DESIGN AND CFD ANALYSIS OF 1 KW PICO HYDROPOWER SIMULATOR WITH CENTRIFUGAL WATER PUMP AND FRANCIS TURBINE

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ABSTRAK

Simulasi penting sebagai hasil kaji sebuah rancang bangun. Artikel ini merupakan hasil penelitian yang bertujuan untuk merancang dan membangun sistem simulasi Pembangkit Listrik *Pico Hydro* dengan menggunakan pompa air sebagai sumber aliran air. Pembangkit Listrik *Pico Hydro* adalah teknologi pembangkit listrik skala kecil yang memanfaatkan energi air sebagai sumber energi terbarukan. Melalui sistem simulasi ini, perancangan dan pengujian desain simulator *Pico Hydro* dapat dilakukan untuk menentukan nilai efisiensi dari desain yang dibuat. Proses perencanaan dimulai dengan menentukan spesifikasi turbin air yang akan digunakan, termasuk debit air, tinggi jatuh air (head), dan kapasitas yang dibutuhkan. Berdasarkan data tersebut, pemilihan jenis pompa air yang sesuai dengan kebutuhan turbin dapat dilakukan. Selanjutnya, komponen *Pico Hydro* seperti turbin, generator, tangki air, saluran air, dan panel sistem dirancang. Proses desain dilakukan dengan menggunakan perangkat lunak CAD (Computer-Aided Design) untuk merancang bagian-bagian dan rakitan pada simulator. Setelah itu, kinerja desain akan dianalisis menggunakan perangkat lunak Computational Fluid Dynamics (CFD). Hasil akhir dari penelitian ini adalah desain simulator *Pico Hydro* yang telah dioptimalkan dan dapat disimulasikan dengan menggunakan pompa air sebagai sumber aliran. Sistem simulasi ini memungkinkan penelitian dan pengembangan dalam bentuk alat pembelajaran bagi siswa untuk memahami cara kerja dan efisiensi pembangkit listrik *Pico Hydro*.

Kata kunci: desain, analisis, simulator *pico hydro*, pompa air, turbin.

ABSTRACT

Simulation is essential for a design study. This article illustrates the result of a research aimed to design and build a Pico Hydro Generator simulation system using a water pump as a source of water flow. Pico Hydro Generator is a small-scale power generation technology that utilizes water energy as a renewable energy resource. Through this simulation system, the design and testing of the Pico Hydropower simulator design can be carried out to determine the efficiency value of the design. The planning process begins by determining the specifications of the water turbine to be used, including water discharge, headwater, and the required capacity. Based on these data, it is possible to select the type of water pump that is suitable for the needs of the turbine. Then the design of Pico Hydropower components such as turbines, generators, water tanks, water channels, and system panels is designed. The design process uses CAD (Computer Aided Design) software to design parts and assemblies on the simulator. Then the design performance will be analyzed using Computational Fluid Dynamic (CFD) software. The final result of this study is a Pico Hydropower simulator design that has been optimized and can be simulated by using a water pump as a flow source. This simulation system can allow research and development in the form of learning tools for students to understand how Pico Hydro power plants work and how to calculate their efficiency.

Keywords: *design, analysis, pico hydropower simulator, water pump, turbine.*

1. INTRODUCTION

Electricity is one of the most important energy sources in the modern world. As most of the energy is still generated for the world from fossil-fuels that cannot be reprocessed, environmental detriment exists in this sector. Hence, it is necessary to develop technologies for generating energy from renewable sources to ensure energy supply in the near future and to minimize adverse environmental impact. One of the renewable resources that can be used to be transformed into electrical energy is hydropower, one of the plants is a Pico hydropower plant. This power plant is designed to work in remote areas which only contain water sources like irrigation, rivers and other water flows. The project involves creating a pico hydro simulator that allows students to study the operation of pico hydro power plants. This simulator was created to simulate the real pico hydro power generator that uses the water flow from natural source such as small rivers. It uses a water pump to act as a water flow and a water tank to serve as a water source [1].

Hydropower energy is one of the renewable energies that is often used in the world, one of which is in Indonesia. Hydropower itself is the process of using alternative energy to produce electrical power by utilizing water to start the engine. In simple terms, hydropower is energy produced from flowing water. Based on the electrical power produced, hydropower energy can be categorized as follows [1]:

1. Pico Hydro: can produce up to 5 kilowatts of power
2. Micro Hydro: can produce 5-100 kilowatts of power
3. Mini Hydro: can produce power above 100 kilowatts
4. Large Hydro: can produce more than 100 megawatts of power

Those categories of hydropower energy include renewable and environmentally friendly energy sources. The flow of tiny rivers, waterfalls, water irrigation, or dammed lakes which then fall from a specific height and have a discharge that will operate a turbine that is connected to an electric generator is the source of the hydropower that is used. There is a correlation between the height of the waterfall and the amount of water's potential energy that can be transformed into electrical energy. [1][2][3].

Using the gradient and the rate of discharge in a water flow, a pico hydropower generator may produce electricity. The mechanical energy is generated when the water flow turns the turbine shaft. In turn, this mechanical energy powers the generator, which in turn generates electrical current. A pico hydropower generator primarily consists of a water supply, turbines, and generators. Fluid mechanics and electromechanical conversion are the guiding concepts of the energy conversion process. The kinetic energy of the flowing water is transferred to the turbine. The blades of the turbine transform the kinetic energy of the moving water into mechanical energy [4][5].

