The performance analysis of a pico-hydro pump as turbine power plant

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Abstract. Hydropower plant is a type of green technologies to generate electricity. One type of hydropower plants is Pump as Turbine (PAT), an economical alternative to building a power plant with small flow water (pico-hydro). The working principle of the PAT is by reversing the pump working. At PAT, the water flow enters the pump in the discharge section and exit through the suction section of the pump. Centrifugal pump is one type of pumps suitable for use as PAT. The motor from the centrifugal pump can be converted into a generator by replacing the magnetic shaft of the stator. The implementation of PAT was performed on Cibalok Waterfall, with a height of 2.5 m and a water flow of 31,915 L/sec at 70 cm water level. Grundfos NF 30-18 centrifugal pump was used at the implementation. Two models of impellers and two water inlet conditions were tested for comparison. The first model of the impeller was the original impeller from Grundfos NF 30-18 with steel metal material. The second model of the impeller was a modified impeller with a brass metal material. Meanwhile, the two water inlet conditions were a single inlet with a 4-inches diameter and an inlet with two 4-inches pipes. The experiments show that compared to the second model of the impeller, the first model of the impeller with two inlets of 4-inches pipes generated maximum water flow-rate, rotation speed and electrical power at 2.42 L/s, 1134.9 rpm, and 12.05 W, respectively.

1. Introduction

Energy has an essential role in many areas of human and commercial activity, therefore electric power generation is significant to improve the infrastructure and economy of a country [1]. Pump as turbine (PAT) is a small-scale power plant that uses hydropower as its driving force. PAT is an appropriate technology innovation that allows the centrifugal pump motor to become a generator to generate electrical energy. A centrifugal pump is essentially composed of a casing, a bearing housing, the pump shaft and an impeller [2]. The working principle of PAT is the opposite of pump work [3]. PAT technology usually uses a commercial pump in which the impeller takes over the function as a turbine to drive the generator. PAT has several advantages such as affordable price, simple design, easy to assemble and install compared with other hydropower systems, wide application, and longer life [4,5]. Numerous research papers about PAT technology have been published [6–9].

In a previous study, the performance analysis of the pump as a turbine has obtained the performance of the pump as a turbine in several different positions and directions of flow; there were three variations of the pump installation as a turbine with the difference of the pump axis to the pipeline [10]. Further research continued with the experimental test of the pump as a turbine on a laboratory scale. The research showed that the vertical flow to the PAT axis produced a higher rotation and electric power. In this research, the experimental tests were performed in the actual site with the actual condition to understand the actual performance of the PAT power plant.
2. Methodology

Figure 1 shows the methodology in this research. The implementation located at the Cibalok Waterfall, Bogor, Indonesia. This waterfall has a height of 2.5 m from the river surface, with an approximate width of 30 m. Based on the data provided by officer water irrigation, this dam has a minimum water level of 10 cm during the dry season and a maximum of 280 cm during the rainy season. The minimum flow rate was 1,662 L/sec in the dry season, meanwhile, the maximum flow rate in the rainy season was up to 314,663 L/sec.

Figure 1. The research methodology.

After surveying and collecting the data of the location, the PAT construction was designed using CAD software to create a model of the frame/scaffold and analyze the strength of the construction. The manufacturing process was performed based on the design. The frame used a SJ275R steel L-profile 50 x 50 mm. The overall dimension of the frame were 720 mm of height and 310 mm of width. The frame was joined by using a welding method to make it more sturdy and robust to withstand the pump and water flow load.

The pump used in PAT implementation was the Grundfos NF 30-18. Two different impeller types were used. The first impeller was the original impellers, made of EN-GJL-200 material with a weight of 1.1 kg. Meanwhile, the second impeller was a modified impeller made of brass metal casting with a weight of 1.7 kg.

The piping installation used a 4-inch diameter pipe as a horizontal water inlet with a length of 1.5 m (Figure 2 and 3). The other components of a connection system are an elbow, reducer, ball valve, and valve socket. There are two condition inlets as data retrieval variations. The electrical installation used two units of 3-Watt of LED lights with a total power of 6 Watts and a 1 A step-up transformer. The overall cost for making the installation was approximately USD 600.

3. Implementation Setup

Figure 2 and 3 show the experimental installation for one and two inlets. A 4-inch diameter pipe was used as a horizontal inlet placed above the waterfall with a length of 1.5 m, and there was a 4-inch ball valve to regulate the water that entered the installation.

