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The Effectiveness of Generated Electrical Power Based on the Water Discharge of Reservoir

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Abstract — Renewable energy has an important role today, one of which is hydroelectric power plants which use water as the main resource. The operation of a hydroelectric power plant generally aims to maximize the water discharge available in the reservoir in order to obtain maximum energy generation. The main driver of hydropower development is the hydraulic turbines. It's a mechanical device that turns the potential energy of water into electrical energy. So researchers are interested in conducting research with the title analysis of the effectiveness of electrical energy based on reservoir conditions. The method used in this research is daily data collection in the form of reservoir elevation level data, outflow, and data on the electrical power generated by the generator. After that, calculate the water volume, hydraulic power, turbine mechanical power along with turbine efficiency, and the efficiency of the generator. Then analyze the values of hydraulic power, turbine mechanical power, electrical power based on water discharge over time. As well as analyzing the efficiency of the generator based on the electrical power that can be generated over a period of one year. Based on research, it is known that an increase in powerplant efficiency occurs after draining the reservoir with a value range of 70% - 72%, because mud deposits accumulate in the reservoir resulting in the reservoir water volume capacity not being optimal.

Keywords: Efficiency, Electrical Power, Hydroelectric Power Plant, Water Discharge, Reservoir.

INTRODUCTION

To be able to meet the electricity needs of consumers, power plants are needed, one of which is a Hydroelectric Power Plant (HPP) which can meet human needs. The advantage of hydroelectric power is the guaranteed availability of electricity for consumers as long as the water supply can be maintained so that the turbines at the plant can continue to operate [1]. Regarding the amount of electrical energy produced by a hydropower plant, it is largely determined by the daily volume of water that can be used to produce electricity at the plan [2]. In determining the advantages of a generator, one of the ways is to look at the availability of water discharge at the hydropower plant. The total energy available from a reservoir is the potential energy that can be generated by the hydropower plant. Therefore, the limit on the availability of water discharge and the amount of water volume stored in the tando pool will

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affect the production of electrical energy that can be generated. Based on operating standards when first operating, reservoir has a maximum water elevation level of 682.50 meters above sea level, and the maximum volume of water that can be accommodated is 116,000 m^3 [3]. The main driver of hydropower development is the hydraulic turbines. It's a mechanical device that turns the potential energy of water into rotational kinetic energy. Hydro turbines are characterized by complex dynamics, with parameters that vary considerably under changing operating conditions [4]. As the hydraulic turbine exhibits highly nonlinear characteristics that vary significantly with the unpredictable load on the unit, this requires controller gain scheduling at different gate positions and speed error [5]. Regardless of the impact of a bump tank and whether or not there is a larger one, the characteristic of turbines and water channels shall be decided by taking into account the rigidity of the gutter and its incompressibility to flow [6].

Hydroelectric power plants rely on potential and kinetic energy from water to produce electrical energy. The process of generating potential water power into electrical energy begins with the utilization of water potential energy or the energy of falling water moving from a reservoir through a penstock that has a slope angle, this potential energy will be converted into kinetic energy. The kinetic energy of this water will move the turbine blades which causes the turbine and generator to rotate on their axis and this process turns into mechanical energy. The generator will convert mechanical energy into electrical energy, this electrical energy will be distributed to consumers [7]. Therefore, the water discharge entering the turbine and the efficiency level of the turbine and generator are factors that influence the production process in a hydropower plant [3]. It's very important for power plants to calculate and analyze the electrical power produced when the water flow is high or when the water flow is low in order to determine the level of efficiency of the plant in producing electrical energy. Measuring the amount of water entering the reservoir and measuring the amount of water flowing through the tunnel to rotate the turbine in the power house are factors that describe how much a generating unit is utilized. In this way, inflow and outflow can be controlled to determine the efficiency of the electrical power produced at the plant [2]. Hydroelectric type reservoir utilizes flowing river water from intake dam going to pool sand for filtering sand/mud carried by water flow. Water then continued going to pool reservoir for damming water, serves to fulfill water supply when the unit will operate in a way full [9]. With the water discharge stored in the reservoir, during the rainy and dry seasons the hydropower plant can operate optimally without interruption [10].