Pico hydropower plants are efficient yet environmentally cordial generation plants and can be exploited in geographically isolated sites as one of power plants. Whereas, the students in the learning process in the academic environment do not fully understand how Pico Hydropower works and identify the main components of Pico Hydropower [2]. This is due to the fact that there are very few props or simulations available to directly demonstrate the working principles of pico hydro. In addition, the simulator enables the student to optimize the design of pico hydro power plants by investigating the influence of variations of water flow parameters on the performance of the turbine and generator. This will standardize an effective design procedure, which can be suitably sited on regions with defined water flow properties

Hence, it resembles the actual pico hydro in practical operation but in laboratory scale. The pico hydro simulator uses elements like centrifugal water pumps as water movers and Francis turbines plant. Furthermore, the design of this simulator needs to be analyzed so that the system's efficiency in generating 1 kW power output as specified can be assessed. Thus, this research will focus on designing and evaluating the performance of a 1 kW Pico Hydropower design simulator.

2. METHOD

This study uses an empirical method which is a research approach based on collecting and analyzing data in numerical form to obtain measurable and objective conclusions. The author collects the necessary data through direct observation and measurement in the field. The collected data is then analyzed and calculated systematically to achieve results in accordance with the research objectives. Thus, the author will obtain measurable and validating results through data calculation and analysis.

2.1 *Observation*

The observation was made by observing the micro hydro power plant which in turn is designed as a didactic tool on a laboratory scale for students, a pico hydro power plant simulator. The observation is focused on simulating the working principle in pico hydro power plants. During the observation, there are some notes as key parameters such as water discharge, turbine speed, and power generated. The results of these observations will be the basis for the refinement of the simulation design.

2.2 *Problem Identification*

The issue discovered within the design of the Pico Hydro Generator is the configuration of the water pump specification which works as a water flow driver that rotates the turbine and generator. To determine the adjustments needed to the specs for the water pump that can turn the turbine, one must analyze the calculations done on the turbine.

2.3 *The Conceptual Design*

Presently in the stage of conceptual design, the author explains the design concept that will be made. There are six main components that will be designed, these components are water source, water current, water pump, turbine, generator, and control panel. The water source is designed using a water tank, which functions to collect water before it has flowed to the turbine. The water current in this system is designed using a piping system that connects the water tank to the water pump, and then to the turbine. The water pump acts to push the water and generate enough pressure to rotate the turbine and generator, after which the water will return to the water tank. The rotation of the generator will produce an electric current, whose voltage can be observed through the control panel. This design allows students to calculate the performance efficiency of the pico hydro power generator.

2.4 *Data Collection and Simulation with CFD*

Collecting data is the first step in designing picro hydro generator. Data on the type of turbine used as well as its specifications (water flow rate and water head that drive the turbine) were collected. The simulation model was established using Computational Fluid Dynamics (CFD), and calculations were performed based on the obtained data.

Furthermore, the author also performed CFD simulations with ANSYS software. This stage is to check some of the designs and revise some data to get the efficiency value. The author, therefore, in the simulation stage succeeded in simulating the water discharge that occurs on the turbine, which in turn was used to analyze and draw key parameters such as pressure, velocity, and torque distribution on the turbine in different conditions to provide insight into the turbine performance under operating conditions.

2.5 *Data Analysis*

After the data are collected, the author then analyzes them. Started with a review of the turbine specification data gathered. Furthermore, the necessary calculations and analysis are performed to decide the specifications of the water pump. The primary aim of this analysis is to make sure that the chosen water pump will generate enough water current and pressure to cause the turbine and generator to function properly. That is to say, technical parameters are considered to optimize the pico hydro simulator system performance as a whole.

2.6 *Final Design*

This stage is the last stage and is the final design of the results of a series of research stages. This final design shows the final result of a simulator design. The final design was designed using Solidworks. This simulator aims to be an effective learning tool but also provides a means for students to conduct further research in the optimization of the pico hydro power generator system. Figure 1 showing an explanation of the methodology used in the form of a flowchart.

