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# Water flow simulation in a pelton turbine bucket with variable bucket dimensions using computational fluid dynamic

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**Abstract:** Today, especially among industrialized and developing nations, the usage of renewable energy sources is growing in popularity as a means of supplying energy needs. One of the renewable energy sources that is now being heavily exploited in Indonesia is the potential of water that may be used as a source of electrical energy by establishing a hydroelectric power plant (PLTA). One of the turbines that are frequently used in hydropower plants as a part that may transform water's kinetic energy into mechanical energy is the Pelton turbine. There is not a lot of literature on the design of Pelton turbine buckets. To determine the most ideal bucket dimensions that can be used with Pelton turbines, this study presents the conceptual and experimental components of the design and analysis of Pelton turbines based on bucket variations. AutoCAD was used to model the bucket and Pelton turbine, and ANSYS Fluent was used to perform the simulation so that results could be analyzed later. By comparing the simulated data of blade variants 1 and 2, the ideal blade dimension variation is identified by the blade simulation of variant 1. The blade variation 2 with average torque of 5.859 Nm, average angular velocity of 40.822 rad/s, and average power of 242,970 watts is the most ideal blade. With an average torque of 4,735 Nm, an average corner speed of 40,404 rad/s, and an average power of 196,794 W, the blade 3 model has lower values.

**Keywords**: Pelton turbine; pelton buckets; optimized buckets; turbine simulation; ANSYS Simulation

## 1. INTRODUCTION

Currently, in all countries, renewable energy sources (EBT) have become the main choice in energy development [1]. One of the most promising NRE potentials is water energy. In flowing water, there is potential energy and kinetic energy that can be utilized. Therefore, building a Hydroelectric Power Plant (PLTA) is an important step in utilizing water as a new, renewable energy source [2].

Hydropower is a form of infrastructure that utilizes hydropower to generate electricity [3]. Its working principle is based on the conversion of the potential and kinetic energy of water into electrical energy. To achieve this, a dam is usually built to control the flow of water. These dams form artificial reservoirs or lakes that can hold large amounts of water [4].

When water is passed through a penstock pipe, its potential energy increases significantly. Then, the water flows into the turbine which is connected to the generator. The turbine rotates due to the pressure of the water, and this motion creates kinetic energy which is used to turn the generator and generate electricity. The generated electricity is then channeled through a cable network to households, industry, and other sectors that require electricity supply [5].

Hydropower utilization has many advantages. First, water energy is a naturally renewable energy source. Water that flows continuously can continue to produce energy, so hydropower provides a stable and sustainable supply of energy. In addition, the use of hydropower also does not produce greenhouse gas emissions that damage the environment, thereby helping to reduce the impact of climate change [6].

In Indonesia, the potential for water energy is very large. The country has many rivers, and islands surrounded by oceans offer wave and tidal power generation potential [7]. Utilizing the potential of EBT in water will assist in diversifying energy sources, reducing dependence on fossil fuels, and increasing the country's energy security. To realize this potential, the government needs to encourage investment and development of hydropower in all regions [8]. Good planning is required, including comprehensive water potential research and careful environmental impact analysis. In addition, hydropower development must also pay attention to the sustainability of water ecosystems and ensure the active participation of local communities [9].

By maximizing the utilization of water energy through hydropower, Indonesia can reduce greenhouse gas emissions, achieve energy sustainability, and generate a reliable and sustainable supply of electricity. This step will help meet the country's energy needs and open up new opportunities in the renewable energy sector, create jobs, and promote sustainable economic growth.

Many technologies and innovations have been applied to build hydroelectric power plants that are more efficient, reliable, and by geographical conditions. One important aspect of the development of technology that can adapt to geographical conditions is the use of Pelton turbines. Pelton turbines are specially designed to utilize the impulse principle, where these turbines require significant head height [10].

Pelton turbines work by utilizing a combination of head, speed, and volume of water flow. Its working principle is based on converting the potential energy of water into velocity energy before the water hits and rotates the turbine runner [11]. The pelton turbine is one type of impulse turbine that is efficient in converting water energy into mechanical energy. The working process of the Pelton turbine begins with flowing water through the penstock pipeline at high pressure. Water flows into a nozzle or boundary plate which has narrow holes, which accelerates the flow of water and converts potential energy into kinetic energy. The water coming out of the nozzle at high speed is directed to the Pelton cup which is mounted on the turbine runner. When water hits the Pelton cup, its kinetic energy is transferred to the Pelton wheel. The Pelton cup is designed in such a way that it can efficiently capture the kinetic energy of water. The kinetic energy of the water hitting the Pelton cup causes the Pelton wheel to rotate at high speed. This rotational motion is then used to drive a generator, which produces electrical energy [12].

