Performance Analysis of Cone Basin-Based Gravitational Water Vortex Power Plant (GWVPP) by Variations in the Number of Blades

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Abstract: The electricity supply is not evenly distributed for all regions in Indonesia. This is due to the lack of transportation access to reach these areas because of difficult terrain conditions. One of abundant energy sources available in nature is water, which can be used for micro-level power generation. Micro hydro generator usually uses a waterfall with a high head. However, not all of the water flow has a head tall. Therefore, this study proposes a promising prototype of a cone basin-based Gravitational Water Vortex Power Plant (GWVPP). The purpose of this study is to determine the performance of the cone basin-based GWVPP prototype by variation in the number of blades. The vortex turbine is designed with a water flow rate of 169.63 liters/minute and a cone basin with square-shaped blades and variations in the number of blades, namely 2, 4, and 6, with the same turbine blade area of 0.01 m^2. It was found that an increase in the number of blades enhances mechanical characteristics of, *e.g.* torque and rotational speed, as well as electrical characteristics, *e.g.* voltage, current, and electric power. The maximum result is achieved when the number of blades is six with the rated power of 5 mW and the rotation speed of 119.351 rpm.

Keywords: Gravitational Water Vortex; Number of Blades; Microhydro; Turbine Power

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I. INTRODUCTION

Electricity is a source of energy commonly used by humans. Electricity is generated through a power generation system. The generators that are widely used are hydropower power plants, natural gas power plants, steam power plants, diesel power plants, and nuclear power plants. In general, steam and diesel power plants use energy sources in the form of coal or oil earth. Power plants utilize hydro-power as the main medium for propulsion turbine and generator. Technically, a micro-hydro generator has three main components, namely water as a source of energy for turbines and generators. Water flowing with a certain capacity is channeled by a certain height through a rapid pipe to the installation house (powerhouse) [1].

Energy has a very important role for the movement of the Indonesian economy. Among other energy user sectors, industry is the largest energy user sector, especially electrical energy. Not only used in the industrial sector, electrical energy is also used in household, political, and academic. In 2019, the General Plan for the Provision of Electricity (RUPTL) of the State Electricity Company (PLN) stated that it was only able to provide 57% of electrical energy from the total needs of the community [2]. This shows that the supply of electrical energy provided by PLN has not been able to meet the needs of the community. The lack of fulfillment of electrical energy in Indonesia can have an impact on several aspects such as economic, academic, political, and so on [3].

Considering those conditions, it is necessary to develop an alternative renewable energy. Indonesia has great potential for the development of renewable alternative energy, such as by utilizing geothermal energy, solar energy, wind, and water [4]. The role of renewable energy has been recognized as great significance for the global environmental concerns [5]. Hydro power is a good example of renewable energy, and its potential application to future power generation cannot be underestimated [6]. The Gravitational Water Vortex Power Plant (GWVPP) has the greatest potential at low-head sites among other hydro power technologies [7, 8].

In this study, to overcome the shortage of electrical energy in Indonesia, the authors conducted research in terms of the Microhydro Power Plant (MPP) system. One of the MPP systems currently being developed is the GWVPP by analyzing the effect of the number of blades on the turbine performance.

II. METHOD

The design of the turbine in this study was carried out in terms of the design of the turbine blade support pole height, the shape and area of the blade, and the number of turbine blades. For the height of the support pole of the turbine blade, due to adjustment to the height of the existing cone basin, the pile height is 80 cm. Furthermore, the determination of the

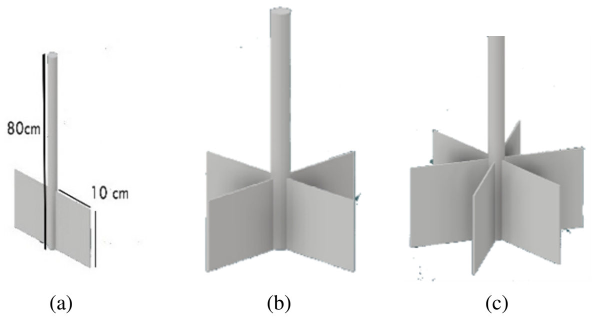

FIG. 1: Turbine blades design of (a) 2 blades, (b) 4 blades, (c) 6 blades.