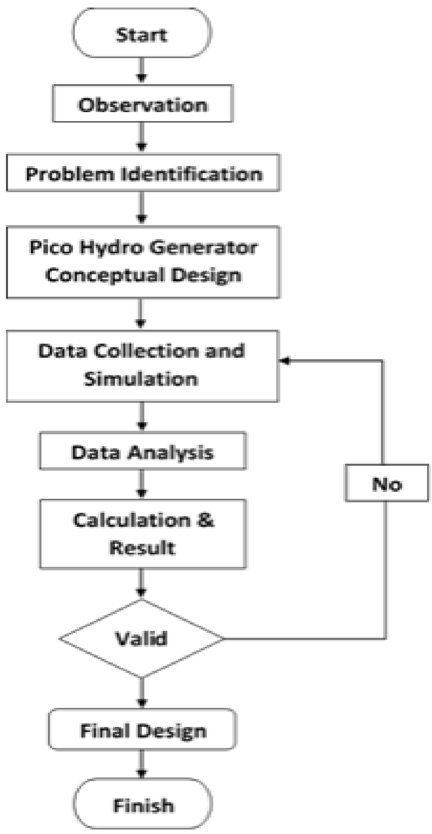

Figure 1. Flowchart of the method

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3. RESULT AND DISCUSSION

3.1 *Collection Data with CFD*

In collecting this data, the author took one of the examples to be used as a data reference on the specifications of hydroelectric turbines with Francis type and used ANSYS software to conduct simulations. The data that will be taken through the simulation is the torque value on the turbine. In addition to that, a simulation in three dimensions will be performed on the flow of the fluid. The gathering of data is intended to determine the efficiency of the turbine by analyzing the power that is input and the power that is produced by the turbine simultaneously. With the CFD (Computational Fluids Dynamics) method, the authors can conduct more in-depth fluid flow simulations, including measurement of flow velocity and pressure distribution around the turbine runner. Figure 2 exhibits an image of the turbine that the author will use in the analysis.

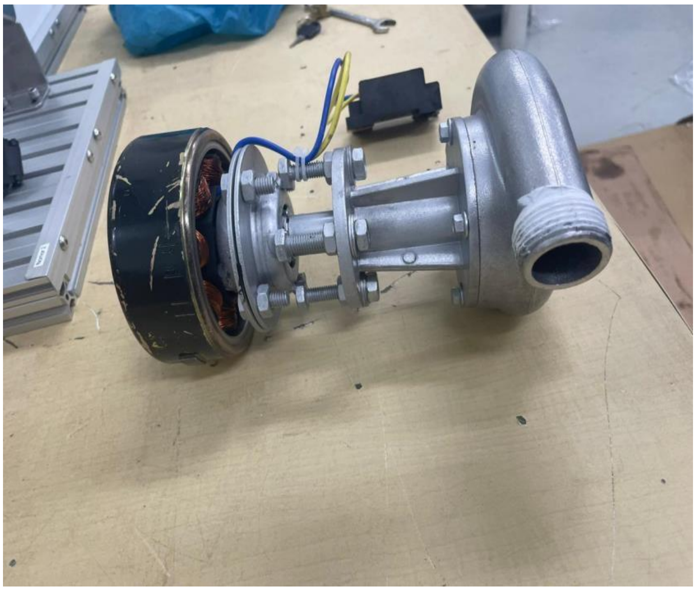

Figure 2. Picture of the francis turbine model coupled with electric generator

3.2 *Creating the Geometry*

To begin data collection using ANSYS software, the author created a geometry in ANSYS Design Modeler. Starting by determining the surface to fill the fluid in the turbine. In the process of creating this geometry, the authors defined two domains: the fluid domain and the impeller rotation. At this stage, there are three main parts after making the domain: Casing (the outer part of the turbine), fluid (which indicates the volume of fluid inside the casing), and rotation (which indicates the rotating part of the impeller). The geometry created in ANSYS is shown in Figure 3.

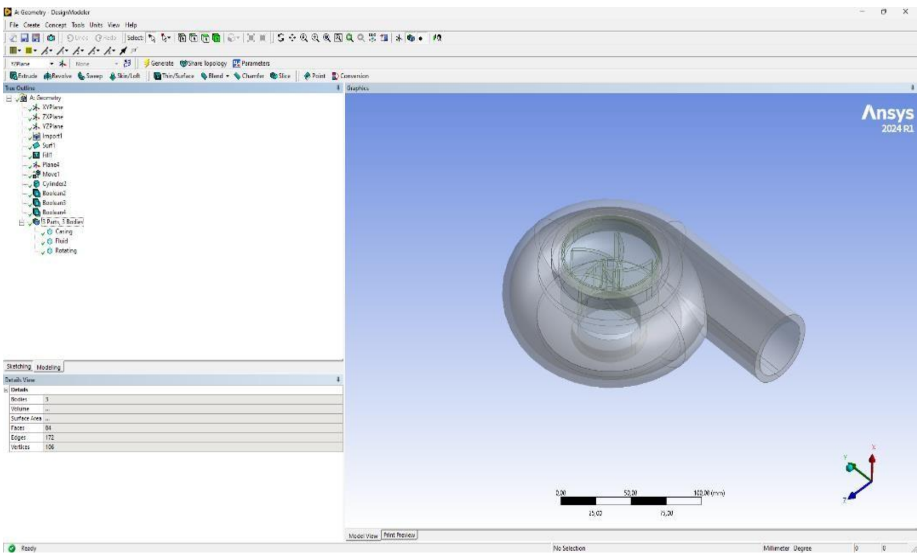

Figure 3. The turbine geometry created in Ansys

3.3 *Meshing Process*

After creating the geometry, the next step is meshing, which is the division of an object. The size of the division should be smaller, and the results produced will be more accurate. Nodes are points that connect elements. At this stage, the author used an element size of 10 millimeters. It has been determined that there are 18932 nodes that have been created, and there are 87372 elements. The meshing result is shown in Figure 4 and the meshing statistics is shown in Figure 5.

