Analysis of Specific Water Consumption Based on Water Discharge Case Study of Batang Agam Hydroelectric Power Plant

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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. So the amount of water is very important for producing every 1 kWh of electricity, this is called specific water consumption. Each hydropower plant has different SWC standards. The research was carried out to determine the SWC value and generator efficiency at the Batang Agam Hydroelectric Power Plant in the period April 2022 to April 2023. The research method was carried out by observing and collecting the required data such as inflow, outflow and daily electrical energy distribution data. Calculate water volume, hydraulic energy and specific water consumption. The research results show that the swc is in the range of 3-4 m^3/kWh, which means this value is below the standard swc value for the Batang Agam Hydroelectric Power Plant, namely 4,808 m3/kWh. This is caused by the unstable condition of the water flow flowing from the river to the Batang Agam Hydroelectric Power Plant which is influenced by rainfall. And based on the electrical energy generated with the distributed electrical energy, the efficiency of the Batang Agam Hydroelectric Power Plant for one year is 71.66%.

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1. INTRODUCTION

One of the main factors contributing to the development of a country is energy. The world has a variety of energy sources, both renewable and nonrenewable. It is considered that renewable energy sources are more environmentally friendly [1]. According to forecasts, renewable energy sources are expected to experience the most rapid expansion within the electricity sector. By 2023, it is anticipated that they will contribute nearly 30% of power demand, a significant increase from the 24% recorded in 2017 [2]. Furthermore, during this time frame, renewables are projected to fulfill over 70% of the growth in global electricity generation [3].

Hydropower, ranked as the third largest provider of global electricity generation, falls behind coal and natural gas in terms of contribution. It plays a crucial role in facilitating low-carbon electricity production, surpassing nuclear energy by 55% and exceeding the combined output of solar and wind energy [4]. Hydroelectric power is a renewable energy source that comes from the flow of water [5]. The main applications of a typical hydroelectric power plant include the generation of electric power, controlling of water flow in the rivers to create pondage, and storage [6].

In general, hydropower plants have essentially five major components: storage reservoir, intake tunnel, surge tank, penstock, and hydro turbine [6]. A typical hydro power plant consists of three parts: an electric power plant that produces electricity, a dam that can be opened or closed to control the flow of water, and a reservoir where water can be stored. The water behind the dam flows through the intake and pushes against the blades of the turbines, causing them to turn. The turbines generate electricity by spinning the generators [7].

How much water drops and how much water moves through the system determines the amount of electricity that can be generated [8].

Indonesia exhibits substantial growth potential, with the potential to emerge as the fourth largest economy globally by 2050. This progress is evident through Indonesia's noteworthy surge in electricity demand, which has exhibited an annual growth rate exceeding 6% since 2000 [9], [10]. Indonesia’s potential energy from hydro for generating electric power is quite immense that is more than 75 GW [11]. Batang Agam Hydroelectric Power Plant is one of the generators in West Sumatra. This power plant utilizes the Batang River Agam as source the water. The Batang Agam hydroelectric power plant, which is a reservoir-type generator owned by PLN, was initially put into operation in 1976 and consisted of 2 generator units. In 1981, an additional unit was installed, increasing the total capacity to 3×3.5 MW. However, with the inclusion of this extra generator unit in 1981, if all 3 units were operated at maximum load, there would be a shortage of water in the tando pond (reservoir), regardless of the high discharge of the Batang Agam river [12].

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 characterised by complex dynamics, with parameters that vary considerably under changing operating conditions [6]. 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 [13]. 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 [14].

The Francis turbines are designed with a specific set of operating conditions which is particularly suited to each hydro power station site. It enables turbines such as these to be able to produce as much hydrokinetic energy as possible, provided that they operate according to the appropriate conditions [15]. Francis turbines feature fixed blades, preventing them to better adapt to available energy and discharge variations, resulting in efficiency loss and the generation of a vortex swirling flow at part load conditions [16] and full load conditions [17]. In addition, when the counter pressure provided by the downstream reservoir water level is low, cavitation may occur. This cavitation may result in a pressure pulsation, which results in wear and tear and vibration leading to an increased risk of failure [18], [19].

The turbine in Fig. 1 used by the Batang Agam Hydroelectric Power Plant is a Francis-type turbine [20]. There is some power produced by turbine performance, namely hydraulic power and mechanical power. Hydraulic power is the power possessed by the potential discharge of water flowing from one place to another which has a potential difference [21], [22]. 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 [20].

