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Comparative Study of Generator Efficiency in Hydroelectric Power Plant and Microhydro Power Plant

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Abstract- Generators function as the center of electricity generation in various systems, including large-scale systems such as hydroelectric power plants and small-scale systems such as micro-hydroelectric power plants. Generators require turbines to operate, the turbines are driven by water flowing in the hydroelectric power plant center, utilizing the mechanical energy generated from the fluid flow. The kinetic energy of the fluid is converted into mechanical energy used to rotate the rotor in the generator. The generator can produce an alternating voltage of 25,000 Volts. This process will produce induction when a conductor wire moves through a magnetic field. EMF (electromotive force) with changes in magnetic flux and depends on the type of core and the number of coil turns used. The electromagnet rotates in another set of coils, thus generating electricity in the outer coil device. In hydroelectric power plants, water falling from the dam is used as a source of energy to drive the turbine. Factors that can affect the size of the electromotive force are: the number of turns on the coil, the speed of the magnetic field, and the number of magnetic field lines or flux. The purpose of writing this article is to explain the concept of generator efficiency and compare the efficiency between hydroelectric power plants and micro-hydroelectric power plants. The method used in writing this article is a literature study on the topic of Electromotive Force, one of which is the generator. The generator discussed in this article is an alternating current generator, also discussing the efficiency of the generator at the Wonogiri Hydroelectric Power Plant and the Parakandowo Micro Hydroelectric Power Plant in Pekalongan Regency. The working principle of the electric generator is the electromagnetic induction system. The development of generators for renewable energy power plants can be seen in the use of various types of generatorsr to generate large power, more efficient technology, and environmentally friendly. The efficiency results obtained for the Wonogiri Hydroelectric Power Plant for 7 days, the lowest efficiency was in74.44% occurred when the load was 3.6 MW, while the highest efficiency of 92.85% occurred when given a load of 6.2 MW, while for the Parakandowo PLTMH in Pekalongan Regency it was carried out for 3 days with an average efficiency of 65.33%, this happened because of the weather during the dry season, lack of low water discharge, generator efficiency decreased because it was not operating at optimal capacity.

Keywords: *Efficiency, Electromotive Force, Generator*

1 Introduction

The need for energy is increasing along with the times. One type of energy that is very important for human life is electrical energy. Sources of electrical energy that have been widely used include petroleum, natural gas, and coal, while sources of water, geothermal, solar, and nuclear energy are still being developed (Nugroho, 2023). Hydroelectric power plants (PLTA) are installations that utilize water energy as a resource, by utilizing water flow at a certain height and supporting civil building installations (Hamzah, 2017). Based on the method of damming water, PLTA can be categorized into two. First, run-off river PLTA, which utilizes river flow that is diverted through a dam built across the river. Second, PLTA with a reservoir, where the river flow is dammed using a large dam to store water (Tangkilisan et al., 2015). The power capacity generated by PLTA worldwide is around 675,000 MW or equivalent to 3.6 billion barrels of oil.

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The potential of hydropower that can be optimized by the Indonesian government which has implemented various policies and programs to support the development of renewable energy, one of which is the National Energy General Plan which targets an increase in the contribution of renewable energy in the national energy mix to 23% by 2025, where hydropower is expected to be one of the main contributors (Saidah & Cania, 2024). There is a case in Indonesia, namely water hyacinth plants often cause blockages in water filters and increase the rate of evaporation in reservoirs, which is one of the operational problems in hydropower. Hydroelectric Power Plants with a capacity of less than 100 kW are usually known as Micro Hydro Power Plants (PLTMH). PLTMH are generally built in several villages. In terms of economy, PLTMH can be a profitable solution if the location has a good waterfall, simple civil structure, and other adequate supporting conditions. PLTMH can use a Kaplan turbine with a generator immersed in a water flow to facilitate the synchronization process in parallel operations with an interconnection system using a synchronous generator commonly called an alternator. The working principle of the Micro Hydro Power Plant is highly dependent on constant and consistent water flow, therefore, choosing the right location is a key factor in optimizing the performance of the Micro Hydro Power Plant (Darmana et al., 2024). The existence of this power plant can have a positive impact, namely in the form of maintaining the existence of trees that function as water storage and providing additional benefits in the form of stored water that can be used for agricultural irrigation and providing clean water for the flow of micro hydro power plants (Valipour, 2015).

The development of electric generators began in 1830, when Michael Faraday conducted an experiment on electromagnetic induction. Faraday discovered that the magnitude of the induced current depends on the rate of motion of the bar magnet relative to the coil. Induced emf produces a current whose magnetic field will oppose the change in magnetic flux that causes it (Lenz's Law). The magnitude of the deflection of the galvanometer needle in the electromagnetic induction experiment will be greater if the coil used has a greater number of turns. This shows that the magnitude of the induced emf also depends on the number of turns of the coil affected by changes in the magnetic field. Changes in the magnetic field in the anchor coil, where voltage is generated in the generator, cause changes in energy, when the coil is rotated in a magnetic field, the magnetic field flux through the coil will always change so that an electromotive force appears in the coil (Sani, 2019).