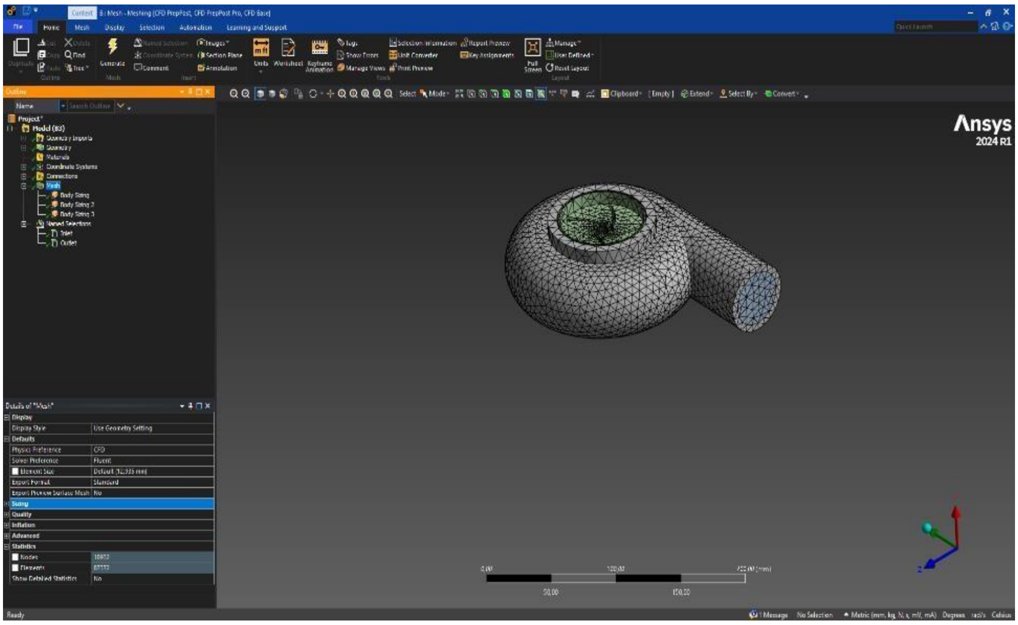

Figure 4. The meshing result

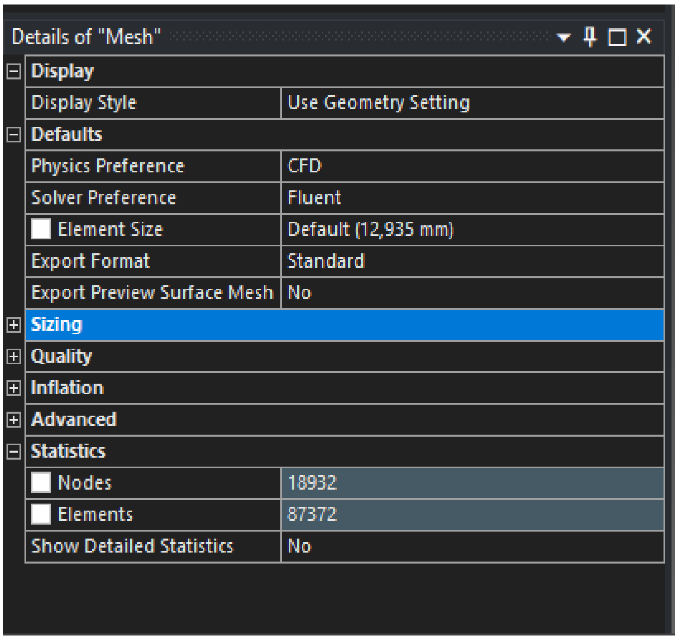

Figure 5. Details of statistics mesh used

3.4 *Create the Boundary Conditions on Geometry (SETUP)*

At this stage, the required boundary conditions are identified, including the type of fluid, its characteristics, and other limits. The data entered will be used as a calculation parameter, the more boundary conditions are entered, the more accurate the calculation results will be.

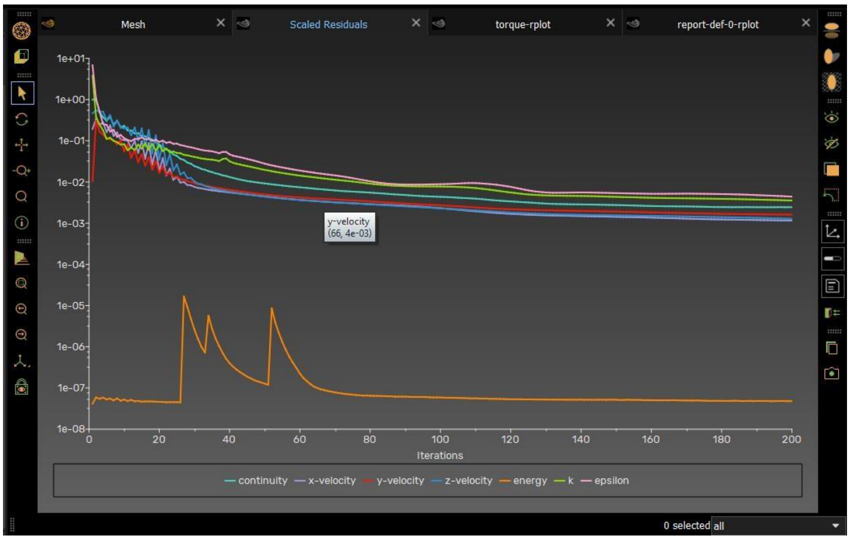

Figure 6. Graphic of scaled residuals

The graph in Figure 6 shows a straight line, and that line shows convergent. This stage is also carried out to determine the torque value of the turbine. The torque value after being set at the condition limit was obtained at a value of 2.85 Nm, which is the result of analyzing the fluid energy that flows to the turbine blades. Figure 7 shows the energy and flow of the type of fluid of the impeller rotation chart that has been determined.