Fig. 1. Francis Turbine

Apart from turbines, generators also have an important role in hydroelectric power plants. Hydro generators are commonly evaluated based on continuous duty performance to produce net MVA output at a specific voltage, frequency, speed, power factor, and designated cooling medium temperature. The choice between synchronous or asynchronous generators is determined by the power plant's operation needs and can be tailored to enhance the overall capability of the system [4], [23]. The generator used is a synchronous generator [24]. 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. An electromagnetic induction process is generated by the combination of rotor rotation and magnet field created by a stator. Which creates alternating currents in the stator coils. That's how the mechanical energy is converted into electrical energy [25].

The reliable functioning of the primary electrical equipment of hydroelectric power plants is closely linked to the dependable operation of the electrical equipment currently in use. The assessment of the flawless performance of power transformers at hydroelectric power plants is based on their technical state. This state is determined by both their electrical and non-electrical indicator values [26]. In power plants, the production of medium voltage energy occurs, with levels ranging from 6 to 20 kV depending on the type of alternator being used. To facilitate the connection of these power plants to the electricity network, it is necessary to raise the voltage for the purpose of transportation or distribution at high voltage, depending on the specific network to which they will be connected. To accomplish this, the power plants are equipped with stepping-up substations, with the transformer serving as the primary component [27]. At the Batang Agam Hydroelectric Power Plant, there exist three transformer units which serve the purpose of converting the 20 kV voltage to 380 Volts. These transformers possess a capacity of 125 kVA and are primarily utilized as energy sources for various electrical equipment within the power plant premises. Such equipment includes but is not limited to lighting fixtures, pump motors, compressors, and computers [28]

There will be a significant improvement in the performance of the hydropower plant [29]. When the water discharge value is high, it will produce more power and efficiency than when the discharge condition is low, as a result of the potential water discharge from the reservoir. Because it is not always possible to guarantee constant value for the source condition. Therefore, in order to maximize the use of water resources available, hydroelectric plants should optimize their operation for a better efficiency.

So, process convention water used from water sources will be converted into electrical energy through several stages of energy conversion with the help of mechanical equipment such as turbine, generators, and transformer. The inflow of water into the generating house might be subject to a reduction in the discharge rate due to various factors, including the accumulation of sediment in retention ponds. Another key factor to consider is the impact of water friction that arises along the perimeter of the penstock. The penstock, a tunnel that connects to the power house, encompasses a head which contributes to the decrease in height as water flows through the penstock at a specified angle.

The quantity of water that can be transformed into electrical energy prior to reaching the power house will ultimately dictate the quantity of electrical energy generated. In hydroelectric power plants, there exists a designated value for water consumption. Specific water consumption denotes the quantity of water necessary to generate 1 kWh of electrical energy. At the Batang Agam hydroelectric power plant, the specific water consumption standard during commissioning is 4,808 m^3/kWh, which means that 4,808 m^3 of water is required to produce 1 kWh of electrical energy.

Alterations in individual hydropower facilities may transpire gradually, with the Batang Agam hydropower plant being no exception. It is possible to ascertain such transformations by monitoring the water discharge employed by the plant's powerhouses on a daily basis, as this is the crucial factor enabling the generation of electrical energy. Consequently, the writer conducted a comprehensive analysis by observing the quantity of water emanating from the primary water source (Batang Agam River) and the corresponding cumulative electrical energy output over a year-long timeframe commencing from April 2022 through April 2023.

Based on the given observations, this paper aims to determine the specific water consumption value for each unit of water used in the production of electrical energy. Then determine the efficiency of the hydroelectric power plant based on the energy generated and the electrical energy distributed.

2. METHODS

Batang Agam hydropower plant is a reservoir type hydropower plant [20]. Batang Agam Hydroelectric Power Plant uses water from the Batang Agam River as a water source. Water from the Batang Agam river flows from the intake weir through tunnel I to the sand trap. Sand traps are used to filter existing sand/mud. After that, the water is sent from tunnel II to the tando pool. The water collected in the tando pool functions to fulfill the water supply for unit operation. This is done because if we only use direct discharge from the Batang Agam River, it will not be enough to operate three units fully. Then the water flow will go to the power house and enter the turbine, the turbine shaft rotates together with the generator shaft to produce electrical energy. The tail race is the last part of the water flow system in a hydropower plant where the water that has been used to rotate the turbine will flow into the draft tube which will then be continued to the tail race so that the water will flow back into the Batang Agam River (Fig. 2).