A generator is a device that can convert mechanical energy into electrical energy through magnetic field induction. A generator consists of a stator (the stationary part) and a rotor (the moving part). These two components form a symmetrical and cylindrical magnetic circuit. In addition, a synchronous generator has an air gap between the stator and rotor which functions as a place for the flux of electrical energy from the rotor to the stator (AC Generator Working System Analysis, 2020). Direct current generators have a voltage whose polarity does not change, resulting in more efficient and sustainable energy use. Meanwhile, alternating current generators have a voltage polarity that changes periodically. This generator itself has its efficiency. Generator efficiency is the efficiency that refers to the ability of an electric generator to convert mechanical energy from a turbine into electrical energy. Higher generator efficiency means less energy is lost during conversion and higher electrical power output (Saleh et al., 2024).

2 Research Methodology

The methodology of this research is a literature study, where this article will take 2 research locations, namely the Wonogiri Hydroelectric Power Plant and the Parakandowo Micro Hydroelectric Power Plant in Pekalongan Regency. Hydroelectric power plants (PLTA) operate by converting the potential energy of water in a dam or waterfall into mechanical energy using a water turbine, and then the mechanical energy is converted into electrical energy with the help of a generator. PLTA utilizes the energy from falling water flow to generate electricity. The turbine converts the kinetic energy of falling water into mechanical energy, which is then converted by the generator into electrical energy. The generator is connected to the turbine via gears so that when the turbine blades rotate, the generator also rotates (Hidayat 2019). The generator in PLTA functions similarly to other power plant generators

2.1 Preparation of figures and tables

The following is a compilation of images and tables of turbine-driven generator specifications, used for hydroelectric and microhydro power plant operations. The images and tables are arranged systematically, understanding the concepts to be discussed, and supporting analysis of generator efficiency that can help readers understand the information provided.

2.1.1 Hydroelectric and Microhydro Generator Specification Table

Table 1: Wonogiri Hydroelectric Power Plant Generator Specifications (Oktavian et al., 2021)

Brand	Shinko Electric
Type	FENKL2-AW-3700
Machine No.	092260
Power Capacity	7750 kVa
Phase	3
Electrical voltage	6600 V
Electric current	678 A
frequency	50Hz
Pole	22
Speed	273 rpm
Power Factor	0.9 lag
Power Voltage	220

Table 2: Wonogiri Hydroelectric Power Plant Turbine Specifications (Oktavian et al., 2021)

Brand	Ebara
Type	Vertical Shaft Kaplan
Measurable District	273 rpm
Landasan Pacu Subdistrict	765rpm
Serial No.	RA10138-01

The generator specifications used in the Parakandowo PLTMH, Pekalongan Regency are the MJL 160 MA4 generator, with a measured power of 28KVA, operating at a frequency of 50 Hz and having an input power of 22.4 Kw (Murni & Suryanto, 2021).

2.1.2 Working Principles of Hydroelectric Power Plants and Micro Hydroelectric Power Plants

The following are presented elements of turbines and generators to support the process of efficiency in hydroelectric power plants and micro-hydroelectric power plants to understand how the process of water energy is converted into electrical energy. The images presented begin by recognizing the basic elements of a turbine-driven generator, then images of direct current generators and alternating current generators.

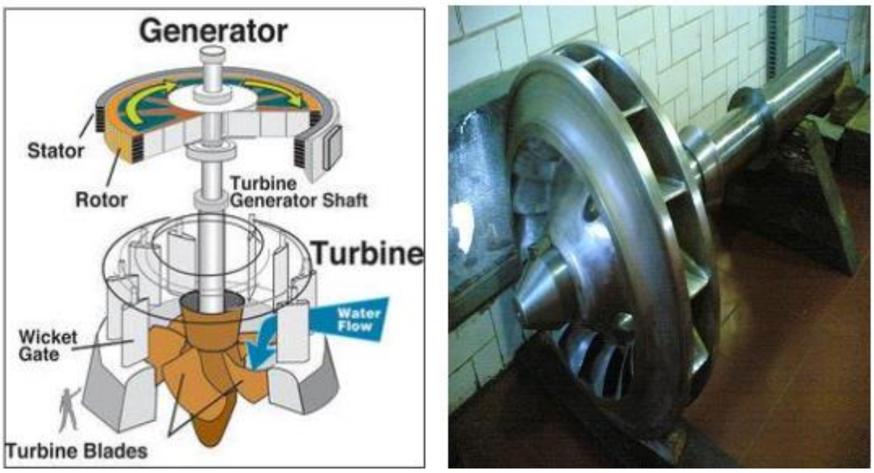

Figure 1: (a) Turbine, (b) Generator (Bucchi & Trench, 2021).

