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Development of laboratory-scale crossflow turbine power plant

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ABSTRACT

Hydropower is a primary renewable energy source that is widely used. The crossflow turbine is one of hydroelectric power technology which is commonly used for low head applications. This turbine utilizes the impact energy from water that falls from a height such as a natural waterfall. This study aims to design and construct a laboratory-scale power plant with a cross-flow power plant for further research. Experiments were performed to identify the developed cross-flow turbine performance. The flow-rate, shaft rotational speed, current, and voltage were measured for five different opening valves, which is 20%, 40%, 60%, 80%, and 100% of valve. It is found that 80% and 100% of valve opening where the flowrate 0.27 and 0.33 l/min was generating electricity up to 67.2 Watt. It can be concluded that the developed power plant is adequate to use for further research.

Keywords: Pico Hydro Power Plant, Design Analysis, Crossflow Turbine

1. Introduction

Hydroelectric power has been the primary energy source for over a century and is still the primary renewable energy source worldwide [1]. The number of significant new hydro plants per year is strongly reduced due to increased social sensitivity to the river's ecological and transport equilibrium, leaving a few sites available for large new hydro-plant construction. On the other hand, the ongoing transformation of the centralized system of energy production and transportation into a more flexible distributed system (smart grids) has given a solid input for the construction of pico and micro hydro-energy production devices (from few to 1000 kW) [2]. This type of turbine can be easily installed: 1) along small rivers, where it is possible to transform the potential hydraulic energy dissipated along a short reach between two river sections in electricity without diverting the minimum flow rate required to maintain the ecological equilibrium therein; 2) at the end of a water pipe delivering the water from a primary source (spring, water well, natural or artificial basin) to a tank serving a city water district; 3) at the end of a sewer pipe delivering the treated wastewater to its final receiving water body [3]. The large hydropower generation is relatively mature, and most of the large water resources and geodetic heights have already been exploited. Small-scale hydropower has been studied in the last decades, and it is considered a solution for electricity production in rural and remote zones where the electrical grid cannot be built. Its application can also be extended to other sectors to reduce the pollutants released in the atmosphere and the production of electricity, which leads to economic benefits [4].
Hydroelectric power is a renewable energy resource that comes from flowing water. To generate electricity, water must be in motion. When the water falls under the force of gravity, its potential energy converts into

kinetic energy. This kinetic energy of the flowing water turns blades or vanes in a hydraulic turbine, changing the form of energy to mechanical energy. The turbine turns the generator rotor, which converts this mechanical energy into electrical energy, and the system is called a hydroelectric power station [5]. Micro-hydro-electric power plants are one of the alternative sources of energy generation. They are the most minor type of hydroelectric energy systems. When installed across rivers and streams, it generates in the range of 5 and 100 Kilowatt of power [6].

One type of MHPP turbine is a crossflow turbine. The Michell-Banki turbine is an impulse turbine optimized to work with low flows (from a few liters per second to several hundred liters per second) and low jumps (from a few meters to hundreds of meters), ranking in the turbine-discharge-load diagram near the origin of the axes. Water from a river or a pipe is conveyed toward the impeller, housed in a particular production chamber by a duct element with a rectangular section. A distributor may be present to partialize the duct section according to the actual discharge value. The impeller has the shape of an empty wheel, consisting of two circular plates linked by a series of blades, shaped so that the jet is directed towards the center of the wheel and then again crossing other blades before exiting. The jet then passes through the impeller, and this is the origin of the name "crossflow." The impeller is connected to an asynchronous generator for electricity production [7].

Cross flow turbines are considered more profitable compared to other water wheels, because the size of the crossflow turbine is smaller and more compact than the others. The diameter of a water wheel, namely the road wheel or runner, is usually 2 meters and above, but the diameter of a cross flow turbine can be made only 20 cm, that required less materials. It makes crossflow turbine very profitable compared to other turbines. Likewise, the power can be higher than the power of other waterwheels.

The goal of the research is to design and build a Crossflow Turbine Micro Hydro Power Plant with ANSYS Software's help to determine the power plant's flow simulation. The type of turbine used in this research is a concave turbine with a drop height as high as 2 meters above the turbine.