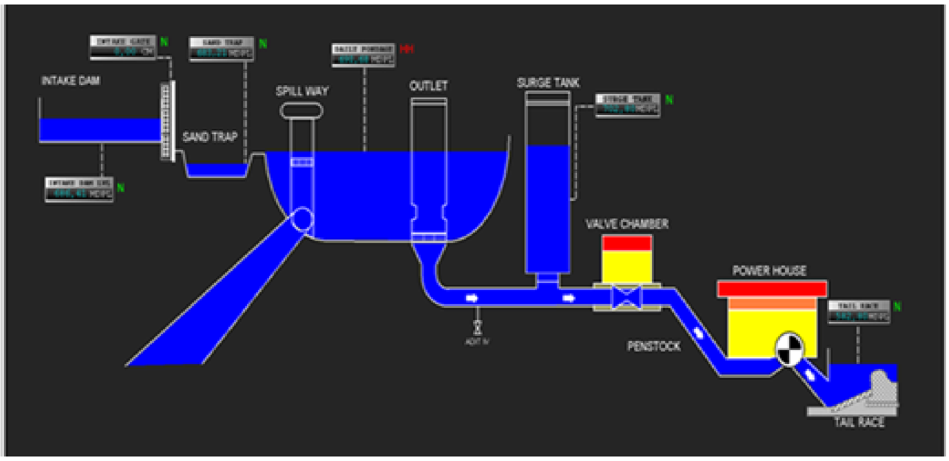

Fig. 2. Working Principles of the Batang Agam Hydroelectric Power Plant

Batang Agam Hydroelectric Power Plant uses a Francis turbine which works to convert rotating water into mechanical energy that will be used by a generator. The power generated by this turbine is 3500 kW with a rotation speed of 750 rpm. Then, the generators used at the Batang Agam Hydroelectric Power Plant are MEIDENSHA type TC-AF AC Generators, totaling three units. This generator is a three-phase generator which has an output of 4700 kVA, voltage of 6300 V, and a frequency of 50 Hz. Additionally, there are three transformer units [30], [31]. The transformers at the Batang Agam Hydroelectric Power Plant are installed with a star connection on the high voltage side and a delta connection on the low voltage side. Based on Fig. 3 here is a diagram illustrating the sequential stages executed for the completion of this paper:

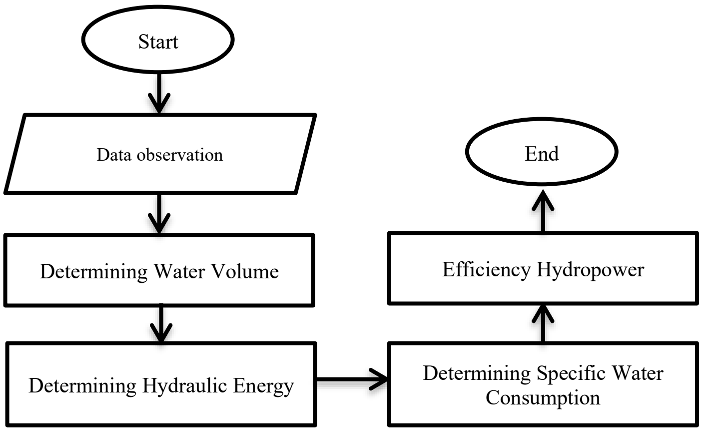

Fig. 3. Flowchart

2.1. Determining Water Volume

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 [32]. 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. An increase in the incoming water flow leads to an elevation in the height and difference of the fall, while a decrease has the opposite effect [33].

$$Q = \frac{V}{t} \tag{1}$$

where Q is water discharge (m^3/s), V is volume (m^3), t is time (s). At the Batang Agam Hydroelectric Power Plant, water discharge values are divided into two types: inflow and outflow. Inflow is the water discharge that enters the holding pond, while outflow is the water discharge that comes out of the holding pond. By recording the debit value measured by the operator, we can determine the debit value every hour. Based on the explanation of formula 1, if the discharge value is known, the water volume value can be calculated. According to the explanation of Formula 1, if the discharge value is known, the water volume value can be calculated by multiplying the discharge value by the unit of time. The volume of water entering the reservoir can be determined by analyzing the inflow, while the amount of water leaving the reservoir can be determined by examining the outflow. In this research, inflow and outflow data have been observed in the period April 2022 to April 2023.