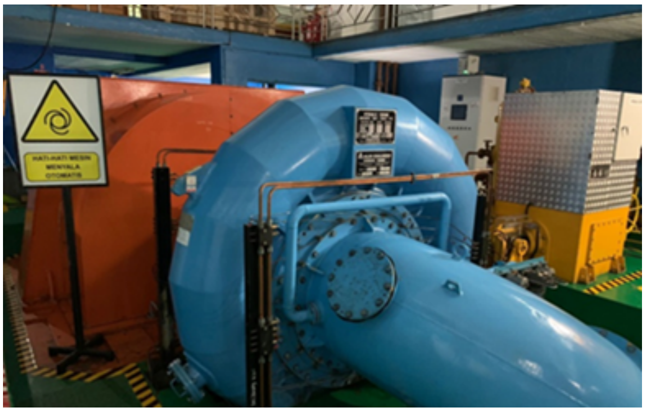

Figure 1. Francis Turbine

There is some power produced by turbine performance, namely hydraulic power and mechanical power, so that the efficiency value of the turbine can be known. Hydraulic power is the power possessed by the potential discharge of water flowing from one place to another which has a potential difference [11]. Meanwhile, mechanical power is the power produced by the rotation of the turbine shaft, which also causes the generator to rotate to produce electrical energy [12].

Figure 2. Generator of Synchronous

Synchronous generators generally consist of three main parts, one of which is the rotor which is a rotating component, the stator is a fixed or stationary part, and the air gap is the space between the rotor and the stator. The combination of rotor rotation in the magnetic field produced by the stator, an electromagnetic induction process occurs which produces alternating current in the stator coils. This is what converts mechanical energy into electrical energy [3]. The performance of a hydropower plant will be greatly influenced by the potential water discharge available at the reservoir, when the water discharge value is large it will produce more power and efficiency than when the discharge condition is small. Because the condition of the source cannot always be guaranteed to be at a constant value, therefore, hydropower needs to carry out calculations and analyzes regarding the electrical power produced in various conditions, both when the water flow is high and low. By carrying out these analyzes and calculations, hydropower plants can optimize their operations to achieve higher efficiency and maximize the use of available water resources [13].

METHODOLOGY

Discharge refers to the quantity of water that passes through a specific cross-section within a given time period. The measurement of river discharge holds significant significance in assessing the potential energy that can be generated by hydropower plants. The height and variances in height of falling water in a hydropower plant are influenced by the volume of water inflow into the reservoir and the outflow from it. Water from river Agam streamed from the intake weir through tunnel 1 to the sand trap. Which functions to filter existing sand / mud. After that the water is sent to the pool tando so that water is collected to fill it water supply for unit operation. Then the water flow will goes to the power house and enters the turbine, shaft turbine twist together with the generator shaft to produce electrical energy. Tail race is part final from system water flow in hydropower plants [17].

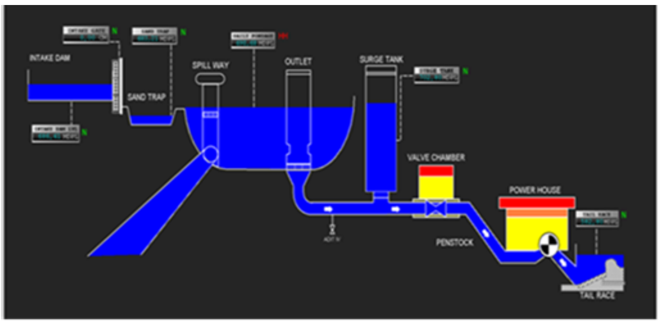

Figure 3. The Batang Agam Hydroelectric Power Plant

A. Outflow Discharge Measurement

Based on measurement data from the Batang Agam hydropower operator, it can be seenthat the outflow discharge value fluctuates from day to day. This plant has an SOP that records are calculated for 24 hours. The outflow that enters every hour to power house will produce hydraulic power become turbine power input.