2. Material and Methods

Figure 1 shows the research methodology.

2.1. Design Process

A crossflow turbine consists of mainly two components, which is runners as a rotating component and distributor as a stationary component. The runner is composed of two or more concave plates that are arranged into a circular plate. Figure 2 shows the design on crossflow developed in this research.

The design process was performed using the Quality Function Deployment (QFD) method and 3D SolidWorks Software for model simulation. The Quality Function Deployment method is a method that is usually used during the process of research and development of a product to specify the needs and the plant of the maker, which also systematically evaluates the quality of the product on fulfilling the needs of the maker. The 3D SolidWorks Software is a drawing application widely used during a product's design process. There are two stages during the drawing process using the SolidWorks application: the first is part drawing, and the second one is part assembly.

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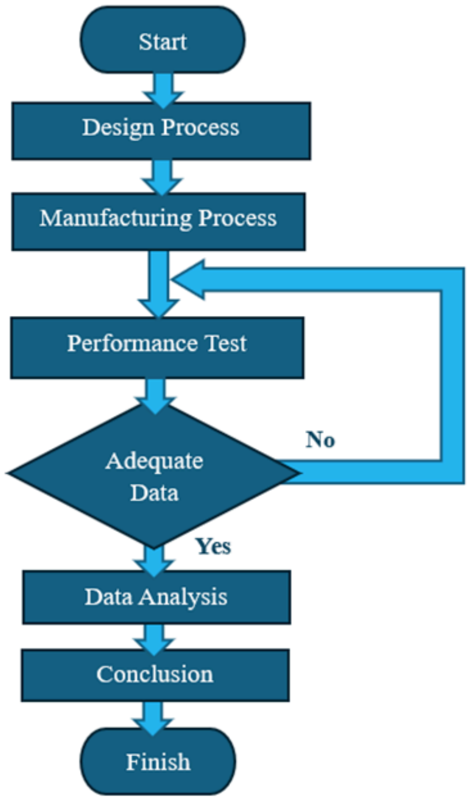

Figure 1: The Research Methodology

After getting the result from the Quality Function Deployment method and 3D SolidWorks Software, a simulation analysis was carried out to determine the flow simulation inside the turbine. This process uses ANSYS Fluent software. The simulation analysis results are the velocity and pressure of the water inside the turbine to show how constantly the fluid flows inside the turbine.

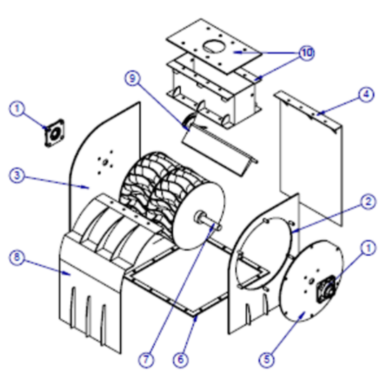

Figure 2: Design of Crossflow Construction

The chosen runner model is a curvature blade with a radius of 50 mm, as shown in Figure 2. Based on literature studies, a runner or impeller with a total of 20 blades with an angle of β1=18^o is a promising design [1,2]. The dimensions of the runner must be adjusted to the test installations available in the laboratory. The design will be analyzed to estimate the flow that occurs.

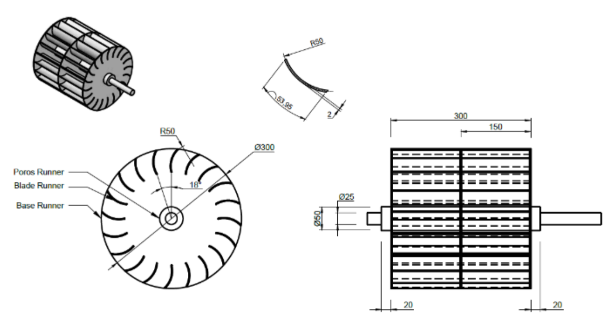

Figure 2: Design of The Runner

2.2. Manufacturing Process

The next step was manufacturing the crossflow turbine and building the base runner, which will be continued by the manufacturing process of the turbine components such as the runner blades, runner shaft, runner discs, and turbine housing.
Numerous manufacturing processes were used to develop the crossflow turbine. A laser cutting machine was used to cut a ST37 plate as a raw material to 20 runner blades, housing, the runner discs and other plate components. Bending processes were performed to curvature the blade with a radius of 50 mm and the runner housing. Machining processes such as milling and turning were performed to prepare the runner shaft. Figure 3 (a) shows the assembled crossflow turbine that consists of runner blade and runner disc. Meanwhile Figure 3 (b) shows the crossflow turbine that was inserted into turbine housing.