2.2. Determining Hydraulic Energy

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 [34], [35]. Hydraulic energy occurs when the water will enter the turbine pass penstock that has slope and result happen friction [36]. To find out this hydraulic energy, it can be determined using the following equation:

$$P = \rho g h Q \tag{2}$$

where is P is hydraulic energy, ρ is density of water (kg/m³), Q is water discharge (m³/s), h is water fall height (m). At the Batang Agam Hydroelectric Power Plant, penstock located beside building powerhouse who owns 240 m long as well slope as big as 7. Slope this penstock causes exists water friction when pass penstock and resulting exists mark factor slope ($\eta = 0.9$) so that mechanical energy occurs consequence water potential. And by using the effective head value of the Batang Hydroelectric Power Plant Agam namely 98,7 m then it will hydraulic energy is obtained.

2.3. Determining Specific Water Consumption

The hydropower sector stresses the need for the development of a conceptual framework for calculating water consumption with common definitions and methodologies. This is because the current approach does not take into account the benefits of water storage, such as increased water availability. Therefore, it might give a biased picture of the role of hydropower and water storage reservoirs in general [37].The dominant calculation method is the gross evaporation from the reservoirs divided by the annual power production, which appears to be an over-simplistic calculation method that possibly produces a biased picture of the water consumption of hydropower plants [38].

The SWC value is usually calculated based on mark planning the specified optimum as standard value for calculating water discharge used by a hydropower plant [39].

$$SWC = \frac{Q}{W} \tag{3}$$

where Q is amount of water discharge (m³), W is energy (kWh). Every hydropower plant has different SWC values, this is based on potential each generator in the initial design. Batang Hydroelectric Power Plant Agam own decision The SWC value was 4.808 m³ /kWh in the initial design. The calculation of SWC is performed by utilizing the outcomes of water volume calculations derived from first-stage inflow. Subsequently, it is divided by the computed hydraulic energy in the second stage, yielding the SWC value denoting the quantity of water necessary for generating every 1 kWh of electricity.

2.4. Efficiency of Hydropower

Efficiency refers to the optimal ratio between the input entered and the results obtained, both in terms of profit and use of resources. In general, something is considered efficient if there is no waste of resources in carrying out the process, or in other words, if it achieves optimal results. Thus, efficiency involves efforts made by using as few resources as possible while producing the greatest or optimal output [40].

In a generating system, performance efficiency is the percentage of generating performance in the form of a comparison of the amount of electrical energy that can be distributed with the electrical energy that is generated, with the following the equation:

$$\eta = \frac{\text{output}}{\text{input}} \times 100\% \tag{4}$$

with output is distributed electrical energy (kWh), input is generated electrical energy (kWh). The input energy referred to here is the hydraulic energy that has been calculated in the previous stage, while the output energy is the energy data distributed to customers. The Batang Agam Hydroelectric Power Plant consists of three turbine and generator units, each with a capacity of 3×3.5 MW, dedicated to the production of electrical energy. This energy is distributed through four feeders. However, not all three units are constantly operational as their functioning depends on the availability of water in the holding pond. Consequently, the units operate in a rotation or at full capacity throughout the day. At the Batang Agam Hydroelectric Power Plant, there is a standard operating procedure (SOP) that requires operators to record operations at 24 intervals. This ensures that the electrical energy distributed to the network is documented by the operator every hour.

3. RESULTS AND DISCUSSION

3.1. Analysis of Water Volume

The current water volume is determined by conducting calculations on the inflow values observed during the period from April 2022 to April 2023, as per the research data. Based on Fig. 4, November 2022 the highest water volume occurred with a value of 789,609,103 m3 , while the lowest volume occurred in July 2022 with a value of 261,821,647 m^3. So that obtained mark fluctuation between mark lowest and highest amounting to 527,787,456 m^3. This water volume fluctuation occurs because it depends on the availability of water in the Batang Agam River. One thing that influences the value of river water discharge is rainfall. When rainfall is high, the river water discharge is high, but on the other hand, in the dry season, the water discharge is at a low value. So, this affects the flow of water that will be channeled to the reservoir and causes fluctuations in the inflow value. If long-term water fluctuations occur, they can affect the distribution of water that can be accommodated by the reservoir and affect electrical energy production.