B. Determining Hydraulic Power

Hydroelectric power is a form of power change from hydropower with a certain height and flows into electric power, using a water turbine and a generator. Therefore, the power generated is dependent on the high and flowrate of the water Hydraulic energy occurs when the water will enter the turbine pass penstock that has slope and result happen friction. To find out this hydraulic power, it can be determined using the following equation [12]:

$$P_{hid} = \rho * g * Q * H \quad (1)$$

Where is P_{hid} is hydraulic power (Watt), ρ is density of water (kg/m³), Q is water discharge (m³/s), H is water fall height (m). Penstock located beside building powerhouse who owns 240 m long as well slope as big as 70̊. Slope This penstock causes exists water friction when pass penstock and resulting exists mark factor slope (η = 0.9), that mechanical energy occurs consequence water potential. The effective head value of the Hydroelectric Power Plant Batang Agam namely 98.7 m then it will hydraulic energy is obtained.

C. Determining Turbine Mechanical Power

The turbine output power is shaft power because the purpose of the turbine is to convert kinetic energy from water into mechanical energy. To determine the mechanical power of the turbine, it can be determined using the following equation [12]:

$$P_m = 2 * \pi * n * T/60 \quad (2)$$

Where is P_m is turbine mechanical power (Watt), n is turbine rotational speed (rpm), T is torque (Nm). Water turbines have role Main in converting water energy into mechanical energy, which is then converted into electrical energy by a generator [18]. Hydroelectric water turbines consist of several components, with moving parts known as a rotor, temporary the silent part is known as a stator [14].

D. Electric Power Measurement

Batang Agam Hydroelectric Power Plant has three turbine and generator units with a capacity of 3 * 3.5 MW to produce electrical energy. The electrical energy produced will be distributed through 4 feeders. In producing electrical energy, all three units are not always operational because the units will operate depending on the amount of water available in the holding pond, so that within a day the unit operations can take turns or operate fully. At the Batang Agam Hydroelectric Power Plant, when recording operations, this plant has an SOP that records are calculated for 24 hours.

E. Turbine Efficiency

Turbine efficiency has a variable value, this is caused by load conditions and the type of turbine. In calculating turbine efficiency, you can compare the value of turbine mechanical power with hydraulic power [12]:

$$\eta = \frac{P_m}{P_h} * 100\% \quad (3)$$

Where is P_m is turbine mechanical power (Watt), P_h is hydraulic power (Watt). Turbine efficiency has a variable value, this is caused by load conditions and the type of turbine. In calculating turbine efficiency, you can compare the value of turbine mechanical power with hydraulic power.

F. Mechanism for Hydropower

In a generator system, performance efficiency is the percentage of generator performance in the form of a comparison of the amount of power successfully generated by the generator to the hydraulic power, with the following formula [15]:

$$\eta\% = P\,out/P\,i * 100\% \quad (4)$$

Where is P_{out} is electrical power (Watt), Pin is hydraulic power (Watt). The input power referred to here is the hydraulic power entering the turbine which has been calculated in the previous stage, while the output power is the power generated by the generator.

RESULT AND DISCUSSION

A. Hydroelectric Energy of Batang Agam

Hydroelectric Power Plant uses water from the Batang Agam River as water source. The water from river Steam Agam streamed from the intake weir through tunnel 1 leads to the sand trap. Which functions to filter existing sand/mud. After that the water is sent to the pool tando so that water is collected to fill it water supply for unit operation. Then the water flow will go to the power house and enters the turbine, shaft turbine twist together with the generator shaft to produce electrical energy. Tail race is part final from system water flow in hydropower plants.