(a) (b)

Figure 3: The Runner and the Crossflow Turbine

The assembly processes were performed by mechanical fastening and arc welding. Figure 4 shows the manufactured crossflow turbine. The turbine then installed to the testing facility that equipped with two pumps, a 300 L water tank,

Figure 4: The Developed Crossflow Turbine

2.3. Performance Test

The performance test was performed on a laboratory scale power plant as shown in Figure 5. Two pumps were used to deliver water to the upper tank. The water dropped through a valve that regulated the water flowrate. The lower tank (reservoir) collected the water drop.

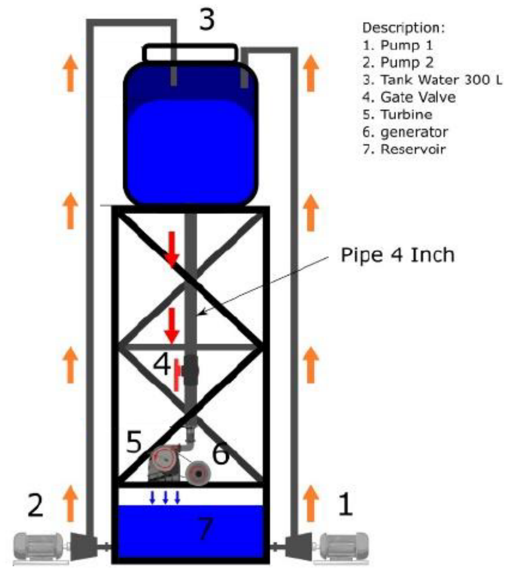

Figure 5: Cross Flow Turbine Power Plant

3. Results and Discussions

The experimental test was performed after the whole turbine system was installed, with the water drop height as high as 2 m. The test began by opening the water valve so the water would drop and hit the runner. The water flowrate was adjusted by opening the valve of 20%, 40%, 60%, 80%, and 100%, respectively. The generated power was determined by the equation of

P=V × A where P = electrical power (Watt); V = voltage (Volt); A = current (Ampere). A multi tester was used to measure the voltage and current, meanwhile a tachometer was used to measure the runner shaft. Table 1 shows the results of the experiments. It showed that the water flow was strong enough to spin the runner when opened at 75˚ and 90˚.

Table 1: Experiment Result

Valve Opening	Q (l/min)	N (rpm)	Current (I, Ampere)	Voltage (V, Volt)	Power (P, Watt)
20%	0,11	0	0	0	0
40%	0.16	0	0	0	0

60%	0.22	0	0	0	0
80%	0.27	38.45	50	0.6	30
100%	0.33	49.52	84	0.8	67.2

$$\eta = \frac{P}{\gamma.q.H} \; x \; 100\% \qquad (1)$$

The efficiency is calculated by Equation 1, where η is the efficiency; P is electrical power of 67.2 Watt; γ is water specific weight at 30°C which is 9,7650 (N/m^2); meanwhile q is flow rate of 0.33 m^3/s; and H is height (m) of 2 m. It results in the efficiency of the laboratory-scale crossflow turbine power is 1.04%.

4. Conclusion

Experiment test showed that has been carried out, the following conclusions can be formed: The ANSYS analysis shows that the water flow converged or flowed at a constant rate with water velocity as high as 0,96 m/s for 75° and 1,508 m/s for 90°. This number was not so different from the number of water velocities obtained from manual analysis $0,81\,m/s$ for 75° and $1,28\,m/s$ 90°. The turbine's efficiency is 0,40% with 2,30 Hp of hydraulic power of the pump. The output from the Crossflow MHPP was 84 Volt, 0,8 Ampere, and 62,7 Watt.

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