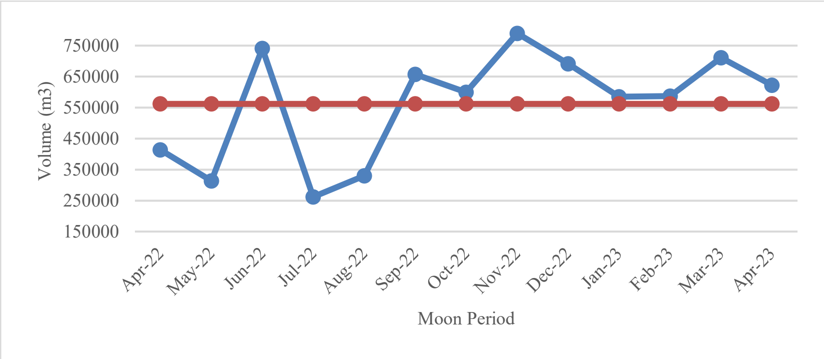

Fig. 4. Water Volume for the Period April 2022 to April 2023

3.2. Analysis of Hydraulic Energy

Fig. 5 provided illustrates a comparison between the hydraulic energy produced by the inflow discharge and the hydraulic energy produced by the outflow discharge from April 2022 to April 2023. It is apparent that the ratio of hydraulic energy derived from inflow and outflow remains relatively stable. This indicates that the quantity of water entering the reservoir from the Batang Agam River and the quantity of water leaving through the penstock may fluctuate at specific intervals. Consequently, it can be inferred that the Batang Agam hydropower reservoir is not experiencing a decrease in depth, which could potentially result from sediment accumulation.

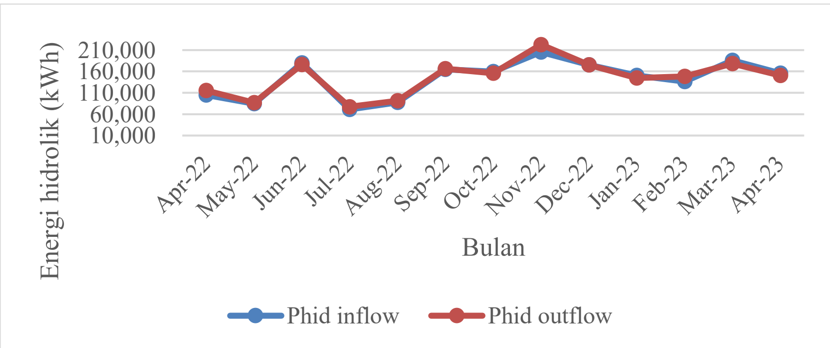

Fig. 5. Hydraulic Energy for the Period April 2022 to April 2023

3.3. Analysis of Specific Water Consumption

Based on Fig. 6, the SWC value is in the range of 3 m^3/kWh – 4 m^3/kWh. Fluctuation This SWC value is caused by the amount of flowing water which also fluctuates from day to day. Highest SWC occurring in April 2023 with a value of 4,170 m^3/kWh. Meanwhile, SWC is the lowest occurring in October 2022 with a value of 3,345 m^3/kWh. High and low The SWC value obtained depends on the amount of water entering from The water source is the Batang River Agam.