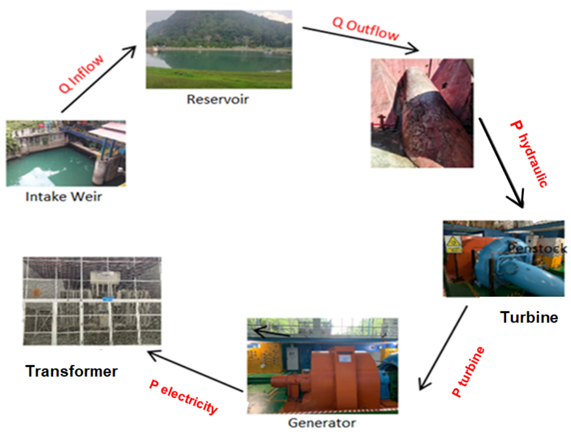

Figure 4. Batang Agam Hydroelectric Power Generation System

B. Outflow Discharge Calculation and Analysis Result

This research has observed the amount of water discharge entering the power house from the reservoir for one year starting from April 2022 to April 2023. Based on measurement data from the Batang Agam hydropower operator, it can be seen in Figure 5 that the outflow discharge value fluctuates from day to day.

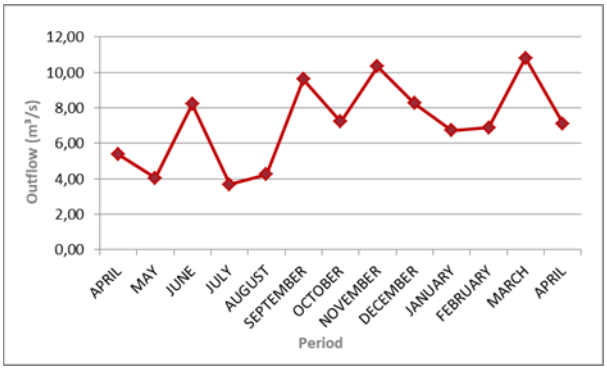

Figure 5. Daily Outflow

Based on Figure 5, in March 2023, the highest monthly outflow debit water volume occurred with a value of 10,82 m³/s, while the lowest monthly outflow occurred in July 2022 a value of 3,68 m³/s. So that obtained mark fluctuation between mark lowest and highest amounting to 7,14 m³/s. Outflow debit fluctuations that occur from time to time, this is the same as the cause daily water volume fluctuations, where the inflow value flowing into the reservoir also varies from time to time so that influence big the value of the water that can be obtained used by the generator so that it can producing electrical energy.

C. Analysis of The Effect of Discharge on Hydraulic Power

Figure 6 shows the monthly discharge and hydraulic power. This shows that the increase in discharge value is directly proportional to the increase in hydraulic power value. The lowest discharge occurred in July 2022 with a value of 3.68 m³/s, and only generated 3,469 MW of hydraulic mechanical power. Likewise, the highest monthly discharge occurred in November 2022 with a value of 10.38 m³/s, which succeeded in generating hydraulic mechanical power of 6,688 MW.

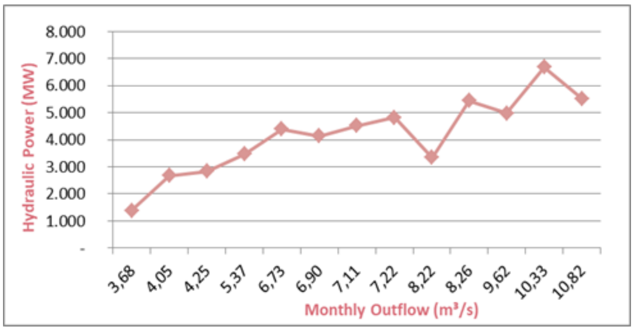

Figure 6. Influence of Discharge on Hydraulic Power

The factor that causes the above to happen is the amount of water flowing into the powerhouse. During the dry season, the volume of water flowing from water sources is also small and causes the hydraulic mechanical power generated to be at its lowest point. On the other hand, during the rainy season, the volume of water flowing from water sources causes a lot of hydraulic power to peak. So it can be concluded that the relationship between water discharge and hydraulic power is directly proportional.