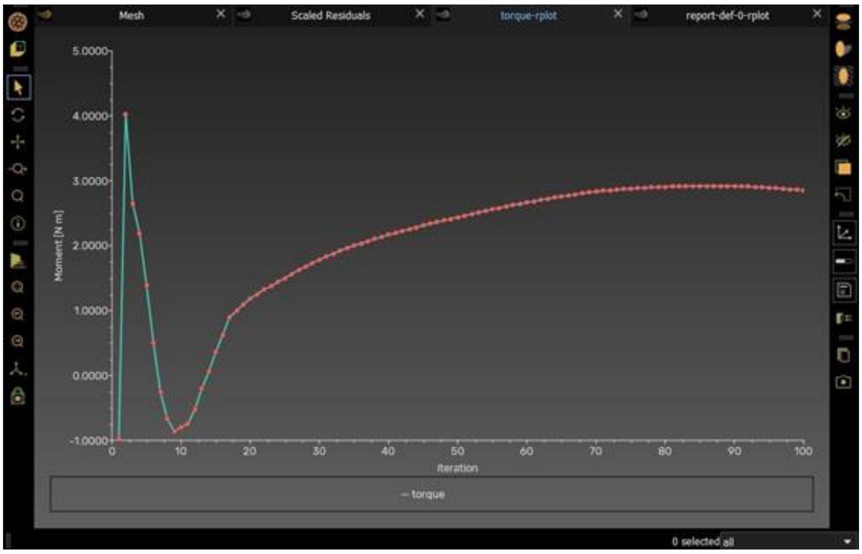

Figure 7. Graphic of torque

In the graph, it can be seen that there are 2 lines, namely the X axis and the Y axis. The two lines explain the value of data retrieval, for the X axis line shows how many iterations occur on the turbine when the calculation is carried out and on the Y axis shows the moment value in Nm.

3.5 *Reading of Result Process*

At this point, ANSYS software is used to display the results of the Computational Fluid Dynamics (CFD) simulation, which will display the fluid flow around the turbine with various parameters. This visualization consists of streamline, contour, vector, and iso- surfaces, which provide a detailed description of the fluid flow characteristics. The streamline depicts the path of the fluid particles using a variety of colors that indicate velocity, and the contour shows the distribution of fluid velocity along the domain, with a variety of colors that make it easy to distinguish high and low-velocity areas. The direction and magnitude of the fluid velocity are given by velocity vectors displayed in the form of arrows within the simulation domain. However, the ISO surface shows a three-dimensional surface that connects points with parameter values such as velocity or pressure, which helps understand the spatial distribution of these parameters around the turbine components. Figure 8 exhibits the simulation result.

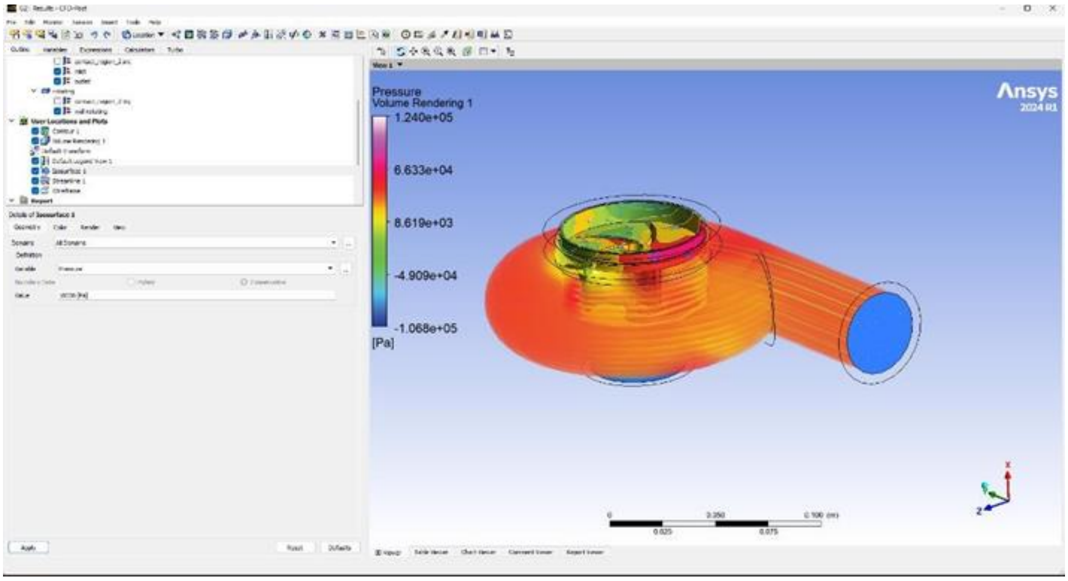

Figure 8. Simulation result

3.6 *Calculation Efficiency Pico Hydropower Simulator*

Before designing with software applications, the author will perform calculations to determine the type and specifications of the appropriate water pump. Based on the data previously obtained, it is possible to perform calculations in order to ascertain the type of water pump that will be utilized as well as its specifications. The table that follows provides information regarding the various types of turbines. Table 1 and 2 show the specification of turbine and electric power generator.