The advantage of the Pelton turbine lies in its efficiency in converting water energy into mechanical energy [12],[13]. By taking advantage of the high head and precisely directed water velocity, the Pelton turbine can produce high power. This makes it very suitable for use in hydropower in areas with geographical conditions that have rivers or waterfalls that have a sufficient fall height [15]–[17]. The application of Pelton turbine technology is important in the development of an efficient and reliable hydropower plant [18], [19].

Much work has been reported for the design and analysis of bucket shapes that cause changes in water jets, but no research has studied the effect of changing bucket dimensions on the performance of a laboratory-scale Pelton turbine. The research method used in this research is quasi-experimental (modeling experiment) using AutoCAD computer software to create Pelton turbine geometry and ANSYS for Computational Fluid Dynamic (CFD) simulations. Research conducted with this method is more efficient and faster in the process of designing a Pelton turbine. The selection of the semi-elliptical turbine blade model is based on scientific research [20][21][22][23]. The determination of bucket dimensions refers to research [24] with a little adjustment so that the load targeted in this study is expected to be achieved.

This research was conducted to determine the most optimal Pelton turbine bucket that can be applied to Pelton turbines and can be a reference for research with similar topics of discussion. The purposes of this study include: analyzing the causes of failure of the Pelton turbine bucket variation 1, investigating the differences in values obtained from the results of the research on the Pelton turbine bucket variation 3 and variation 2, and optimizing the Pelton turbine bucket for the variations studied.

## 2. METHOD

The method used in this research is a quasi-experimental or modeling experiment using ANSYS Fluent software. The specifications of the Pelton turbine to be studied are: Turbine with a horizontal shaft, has a double nozzle with a diameter of 0.20 m, the number of buckets is 22, the diameter of the runner wheel is 0.22 m, the diameter of the water flow pipe is 0.50 m, and the water fluid is simulated to have a pressure of 100,000 Pascal with a volume flow rate of 0.008 m³/s of water. Variations of the dimensions of the Pelton turbine bucket that will be simulated are shown in **Table 1**.

**Table 1**. Dimensional data of pelton turbine bucket variations

| No. | Bucket Variations | Long (m) | Wide (m) | Thick (m) | Diameter of Jet Circle(m) | Bucket Weight (kg) | Fingers (m) |
|---|---|---|---|---|---|---|---|
| | Variasi 1 | 0,077 | 0,066 | 0,028 | 0,022 | 7,189 | 0,022 |
| | Variasi 2 | 0,070 | 0,060 | 0,025 | 0,020 | 6,727 | 0,021 |
| | Variasi 3 | 0,063 | 0,054 | 0,022 | 0,018 | 6,270 | 0,020 |

The stages in this study include the geometry editing process using AutoCAD. Then enter the Geometry Edit Process stage in ANSYS by first inputting AutoCAD image data that has been created and saved with the "sat" extension into ANSYS then determining Structures and Groups. The structure made in this process is named Rotating Dom for the moving runner structure and Static Dom for the overall casing structure. The groups created in this process are Inlet, Outlet, Case, and Runner. The next stage is the Meshing process using the generates feature on ANSYS Fluent, the next stage is the setup process on ANSYS Fluent by entering variables such as Y-axis gravity of -9.81 m/s², Determining Viscous on the Models menu where in this study it is viscously selected is Spalart-Allmaras (1 eqn), input variable fluid water-liquid with density 998.2 kg/m³ and viscosity 0.00103 kg/(m.s), input boundary conditions inlet with operating pressure 101325 Pa and velocity magnitude 4 m /s and discharge (Q) = 0.008 m³/s, input. The next step in the setup process in ANSYS is checking the Prevent reverse flow option, followed by setting the mesh interface by checking Matching in the contact region and inputting parameters to the dynamic mesh. In Dynamic Mesh, the initial steps to take are to check Dynamic Mesh, Smoothing, Layering, and Remeshing and then enter settings by checking Spring on the Smoothing page, checking Height Based on the Layering page, and copying the values contained in the mesh scale info on the Remeshing page. The next step is to check Six DOF on the dynamic mesh then select settings then select create/edit to create Six DOF Properties. The variables that are input in the Six DOF Properties manufacturing process are giving the name Pelton for the turbine, input the variable weight of the Pelton turbine, checking one DOF rotation, entering the value of axis 1 on the Z axis then proceeding with inputting the moment of inertia using the equation: $I = m.\ R^2$. After the setup process, the next step is the Solution Process which functions to determine the methods by selecting SIMPLE on Scmehe, PRESTO on Pressure, First Order for momentum, Turbulent Kinetic energy, and finally on the Solution Methods process is ticking Warped-Face Gradient Correction. Another solution process carried out in this study is to determine and input the desired report data through the Report Definition and Monitors menu. Another solution process carried out in this study is to determine and input the desired report data through the Report Definition and Monitors menus. 300 timesteps where every 1 timestep = 1 second. The last stage in this research is the Result Process on ANSYS Fluent which aims to be able to determine and see animations from simulations that have been run, both animations from fluids and turbine rotation.