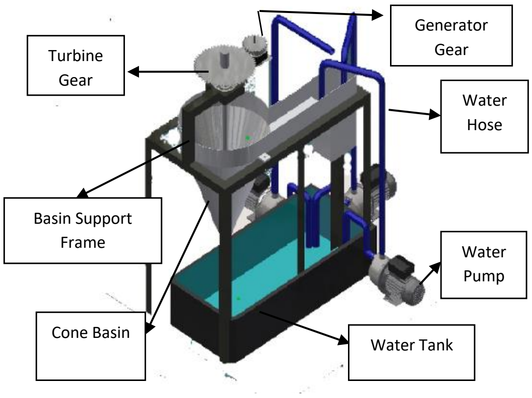

FIG. 2: Design of the cone basin-based Gravitational Water Vortex Power Plant (GWVPP) system.

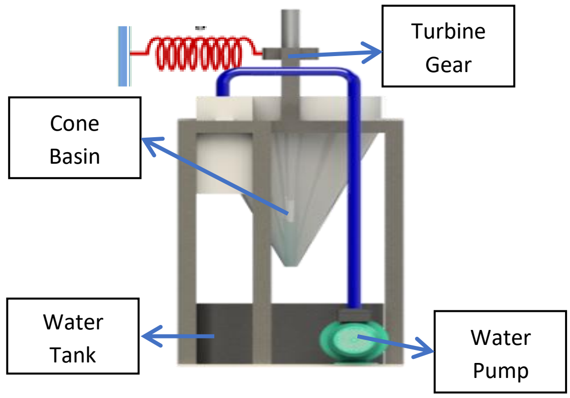

FIG. 3: Torque measurement scheme in a cone basin-based GWVPP.

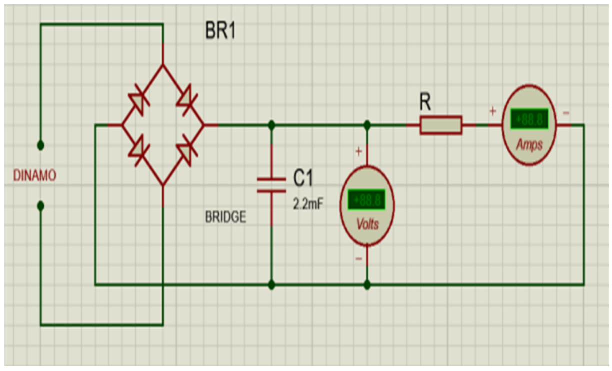

FIG. 4: The measurement circuit of voltage and current with a load resistor.

shape of the turbine blade from research that has been done previously obtained data that the best efficiency on the turbine is used with a straight blade shape with a square shape with a length of each side is 10 cm. The design of the number of turbine blades is determined by 3 variations in the number of vortex turbine blades, which is 2, 4, and 6. The blade design that will be used in the study is shown in Fig. 1. Meanwhile, the cone basin-based GWVPP system design is shown in Fig. 2.

Fig. 2 shows the measurement design of the tool, there are several components other than the turbine which include a basin with a cone shape that is used as a place for vortex formation. The water pump is used as a means of producing water flow, for example, the flow of river water. Water hose is employed as a water channel from the pump to the temporary water reservoir. The turbine gear is used to turn the generator gear. Gear generator is applied as a means of converting the rotation of the gear on the turbine so that later it can be converted into electrical energy. Falling water reservoirs are used for containers of water that fall from the cone out-late basin which will then be flowed continuously to a temporary reservoir by the available water pump.

Data collection begins with measuring the value of the water discharge generated by the tool system. With the use of a stopwatch as a time measurement tool, the rotational speed is obtained for every 60 rotations of the turbine gear. Meanwhile, the torque measurement is carried out using a circuit scheme as shown in Fig. 2 with the addition of a spring as a measuring instrument as shown in Fig. 3. The value of the spring constant used is 119.35 N/m. The data obtained in this study are in the form of torque and rotational speed generated by the turbine, voltage and current generated by the generator, and the total power value obtained by the whirlpool power plant. This study employs variations of the height of the turbine blades with variations in the depth of the turbine to the basin, namely 18, 20, 22, 24 and 26 cm.