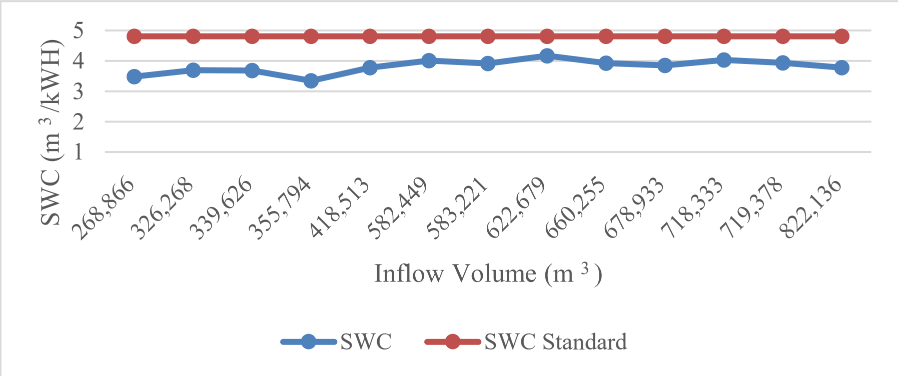

Fig. 6. Graph for Specific Water Consumption

Increases in volume are followed by increases SWC value. However, happen significant decrease _ in a few points. Lowest SWC drop occurred in October with a volume value of 355,794 m^3 producing a SWC of 3,345 m3 / kWh. Meanwhile, SWC is the highest occurring in April 2023 with a volume value of 622,679 m^3 producing a SWC of 4,170 m^3/kWh. This is caused by differences value of the *inflow* volume entering the pool storage and *outflow* pool storage that goes into the powerhouse. So that can conclude that SWC value always is at under *commissioning* SWC value caused by the potential of river water which is no longer suitable for conditions the initial planning will be influence the size of the inflow that will be flows into the pool shelter.

3.4. Efficiency of Hydropower

Fig. 7 shows the percentage of utility efficiency from April 2022 to April 2023. This efficiency is calculated based on input energy or hydraulic energy in comparison to the energy distributed by the Batang Agam hydropower plant. The input energy will always be greater than the output energy, indicating factors that result in a smaller output value, such as air losses during the transportation of air from the source to the power plant.

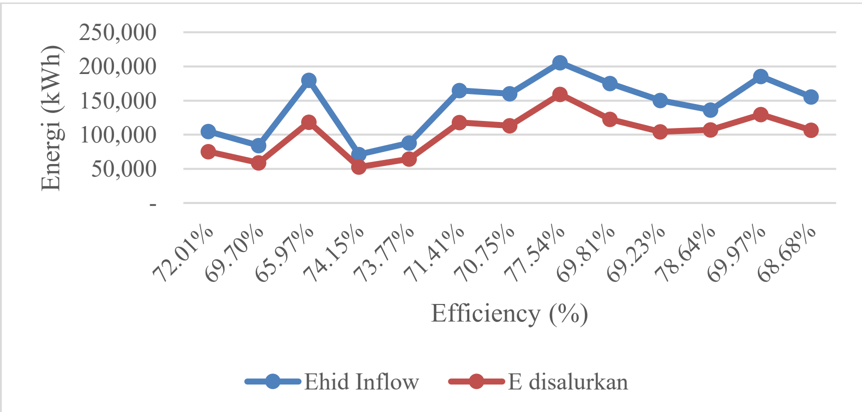

Fig. 7. Hydroelectric Efficiency

Based on the graph, it can be seen that the smaller the difference between the inflow hydraulic energy and the distributed energy, the better the condition of the generator efficiency. This happened in July, where the energy that could be distributed was 52,749 kWh out of 71,135 kWh of potential input energy. This means that 74.15% of the water energy was successfully converted into distributed electrical energy.

This research analyzed the specific water consumption value of the Batang Agam Power Plant. In another research conducted by Tangkilisan in 2015, the specific water consumption value of the Tanggari I Hydroelectric Power Plant in the Minahasa System was also analyzed. In the tankisan research, an increase in the volume value can be followed by an increase in the SWC value, but there is a significant decrease in the SWC value at several points [39]. The research conducted at the Batang Agam Hydroelectric Power Plant showed in Fig. 6 that the increase in water volume values was followed by an increase in SWC. However, there was also a decrease in the SWC value at several points. So, these two hydroelectric shows that the volume value generally causes an increase in the SWC value, but there are several conditions that cause the increase in the volume value to not be followed by the SWC value. This is caused by the overflow of water in the holding pond which causes water to be wasted into the drain, resulting in less water being channeled to the powerhouse.

4. CONCLUSION

The research was carried out from April 2022 to April 2023 at the Batang Agam Hydroelectric Power Plant. The research results show that the highest specific water consumption value in one year is 4,170 m3/kWh, but this value is below the standard SWC value of 4,808 m^3/kWh. The decrease in the SWC value in this study was caused by parameters such as water volume and electrical energy. The volume of water during the observation period experienced fluctuations, which were caused by rainfall. High rainfall will drain a larger volume of water, allowing for the production of greater energy. In this research, hydraulic energy was also observed based on inflow and outflow, which were relatively the same. This shows that the Batang Agam hydropower reservoir did not experience shallowing caused by mud. Therefore, within one year, the Batang Agam Hydroelectric Power Plant is able to reach an average efficiency level of 71.66% based on the energy generated and distributed.

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