## 3. RESULTS AND DISCUSSION

The output data on the simulation results from ANSYS Fluent in this study are Torque ($\tau$) [Nm], Angular Velocity ($\omega$) [rad/s]. The variables needed in this study in determining the most optimal variation of the Pelton turbine bucket are Torque, Angular Velocity, and Power, where power is obtained by using the equation: $PT = \tau \times \omega$. The data from this study can be seen in **Table 2**, **Table 3**, and **Table 4**. The graphs of the simulation results are shown in **Figure 1** and **Figure 2**.

**Table 2**. Torque data ($\tau$) simulation results

| No. | Bucket | Lowest torque | Lowest torque | Average torque |
|---|---|---|---|---|

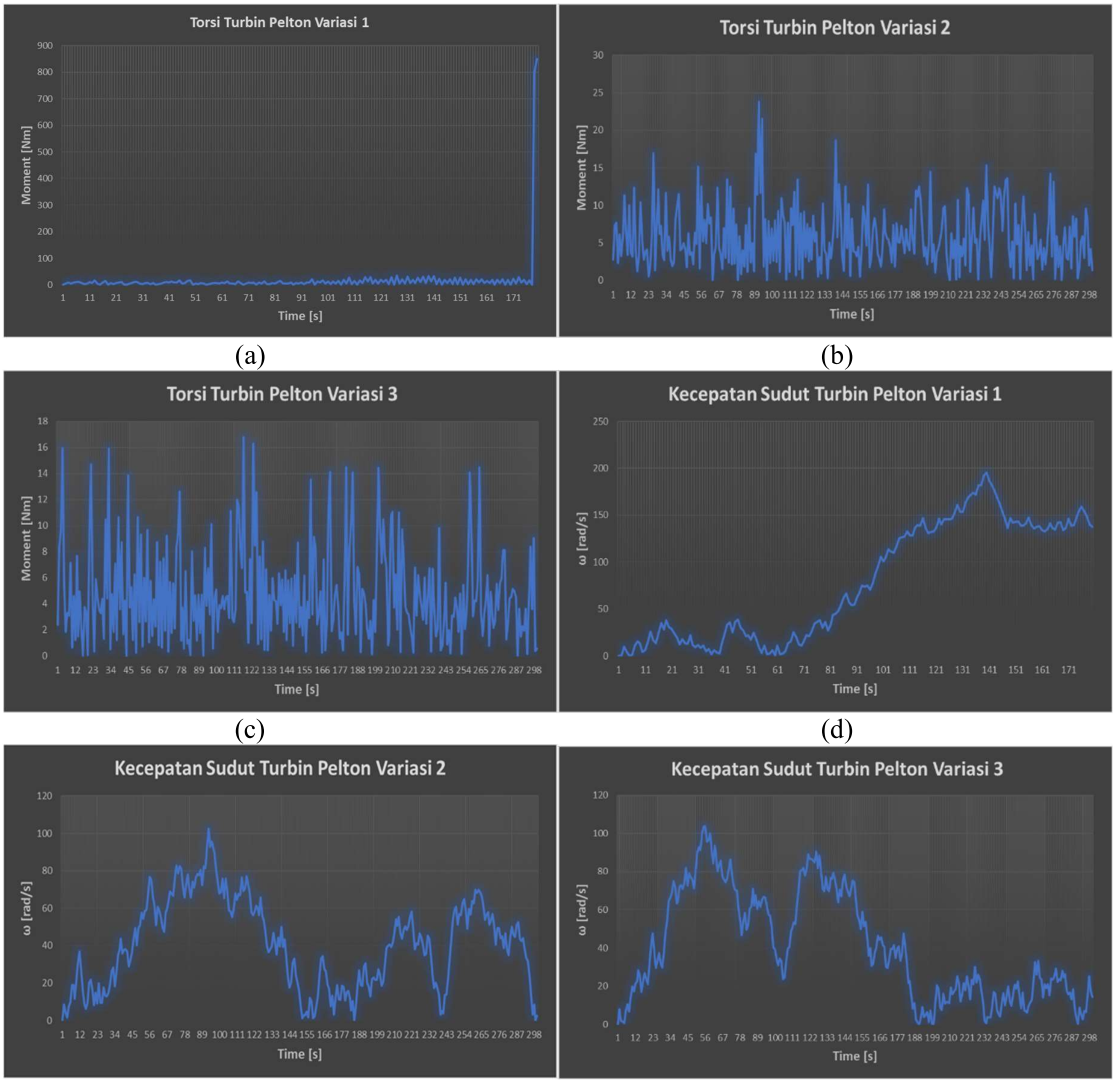
| variation | (Nm) | (Nm) | (Nm) |
|---|---|---|---|
| Variasi 1 | Gagal | Gagal | Gagal |
| Variasi 2 | 0,031 | 23,810 | 5,859 |
| Variasi 3 | 0,002 | 16,791 | 4,735 |

