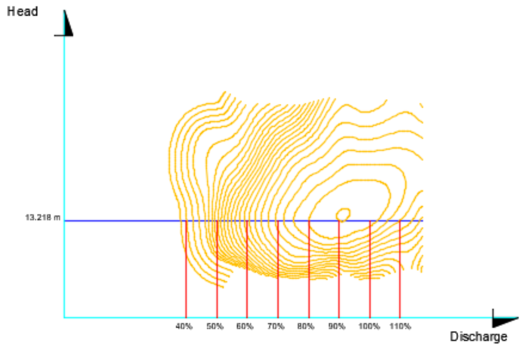


Fig 13. Hill chart Turbine PLTMH Anggi

$$n_r = n\,0.63(n_s)^{1/5} = 980\,rpm$$

The performance curve of the Anggi Micro Hydro Turbine is obtained by extracting the hill chart contours at the design head of the Anggi Micro Hydro Power Plant, which is 13.218 m. Thus, the performance curve is obtained as follows.

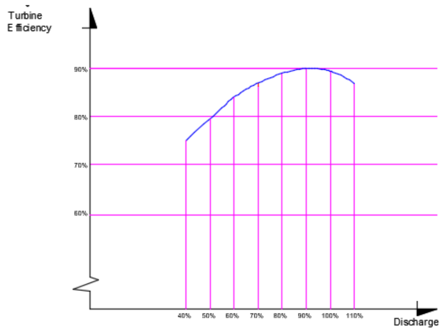


Fig 14 Turbine Performance

Based on the results of data processing as shown in Figure 14, the turbine design for the 2nd unit of the Anggi PLTMH was obtained, using a Francis turbine whose CFD simulation had been carried out and the efficiency was obtained at the level of 90%, and could be implemented at the development stage using the parameters of this simulation result.

CONCLUSION

This study aims to analyze and design a Francis turbine for a Micro-Hydro Power Plant (MHPP) in the Anggi District, Pegunungan Arfak Regency, West Papua Province. Through simulations using ANSYS CFX software, the study found that the Francis turbine design provides high efficiency and is suitable for the development of MHPP in the area. Several key points concluded include the importance of sustainable energy management in Indonesia to enhance the national economy with a commitment to renewable energy; the transition to renewable energy such as solar and micro-hydro to reduce the impact of climate change; the energy needs in remote areas that still lack access to electricity; the Francis turbine design for Anggi MHPP shows a maximum hydraulic efficiency of 90.14% and a runner design efficiency of 95%, which is quite good for the production stage; the use of CFD in design optimization allows for more detailed analysis; an optimal turbine design must consider various design parameters; and technical challenges such as the water hammer phenomenon require solutions like the use of surge tanks or pressure relief valves. By addressing these challenges, ongoing research projects can significantly contribute to the optimization, efficiency, and practical implementation of MHPP design using Francis turbines in the Anggi District.

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