Table 1. Specification and types of the turbine used

Types of turbines	Francis turbine
Turbine speed (n)	3500rpm
Torque	2.85 Nm
Head of water	15 m
Pipe diameter Inlet	25 mm
Water volume flow rate	10 L/s ≈ 0.01 m^3/s

Table 2. Specification of generator

Type Generator	Synchronous
Model Generator	1000 watt
Poles	8
Frequency of Motor	50 Hz

3.7 *Calculation of Turbine Efficiency*

The first calculation is the power input of the turbine using the Fluid Mechanic law formula in this equation [8]:

$$P_{input} = \rho \times g \times Q \times H \tag{1}$$

Then input all the data obtained, but first convert the mass flow rate unit into $m3/s$ using the following formula [8][9].

$$Q_v = \frac{Q_m}{\rho} \tag{2}$$

Therefore, it can be calculated as follows

$Q_v = \frac{5.6\ kg/s}{1000\ kg/m^3}$

$Q_v = 0.01\ m^3/s$

After converting the mass flow rate, then calculate the power input on the turbine as follows.

$P_{input} = \rho \times g \times Q \times H$

P_{input} = $1000\ kg/m^3 \times 9.81\ m/s^3 \times 0.01\ m^3/s \times 15\ m$

P_{input} = 1471.5 watt ≈ 1.47 kW

Thus, the input power generated by the turbine is 1.47 kilowatt. Next, calculate the turbine power output using the following equation formula [7]:

$$P_{output} = \tau \times \omega \tag{3}$$

however, before calculating the power output on the turbine, first calculate the angular velocity using the following formula [8]:

$$\omega = \frac{2\pi}{60} n \tag{4}$$

Therefore, it can be calculated as follows

$\omega = \frac{2\pi}{60} 3500\ rpm$

$\omega = 366.5\ rad/s$

After obtaining the angular velocity value, the power output on the turbine can be calculated as follows

$P_{output} = \tau \times \omega$

$P_{output} = 2.85\ Nm \times 366.5\ \text{rad/s}$

P_{output} = 1044.5 watt ≈ 1.04 kW

Consequently, the turbine is capable of producing 1.04 kilowatts of output power by itself.

After calculating the power input and power output values produced by the turbine, the efficiency value produced by the turbine can then be calculated using the following equation formula [8].

$$\eta_{turbine} = \frac{P_{output}}{P_{input}} \times 100\% \tag{5}$$

Therefore, it can be calculated as follows

$\eta_{turbine} = \frac{1.04\ kW}{1.47\ kW} \times 100\%$

$\eta_{turbine}$ = 71 %

Thus, the efficiency of the turbine is 71 %.

3.8 *Efficiency Calculation of Generator*

Table 3 shows the measurement results for a 1000 watts generator model on a hydroelectric turbine. This table shows the data from the test measurements that will be analyzed to find out at what rotation speed the generator can produce 1000 watts of power.

Table 3. Table of data measurement of the generator

Motor Frequency (Hz)	Voltage
50	235
48	221
46	207
44	195
42	175
40	157
38	139
36	131
34	115
32	105
30	87
28	0

Before calculating the efficiency of the generator, first determine the rotational speed of the turbine by analyzing the generator model. The rotation speed is an important parameter in calculating the efficiency of the generator. Knowing the speed of rotation allows the determination of the exact value of the speed of rotation required to produce 1000 watts of power. This information is valuable because it helps find the optimal spin speed to achieve maximum power. In calculating the rotational velocity, the following equation is used [7].

$$f = \frac{n.p}{120} \quad (6)$$

Therefore, it can be calculated as follows

$$n = \frac{120.f}{p}$$

$$n = \frac{120\ .\ 50}{8}$$

$$n = 750\ rpm$$

Thus, it can be known that the generator can produce 1000 watts at a rotation speed of 750 rpm. By utilizing the data that is already known for the speed and voltage produced by the generator based on test data with the same generator model and calculations, then find the value of the electric current generated using the following equation [11].

$$P = V \times I \ \times cos\phi \quad (7)$$

Therefore, it can be calculated as follows

$$I = \frac{P}{V}$$

$$I = \frac{1000\ watt}{235\ V}$$

$$I = 4.2\ A$$

After knowing the voltage and calculation on the generator using the 1000-watt model. Furthermore, calculations can be performed to calculate the efficiency value of the generator combined with the turbine using the following equation formula [10].

$$\eta_{gen} = \frac{P_{actual}}{P_{input\ turbine}} \times 100\% \quad (8)$$

Therefore, it can be calculated as follows

$$\eta_{gen} = \frac{1000\ watt}{1471.5\ watt} \times 100\%$$

$$\eta_{gen} = 68.5\%$$

Thus, the efficiency value in the generator if presented is 68.5%

3.9 *Result Analysis*

With the efficiency of the turbine and the generator already known, it is now possible to find the overall efficiency of the design of the pico hydropower simulator. This pico hydropower simulator design uses a centrifugal water pump as a water flow to the turbine. In order to give a holistic view of the overall system, one must also determine the efficiency of the water pump.