Table 3. Angular velocity data (ω) simulation results

| No. | Bucket variation | Lowest corner speed | Highest angular speed | Average angular speed |
|---|---|---|---|---|
| 1 | Variation 1 | Fail | Fail | Fail |
| 2 | Variation 2 | 0,098 Nm | 102,546 rad/s | 40,822 rad/s |
| 3 | Variation 3 | 0,123 rad/s | 103,916 rad/s | 40,404 rad/s |

**Table 4**. Simulated power data

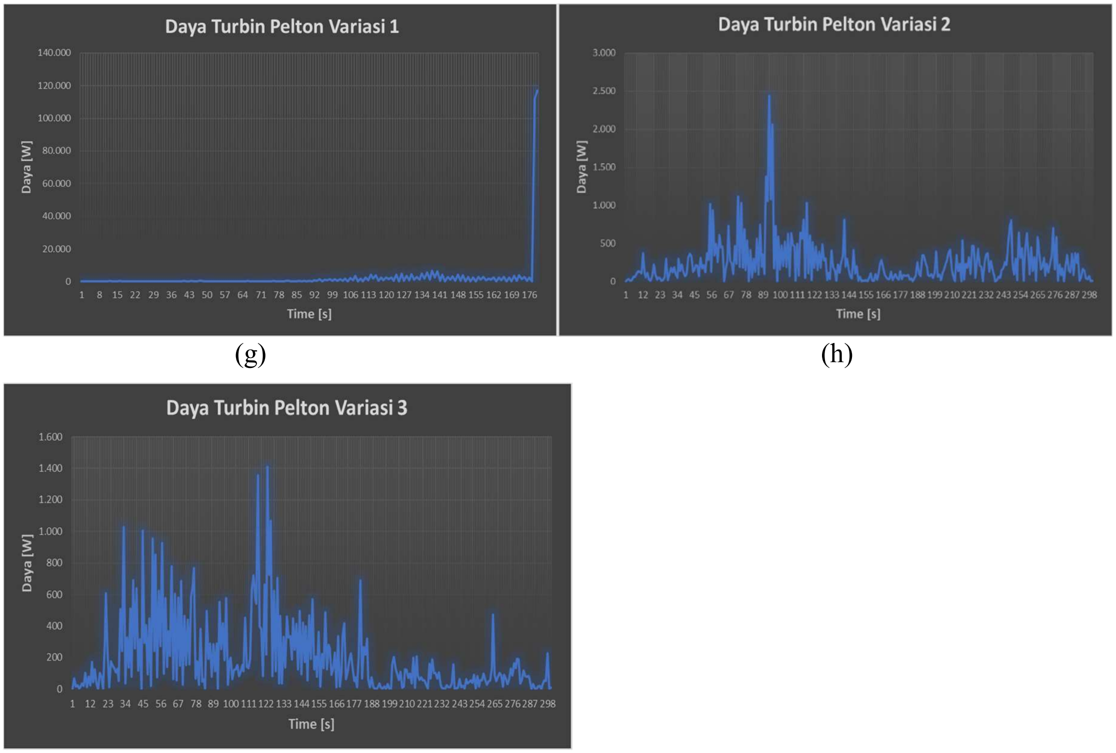
| No. | Bucket variation | Lowest corner Power | Highest angular Power | Average Power |
|---|---|---|---|---|
| 1 | Variation 1 | Fail | Fail | Fail |
| 2 | Variation 2 | 0,408 W | 2.193,847 W | 242,970 W |
| 3 | Variation 3 | 0,129 W | 1.410,934 W | 196,794 W |