The voltage and current were measured with load resistor. The circuit used is shown in Fig. 4. The measurement were performed with a number of resistor variations, 1, 3, 10 and 25 kΩ. Then the last data retrieval is the retrieval of electrical power data by using the current-voltage relationship.

III. RESULTS AND DISCUSSION

The data obtained in this study are the value of rotational, torque, electric current, and electric power. The rotational speed data shows that the largest value is owned by the vari-

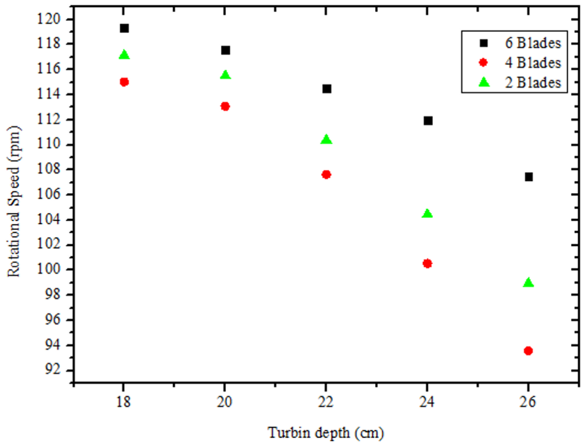

FIG. 5: The rotational speed of the GWVPP with different number of blades.

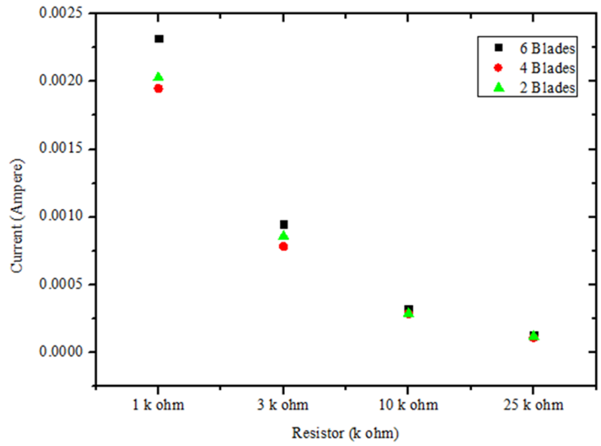

FIG. 7: The measured current as the function of resistance of the GWVPP with different number of blades.

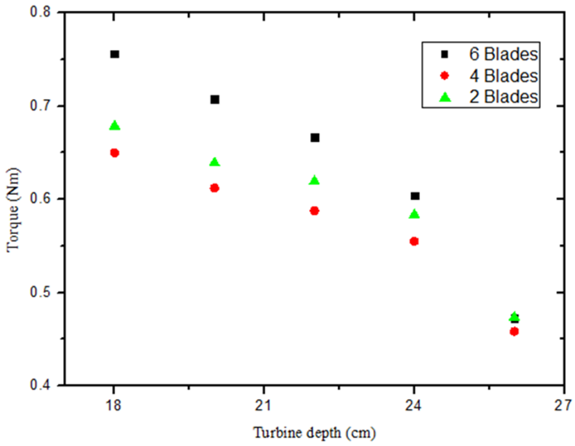

FIG. 6: The torque of the GWVPP with different number of blades.

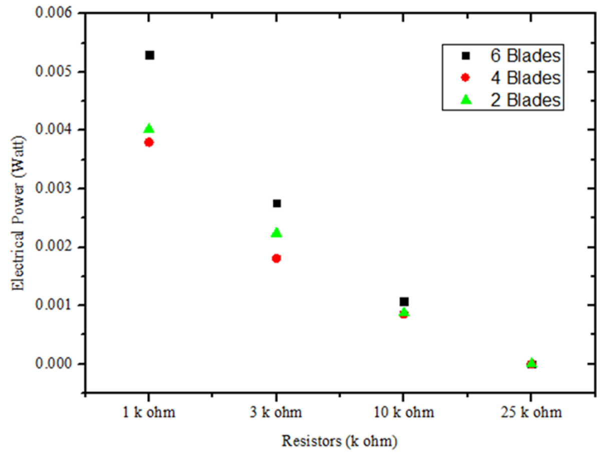

FIG. 8: The estimated power as the function of resistance of the GWVPP with different number of blades.