D. The Effect of Discharge on Turbine Mechanical Power

Figure 7 is the monthly discharge value and turbine mechanical power. This shows that the increase in the discharge value is directly proportional to the increase in the mechanical power value of the turbine. The lowest discharge occurred in July 2022 and the turbine only generated 1,161 MW of power. Likewise, the highest monthly discharge occurred in November 2022 which succeeded in increasing the mechanical power of the turbine by 5,565 MW.

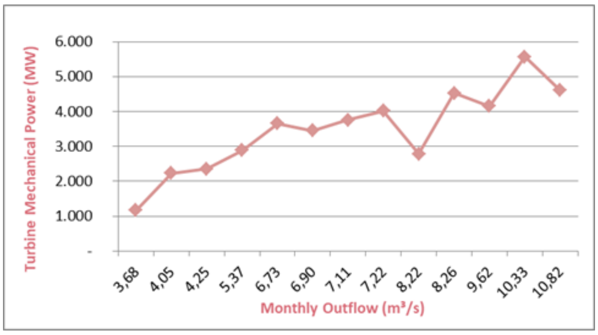

Figure 7. Influence of Discharge on Turbine Mechanical Power

The factor that causes the above to happen is the amount of water flowing into the powerhouse. When the outflow entering the turbine has a large discharge capacity, the turbine will produce greater power than when there is little discharge entering the turbine. So, it can be concluded that the relationship between water discharge and turbine mechanical power is directly proportional.

E. The Effect of Discharge on Electric Power

Figure 8 shows the monthly discharge value and the power generated by the generator. This shows that the increase in the discharge value is directly proportional to the increase in the generator power value. The lowest discharge will occur in July 2022 and the generator can only generate 949 MW of power. Likewise, the highest monthly discharge occurred in November 2022, which succeeded in raising generator power by 4,779 MW.

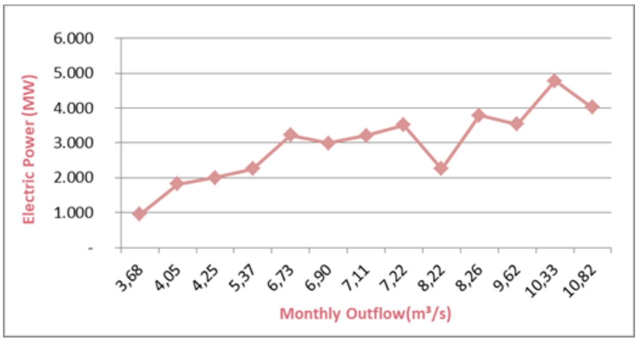

Figure 8. Influence of Discharge on Electric Power

When the discharge entering the generator has a large discharge capacity, the generator will produce greater power than when the discharge entering is small. It can be concluded that the relationship between water discharge and generator power is directly proportional.

F. Turbine Efficiency Result and Analysis

Figure 9 displays the turbine efficiency for one year, this efficiency shows how well the turbine can convert mechanical energy into electrical energy. Based on the curve in Figure 9, it can be seen that the turbine works in the range of 83% to 87%. With monthly turbine power data for one year, it is known that the constant turbine has a work efficiency in the range of 83%.