Figure 1 (a) explains that turbines are important devices in hydroelectric power plants, usually large in size and designed to handle large volumes of water, the type of turbine used is the Francis Turbine. Francis turbines are very flexible and suitable for various water flow conditions on a power plant scale. This Kaplan Turbine has adjustable propellers to obtain maximum efficiency, and the Pelton Turbine is a type used in hydroelectric power plants with high water flow (head) and relatively low flow rate working on the impulse principle where the turbine has constant pressure because the water flow coming out of the nozzle has the same pressure as atmospheric pressure. Figure 2 (b) explains that the Generator that works on hydroelectric power plants also has a large capacity and is capable of producing electricity in Mega Watt sizes to be distributed to a wide electrical network. The resulting voltage will be sinusoidal if the magnetic flux density is distributed in the air gap. As for the PLTMH, the turbine used is smaller than that used in hydroelectric power plants. This turbine is designed for smaller water flows. The types of turbines used include Pelton Turbines, Crossflow Turbines with nominal rotation of 100-1000 rpm, and small-scale Kaplan Turbines. The generators used are also smaller and are designed to produce electricity in kilowatts, used to meet local electricity needs or small communities.

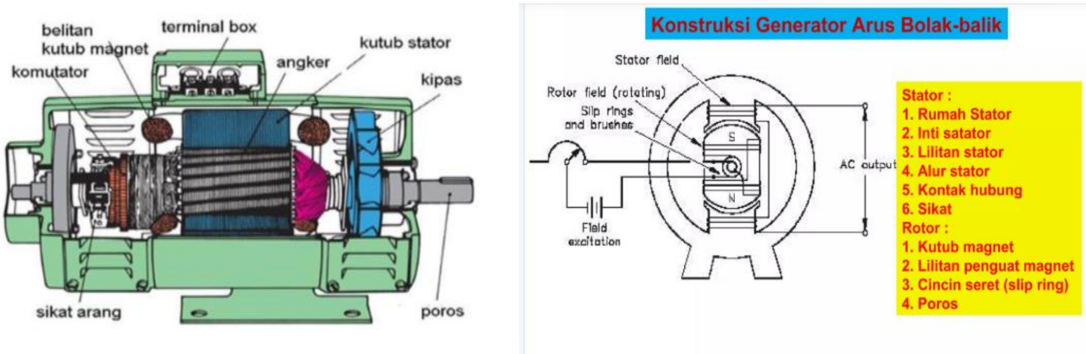

Figure 2: (a) Direct Current Generator Elements, (b) Alternating Current Generator

The generator is connected to the turbine via a shaft and gearbox. According to (Purwantono et al., 2020) generator grouping can be done based on the location or method of placement to withstand axial force or load parallel to the axis of rotation, there are four types of generators, namely:

a) The top of the generator is placed with two guide bearings (stabilize and support the rotating shaft)
b) A guide bearing is placed under the rotor on the umbrella section.
c) The half umbrella section is equipped with a combination of guides placed under the rotor and a second bearing placed above the rotor.
d) The lower support with bearing is placed under the coupling

Figure 2 (a) explains the working principle using the Faraday's Law principle with the function of producing direct current, then supplying electricity needs when the engine is running. If the use of electricity exceeds the capacity produced, the battery will take over some of the electrical load. When the rotor rotates in a magnetic field, there is an interaction between the magnetic field and the wire coils on the rotor. The electromotive force reaches its maximum value when the coil is in a perpendicular position to the direction of the magnetic flux, where the magnetic flux flows from the north pole to the south pole. Conversely, the electromotive force will be at its lowest point if the coil position is parallel to the direction of the magnetic flux (Supardi et al., 2015). The disadvantage of a direct current generator is that the speed is manually controlled, depending on the size of the variable resistor rotation. Its speed cannot be determined with certainty based on the angular velocity (Budiarso et al., 2019). The advantage of a DC generator is its ability to regulate speed stably and smoothly. Physically, it is clear that a DC generator has magnetic poles that protrude when the rotor housing is dismantled. The rotating part in the generator, in the form of a wire coil and supported by a shaft, is called a rotor. At one end of the DC generator is a commutator consisting of copper segments with each end connected to the rotor winding. This commutator requires regular maintenance because it is in direct contact with the carbon brushes, which function to channel electric current from the network to the rotor. The carbon brushes are installed using a brush holder to keep their position stable, while the springs provide pressure so that contact between the carbon brushes and the commutator remains optimal (Hermawan & Andry, 2016).