(a) (b)

(c) (d)

(e) (f)



(g) (h)

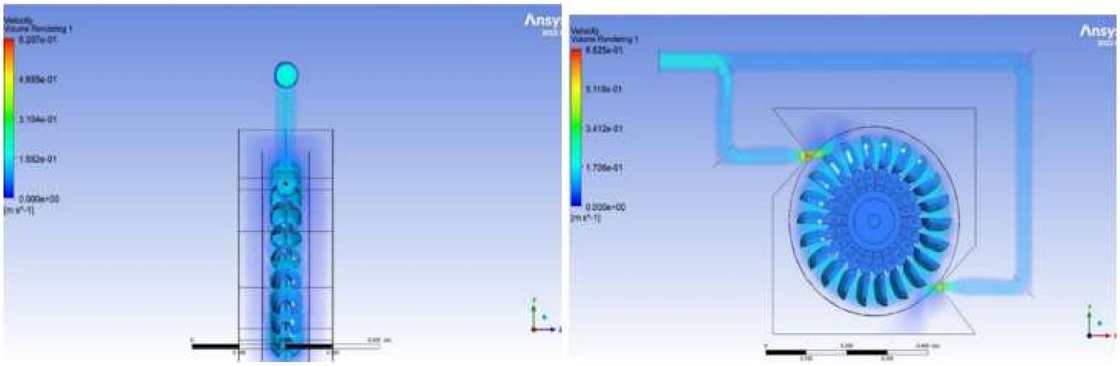
(i)

**Figure 1**. Graph of simulation results

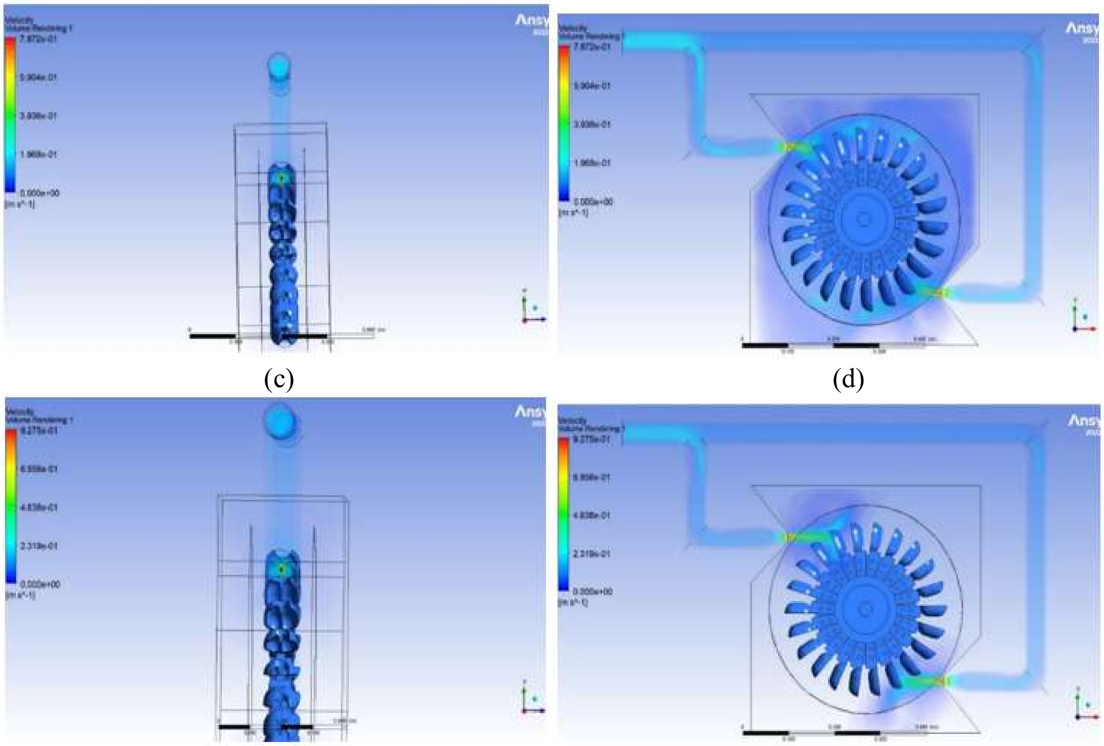
Figure 1. Graph of simulation results: (a) Variation 1 Pelton Turbine torque, (b) Variation 2 Pelton Turbine torque, (c) Variation 3 Pelton Turbine torque, (d) Variation 1 Pelton Turbine angular velocity, (e) Variation 3 Pelton Turbine torque, (f) Variation 3 angular velocity of Pelton Turbine, (g) Power Variation 1 Pelton Turbine, (h) Power Variation 2 Pelton Turbine, and (i) Power Variation 3 Pelton Turbine.