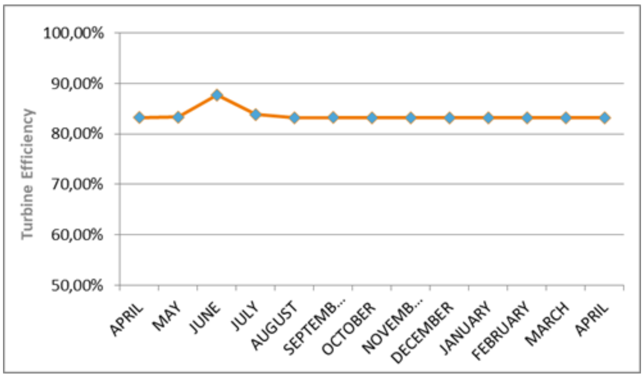

Figure 9. Turbine Efficiency

Friction between the water and the penstock wall can reduce the speed of water flow. This friction factor causes some mechanical energy to be lost, thereby reducing the amount of energy produced by the turbine. Therefore, the greater the water friction factor, the lower the input energy transfer efficiency of the turbine. Optimizing the slope of the penstock can reduce the water friction factor so that the mechanical energy produced by water tension can be maximized and plant efficiency can also increase.

G. Result and Analysis of Power Plant Performance Efficiency

Figure 10 displays the turbine efficiency for one year, this efficiency reflects how effective the generator is in converting water discharge into electrical power. Based on Figure 10, it shows that the Batang Agam Power Plant has the highest efficiency in March 2023 with a value of 72.57% and the lowest efficiency in April 2022 with a value of 64.57%. The average efficiency for one year is 69.95%. Low efficiency values can be caused by several interrelated factors such as fluctuations in water discharge, generator operation patterns, and the efficiency of the generator's turbines and generators.

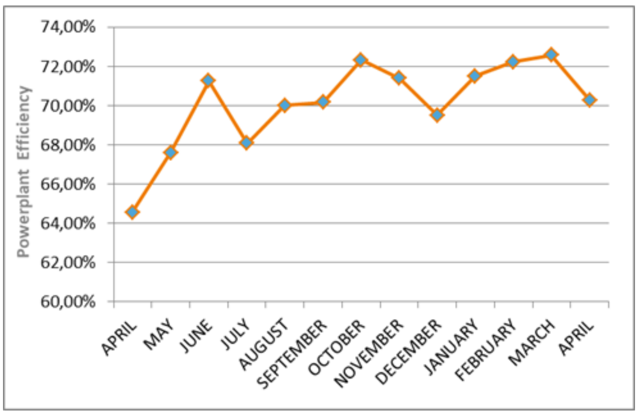

Figure 10. Power Plant Performance Efficiency

It can be seen in the generator performance efficiency curve, in August 2022 to April 2023 the generator performance efficiency is relatively in the range of 70%, which is where the generator performance efficiency is more effective than in the period April 2022 to July 2022. One of the causal factors is, in June 2022 and July 2022, maintenance will be carried out on the reservoir, in the form of draining the mud in the tando pool. Because there is still mud that has not been filtered in the sand trap, the flow of water stored in the tando pool is still carrying mud, as a result, mud is increasingly piling up in the tando pool, resulting in less than optimal water storage in the reservoir.

CONCLUSION

An increase in the outflow value from the reservoir will be followed by an increase in hydraulic power, turbine mechanical power and the electrical power generated. The outflow channeled to the power house will depend on the condition of the water volume available in the reservoir. With an average outflow of 7.12 m^3/s, the Batang Agam Hydroelectric Power Plant succeeded in generating 38,353 MW of electrical power for one year (April 2022 – April 2023). The turbine used by the Batang Agam Hydroelectric Power Plant has an average efficiency of 83.63% for the period April 2022 to April 2023. The efficiency of the Batang Agam Power Plant has a low percentage before the reservoir is drained, which is caused by the accumulation of mud deposits in the reservoir. In June to July, an overhaul of the reservoir was carried out, so that efficiency for August 2022 - April 2023 returned to stability at between 70% - 72%.

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NATASYA INDRA KUSUMA was born on March 26th, 2001 in Baso. She is a college student of the Faculty of Engineering, majoring in Electrical Engineering at the Riau University. She has been at UNRI since 2019. She completed her studies from the University in 2023.