According to Anthony, 2020, Figure 2 (b) explains that the stator construction consists of several important parts:

a) Frame or axle: made of cast iron, serves to support the anchor core.
b) Anchor core: made of malleable iron or silicon steel.
c) Grooves or trenches and teeth: anchor cores are used to place the coils. The grooves can be of open, semi-closed or semi-open design.
d) Anchor coil: made of copper which is placed in the groove.

The rotor is rotated by the prime mover so that the magnetic field changes continuously in the anchor coil in the stator. This change in the magnetic field produces an induced voltage in the generator anchor coil. The type of magnetic pole on the rotor consists of two parts, namely:

a) Salient or salient pole rotor
consists of a pole core, pole body, and pole shoe. The field coil is wound on the pole body, while the pole shoe is also equipped with a damper winding. The pole coil is made of copper, while the pole body and shoe are made of soft iron.
b) Cylindrical pole rotor (non-salient pole)
It has grooves and teeth which are used to place the field coil.

3 Results and Discussion

Efficiency is basically defined as the ratio between output and input in a process, which indicates how well energy is converted from one form to another (llintamon et al., 2019). The results of the study at the Wonogiri Hydroelectric Power Plant showed generator efficiency for seven days. The lowest efficiency was 74.44% at a load of 3.6 MW, while the highest efficiency reached 92.85% at a load of 6.2 MW. Generator efficiency is influenced by the load current and power used. The load is given to produce electrical power that is in accordance with the specified capacity and can test the performance of the generator. The process of converting mechanical energy into electrical energy in a generator is not completely efficient due to power losses, so that efficiency does not reach 100%. These losses include heat losses in the coil, losses in the generator core, and mechanical losses such as air friction during rotor rotation. As a result, generator efficiency changes during the operational process. Every change in water level also affects efficiency. At higher water elevations, efficiency tends to decrease (Oktavian et al., 2021).

The turbine is a key device in the MHP. The flow of water entering through the channel is guided to the turbine, which then converts the kinetic energy of the water into mechanical energy through the rotation of the rotor. This rotor is a component that connects the turbine to the generator. The generator used is a synchronous generator, because it is difficult to find on the market and is easier to maintain. This generator has a small output power, influenced by the value of the excitation capacitor. When the field coil given an excitation current is rotated at a certain speed, the anchor coil on the stator will be induced by the magnetic flux generated by the field coil, resulting in an alternating electric voltage (Farhan et al, 2021).

The requirements for river flow or irrigation to have the potential for MHP, the first is that the river or irrigation has a discharge or volume flow rate, and the second is that the river or irrigation must have a difference in height (Ramdhani et al., 2019). This case study of the Parakandowo MHP in Pekalongan Regency has turbine efficiency that can be influenced by several factors such as blade cleanliness, turbine geometry, and water flow conditions. Micro hydro power plants are useful in areas that have not been connected to the electricity network, such as small islands and areas at the foot of mountains (Pambudi et al., 2020). The efficiency of micro hydro power plants is influenced by variables such as water discharge, turbine efficiency, and generator efficiency. Large water discharge will increase the efficiency of micro hydro power plants, while in the dry season, when the water discharge decreases, efficiency tends to decrease. The efficiency of the Parakandowo Micro Hydro Power Plant in Pekalongan Regency is influenced by the value of these variables. The results of the study were carried out for 3 days with an average of 65.33%, this shows inefficiency because micro hydro power plants are said to be efficient if the percentage is 70-90% (Murni & Suryanto, 2021). This obstacle can be minimized by combining power distribution with PLN. This is supported by the policy in the Electricity Supply Business Plan (RUPTL), which provides opportunities for small and distributed power plants to connect to the PLN network (Nugroho, 2015).

4 Conclusion

Generators connected to the grid, when the generator starts to channel current to the grid, the frequency, amplitude, and phase of the voltage produced by the turbine must match the grid. Generator efficiency in hydroelectric power plants ranges from 70% to 90%. The efficiency results obtained from the Wonogiri Hydroelectric Power Plant are able to show the efficiency of the generator working well, because the water system from the dam, the water discharge that rotates the turbine to the generator, and in large scale form. The generator efficiency at the Parakandowo PLTMH in Pekalongan Regency has measurement results with a very small average efficiency, because the results obtained occurred during the dry season, resulting in the equipment or system not working optimally at the PLTMH, and a decrease in water discharge. The specifications of the turbine and generator are also different, this depends on the location of the water source, the design and selection of the turbine and generator, the electrical system and the most important thing is the maintenance and periodic checking of the equipment system. Further research is needed to develop more efficient generator technology and obtain optimal measurement results.

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