In the variation 1 bucket simulation, the simulation process stops at the 179th timestep which indicates that the simulation for variation 1 bucket failed so that the data obtained in the variation 1 bucket simulation becomes irrelevant. An analysis of the failure of the Pelton turbine bucket simulation variation 1 can be identified by looking at the animation of the simulation results as shown in **Figure 2**.

**Figure 2** animation of simulation results: (a) Pelton Turbine Water Flow 1 side X Variation, (b) Pelton Turbine Water Flow 1 side X Variation, (c) Pelton Turbine Water Flow 2 side X Variation, (d) Pelton Turbine Water Flow Variation 2 sides Y, (e) Water Flow Pelton Turbine Variation 3 sides X, and (f) Water Flow Pelton Turbine 3 sides Variation Y.



(a) (b)



(c) (d)

(e) (f)

**Figure 2**. Animation of simulation results

The simulation of the water flow hitting the Pelton turbine bucket variation 1 did not go well. From the results of the analysis carried out by paying attention to the animation of the simulation results, it can be seen that the water coming out of the nozzle does not perfectly hit the center of the jet circle and the splitter bucket. The next analysis is the jet water from the splitter which has hit the bucket, hitting the bucket in front of it, causing a repulsive force and a lot of fluid trapped between bucket 1 and the other bucket

The Variation 1 Pelton turbine bucket failed because the nozzle diameter was smaller than the Pelton turbine variation 1 jet circle bucket and the gap or distance between one bucket and the other buckets in the Pelton turbine variation 1 was small, namely 0.009 M, where the gap between buckets in the Variation Pelton turbine 2 is 0.015 M and variation 3 is 0.019 M. The diameter of the nozzle is smaller than the diameter of the jet circle and the small gap between the buckets in the Pelton turbine variation 1 causes the collision of water from the nozzle to the bucket to be imperfect because it is blocked by the bucket in front of it, both things it also resulted in the reflection of the water jets from the splitter not completely decomposing the sides of the bucket.

The failure of the variation 1 bucket simulation determines of the most optimal bucket dimension variation lies in the comparison of simulated data of variation 1 and variation 2 buckets. The most optimal bucket is the variation 2 bucket with an average torque value of 5.859 Nm, an average corner speed value of 40.822 rad/s, and an average power output of 242.970 Watts. The bucket variation 3 has a smaller value, namely an average torque of 4.735 Nm, an average corner speed of 40.404 rad/s, and an average power generated of 196.794 W.

The simulation results, of the Pelton turbine bucket variation 2 are better than the Pelton turbine bucket variation 3 because the nozzle diameter corresponds to the jet circle diameter in the variation 2 bucket but is larger than the jet circle diameter in the Pelton turbine bucket variation 3. Another analysis of the data comparison of the Pelton turbine bucket Variations 2 and 3 are larger in the bucket dimensions of variation 2 compared to the bucket dimensions of the Pelton turbine variation 3, thus affecting the ability of the bucket to receive or accommodate the volume of water emitted by the nozzle so that it can convert the water jets into kinetic energy better. This is because the Pelton turbine is an impulse turbine where the thrust of the water volume directly affects the kinetic energy produced.

## 3 CONCLUSION

From the simulation results, it can be concluded that the variation 1 bucket failed at the 179-second timestep, so the data obtained in the variation 1 Pelton turbine bucket simulation becomes irrelevant. The value obtained from the results of the Pelton turbine bucket research variation 3 is smaller than the value obtained in the Pelton turbine bucket research variation 2. All the conclusions and explanations above, the determination of the most optimal Pelton turbine bucket that can be applied falls on the Pelton turbine bucket variation 2.

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