A relevant article is utilized for reference to ascertain the effectiveness of a centrifugal water pump. As described in the article "How to Define & Measure Centrifugal Pump Efficiency: Part 1" written by Jim Elsey, about the efficiency of a centrifugal water pump, this will set around a maximum value of about 94 percent. But pumping efficiency is size-dependent; small pumps are 55 percent efficient and pump efficiencies of 70 percent require a large pump. [6]

The design of the pico hydropower simulator uses a water pump with a flow specification of 840 liter/minute, which can be categorized as a large pump. Thus, it can be assumed that the efficiency of the water pump used is 70%.

With this information, the calculation of the efficiency of the pico hydropower simulator is carried out as follows:

$$\eta_{pico\ hydro\ simulator} = \eta_{turbine-generator} \times \eta_{water\ pump}$$

$$\eta_{pico\ hydro\ simulator} = 68.5\% \text{ x } 70\%$$

$$\eta_{pico\ hydro\ simulator} = 48.5\%$$

Thus, the efficiency of the pico hydropower simulator design is 48.5%. With this efficiency if we want the output power of 1 kW we need the input power of 2.1 kW.

3.10 *Final Design*

Figure 9 shows the final assembly of the design. This assembly consists of 3 types of parts, namely Pipe installation, Water tank, and Electrical Panel. It contains 95 sections. 2 Inlet pipe installation, 1 Outlet pipe installation, 1 Bypass- pipe installation, 1 Turbine and generator series, Water pump, Pressure gauge, 2 Gate valves, Inverter single phase, 1 Circuit breaker electric, Rotary Switch Padlock, 3 Led lights, 3 Switch on/off, 5 Push button, 1 Emergency Stop, 64 Banana plug, 1 Panel frequency meter, 1 Panel Voltmeter AC, 1 AC Amperemeter Panel, 1 DC Voltmeter Panel, 1 DC Amperemeter Panel, and 1 12 V 33Ah Battery.

Figure 9. Final design of pico hydro simulator

Figure 10 shows the design of the turbine. The turbine is a Francis turbine with a model of 1 kilowatt and a voltage of 220V. This water turbine has a water level capacity, namely a vertical drop of 15 meters with a pipe diameter of 75 mm. This turbine can rotate with a required 10 liters per second and a water discharge pressure of 10 kPa.

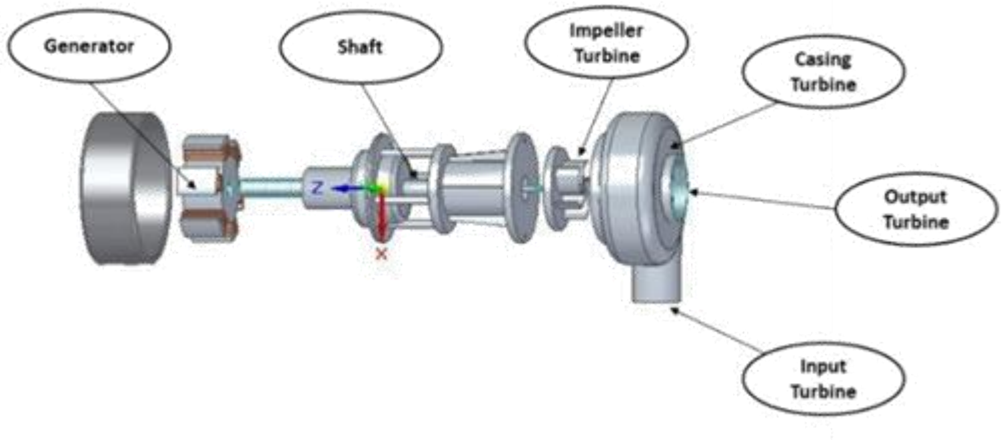

Figure 10. Part design of turbine

The water pump is a type of centrifugal water pump with a 2.2 kW model and can pump 840 liters of water per minute. The pipe installation in the design has 3 parts, namely the inlet water from the water tank, the Main flow water, which is the inlet to the turbine, and the Bypass flow water, which is the discharge of water into the water tank. The piping installation is shown in Figure 11.

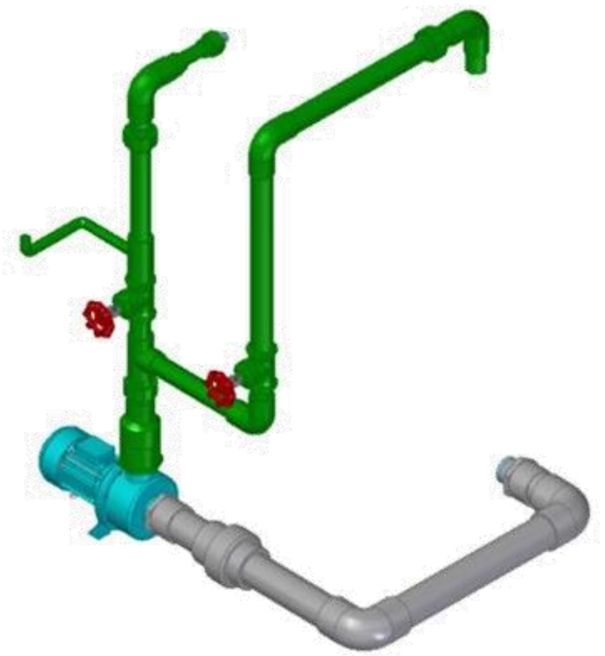

Figure 11. Design water pump and piping installation

While the description of the P&IDs diagrams in Figure 12 is as follows:

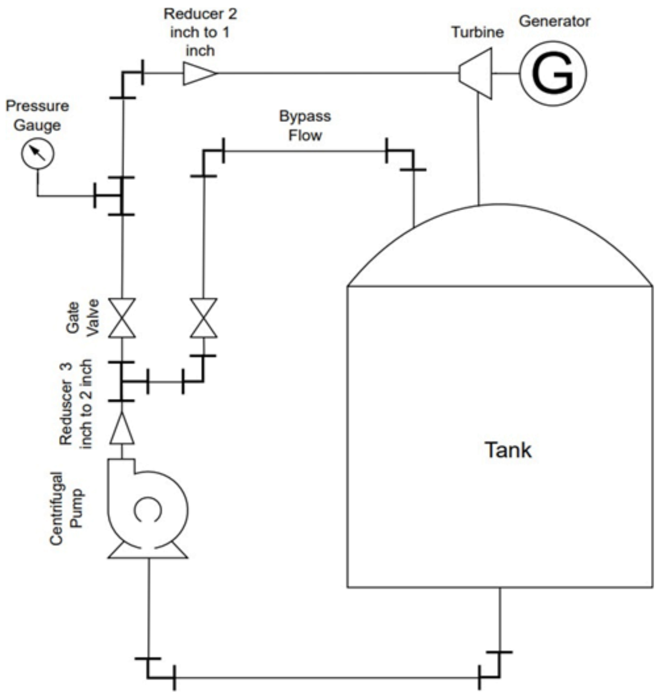

Figure 12. P&IDs of pico hydro simulator

The panel is designed by following the panels in the power plant. The function of the panel is as an auxiliary tool to change the electric current. Turbines produce a type of Alternating Current (AC) electric current where the electric current is unstable and not suitable for direct use in electronic equipment. By utilizing a converter in the capacity of a transformer, the panel in question plays a part in the process of converting alternating current (AC) electric current into direct current (DC) electric current. Because the flow of direct current (DC) electric current is both steady and consistent, it is safe to use in electronic equipment because of its consistent flow. This panel also functions to store power in the battery. In addition, the panel is also equipped with an inverter as a motor frequency regulator on the water pump. The panel design is exhibited in Figure 13.

Figure 13. Design electric panel & battery

4. CONCLUSION

From the results of the overall calculation and analysis of the efficiency of the Pico hydropower simulator design, the following conclusions can be drawn:

1. According to the analysis conducted, the turbine generator efficiency value has an efficiency level of 71% with a power output of 1.04 kilowatts. Meanwhile, the generator produces 1 kilowatt of power at 750 rpm and generates a current of 4.2 amperes, resulting in an efficiency value of 68.5%. This value has been calculated by combining the turbine and generator. Therefore, the overall efficiency of the Pico hydropower simulator design is 48.5%, and
2. The performance of Pico hydropower systems is highly influenced by variations in water flow parameters like discharge and water pressure. These parameters can be switched to optimize the power generated, subject to the limited efficiency of the turbine and generator.

REFERENCES

[1] Renewable Energy Indonesia, “Learning Hub Energi Air – 03 Sept 2024”, Learning Hub Energi Air, 3 Sept. 2024. [Online]. Available: https://renewableenergy.id/energi-air/

[2] P. A. Armi and P. Sepdian, “Prototype Pembangkit Listrik Tenaga Mikro Hidro,” ELTI Jurnal Elektronika, Listrik dan Teknologi Informasi Terapan, vol. 1, no. 1, pp. 28–32, July 2019.

[3] J. Twidell and T. Weir, Renewable Energy Resources, 3rd ed., New York: Routledge, 2015.

[4] M. Nechleba, Hydraulic Turbines, Their Design and Equipment, London–Prague: Artia, 1957.

[5] J. Gulliver and R. Arndt, Hydropower Engineering Handbook, 1st ed., McGraw-Hill, 1991.

[6] J. Elsey, “How to Define & Measure Centrifugal Pump Efficiency: Part 1,” Pumps & Systems, Nov. 05 2020. [Online]. Available: www.pumpsandsystems.com

[7] K. P. Alif et al., “Analisis perhitungan Turbin dan Generator di PLTA Sempor,” Universitas Muhammadiyah Yogyakarta, Bantul, Skripsi/Publikasi internal, 2019. [Online]. Available: https://repository.umy.ac.id/handle/123456789/30286

[8] E. M. Bancin, “Turbin Archimedes Screw di PLTMH,” Skripsi, Universitas Medan Area, Program Studi Teknik Elektro, Fak. Teknik, vol. 1, no. 1, p. 6, 2020.

[9] Rendi et al., “Turbin Air Arus Sungai Model Sudu Propeller Menggunakan Nozzle-Diffuser,” J. Engine, vol. 4, no. 1, pp. 27-33, 2020.

[10] T. Priambodo, “Analisa Perhitungan Efisiensi Daya Turbine Generator Siemens ST-300 7 MW di PTPN XI PG Semboro,” J. Tek. Elektro Univ. Muhammadiyah Jember, vol. 8-9, 2019.

[11] A. Dani and M. Hasanuddin, “Perbaikan Faktor Daya Menggunakan Kapasitor Sebagai Kompensator Daya Reaktif (Studi Kasus STT Sinar Husni),” STMIK R. – AMIK R., vol. 1, no. 1, pp. 673-678, 2018.