ation of 6 turbine blades, followed by 2 and 4 turbine blades. The simulations carried out by Min Sung Kim, *et. al.* [9], reached a steady state after 2000 iterations, even if run further, up to 5000 iterations. Torque variation is thought to be related to the power extracted for a given rotation speed. Head is related to the power available to a constant flow rate [9]. This is in line with this study that the effect of the number of blades on the turbine vortex and the effect of the turbine depth were observed for different rotational speeds as shown in Fig. 5 and 6.

Fig. 5 shows the value for each variation in the number of blades increasing at the depth level used. Furthermore, the torque value obtained in this study is shown in Fig. 6. The results obtained is rotational speed, torque, and electric power. From the overall results, it is found that the highest value is owned by the turbine blade with the highest number of blades. This is because when the number of turbine blades is increased, it will affect the angle produced. Because the resulting angle will be smaller so that it will affect the cross-sectional area that will be exposed to the existing vortex flow. And for the influence of the weight of this turbine, it will be covered by the effect of the area imposed by the vortex flow.

Interestingly, the smallest value is not found in the small number of turbine blades. This is because when the number of blades is 4, it will make the resulting angle of 90 degrees. And with such an angle, it will result in the rotation of the turbine blade hampered, hence will reduce the rotation speed of the turbine. And for the number of 2 blades, it will form an angle of 180 degrees which does not have much impact in reducing the rotational speed of the turbine so that it will rotate normally but not too optimally. When the number of blades increased from two to six no significant difference was observed, but there was a slight reduction at higher rotations speed. The main reason for the increase in efficiency turbine with more number of blades is an increase torque. The current value against the resistance is shown in Fig. 7, and the electric power against the resistance is shown in Fig. 8.

Fig. 7 shows that the results of the highest current value is owned by the blade with a total number of 6 and the lowest value is owned by a blade with a total number of 4. Fig. 8 shows the increase in the yield of electrical power generated and is influenced by the number of turbine blades.

The values of rotational speed, torque, voltage, current, and power are related to each other. The highest rotational speed is achieved at 6 turbine blades, as well as that of the highest values for torque, voltage, current, and power. This is because they mutually influence each other in data collection. The overall conclusion of this study is to explain that the turbine with 6 blades has the highest value, and the turbine with 4 blades has the lowest value, both in terms of rotational speed, torque, voltage, current, and electric power.

Three main parameters are related: water level, velocity, and pressure contour. For turbines with different number of blades, its performance was observed to increase when the number of bar increased from two to six. When the knife number upgraded, the turbine exposes a large area to the vortex, extracting a relatively large amount of energy. Because of that, turbine torque increases at optimum rotation speed between 110 and 120 rpm. On the other hand, there is no significant change in performance noted when the number of blades is increased to four, although the effective area of the turbine increased significantly. This is because the four blade turbine will block the flow of water while avoiding the formation of an air core. In the presence of the vortex turbine, the air core splits and propagated behind the turbine blades, maintaining a low pressure area, while discharging the charge around the exhaust duct shop. Therefore, without an air core, a low pressure area is not maintained, and therefore, the pressure drop across the turbine blades is reduced.

IV. CONCLUSION

The number of blades affects the performance of the kinetic turbine. Electrical characteristics are highly dependent on the amount of torque and rotation. Water discharge is very influential on torque and rotation. At a discharge of 169.63 liters/minute, a conical basin with a square-shaped blade and variations in the number of blades, namely 2, 4, and 6 with the same turbine blade area of 0.01 m^2, the maximum data obtained for the mechanical characteristics of the 6-blade variation are 119.351 rpm, and the maximum value is 119.351 rpm with the torque of 0.762 Nm. The electrical characteristics are also found to be optimum when the number of blades is 6 with the maximum value of the 3.597 V voltage, the 0.00232 A current, and the the 0.005 W power. The results of the turbine rotation and torque measurements show that the number of blades sufficiently affects the mechanical characteristics of the turbine and the value of its electrical characteristics.

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