Furthermore, the 90° elbow connection type was used to guide the water to the vertical position of the waterfall, followed by a 4x3 inch reducer, 3x2 inch reducer and the 3-inch ball valve that was placed vertically on the waterfall. The water flowed through the 2-inch pipeline that entered the pump, to rotate the impeller on the pump. The rotational speed of the impeller was measured using the Nankai DT 6236B digital tachometer with an accuracy of ± 0.05% + 1 digit. Meanwhile, the voltage and current generated by the pump motor were measured using a Fluke 73 series II digital multimeter with an accuracy of ± 0.4% + 1.
The power generated by the PAT was determined using the following equation:

\[ P = V \times A \]  
\[ (1) \]

Where \( P \) = electrical power (Watt); \( V \) = voltage (Volt); \( A \) = current (Ampere)

The efficiency of PAT was calculated by the equation:

\[ \eta = \frac{P}{\gamma \cdot q \cdot H} \times 100\% \]  
\[ (2) \]

Where \( \eta \) = efficiency of PAT; \( P \) = electrical power (Watt); \( \gamma \) = water Specific weight at 30°C = 9.7650 (N/m²); \( q \) = flow rate (m³/s); \( H \) = height (m).

In the second condition implementation setup, two pipes were placed at the top of the waterfall with a horizontal position of 1.5 m. This pipe functioned as an inlet, then the pump was applied at the bottom of the waterfall and connected to a 2.5 m long vertical pipe.

### 4. Result and discussion

The test was performed in sunny weather with the range of temperature 20°C - 25°C. The river water flow was 31.915 L/sec at 70 cm of the water level. Table 1 shows the result of each setup (one- and two-inlets) for the original and modified impeller. The flow rate was controlled by a valve that was placed at 2 m above the PAT. There were ten opening positions of the valve namely 40°, 70°, 110°, 145°, 180°, 215°, 250°, 300°, 325°, and 360°, which resulted in ten different approximate flow rates. The flow rate values were rounded to a more straightforward analysis. The electrical power and the efficiency of the PAT were calculated with equation (1) and (2), respectively. Figure 4 shows the graphics that plots the data of Table 1.
Table 1. Implementation result.

| No | Flow rate, Q (L/min) | Rotational speed (rpm) | Electrical power (W) | Efficiency (%) | No | Flow rate, Q (L/min) | Rotational speed (rpm) | Electrical power (W) | Efficiency (%) |
|----|----------------------|------------------------|----------------------|----------------|----|----------------------|------------------------|----------------------|---------------|
| 1  | 45                   | 569.6                  | 1.85                 | 10.1           | 1  | 45                   | 411.6                  | 0.875                | 4.78          |
| 2  | 50                   | 617                    | 2.255                | 11.08          | 2  | 50                   | 472.3                  | 1.269                | 6.24          |
| 3  | 55                   | 684.3                  | 2.873                | 12.84          | 3  | 55                   | 510.5                  | 1.815                | 8.11          |
| 4  | 60                   | 720.5                  | 3.705                | 15.18          | 4  | 60                   | 561.7                  | 2.184                | 8.95          |
| 5  | 65                   | 753.1                  | 4.352                | 16.46          | 5  | 65                   | 612.2                  | 2.548                | 9.63          |
| 6  | 70                   | 782.9                  | 4.77                 | 16.75          | 6  | 70                   | 643.5                  | 3.066                | 10.76         |
| 7  | 75                   | 803.1                  | 5.206                | 17.06          | 7  | 75                   | 670.2                  | 3.51                 | 11.5          |
| 8  | 80                   | 815.4                  | 5.58                 | 17.14          | 8  | 80                   | 704.8                  | 3.856                | 11.85         |
| 9  | 85                   | 835.3                  | 5.985                | 17.31          | 9  | 85                   | 726.7                  | 4.131                | 11.94         |
| 10 | 90                   | 862.4                  | 6.38                 | 17.42          | 10 | 90                   | 737.3                  | 4.403                | 12.02         |

| No | Flow rate, Q (L/min) | Rotational speed (rpm) | Electrical power (W) | Efficiency (%) | No | Flow rate, Q (L/min) | Rotational speed (rpm) | Electrical power (W) | Efficiency (%) |
|----|----------------------|------------------------|----------------------|----------------|----|----------------------|------------------------|----------------------|---------------|
| 1  | 100                  | 883.2                  | 7.22                 | 17.75          | 1  | 100                  | 751.6                  | 4.31                 | 10.59         |
| 2  | 105                  | 898.5                  | 7.72                 | 18.08          | 2  | 105                  | 784.8                  | 4.77                 | 11.17         |
| 3  | 110                  | 910.1                  | 8.19                 | 18.3           | 3  | 110                  | 799.2                  | 5.11                 | 11.42         |
| 4  | 115                  | 935.7                  | 8.77                 | 18.75          | 4  | 115                  | 820.9                  | 5.69                 | 12.16         |
| 5  | 120                  | 989.3                  | 9.26                 | 18.98          | 5  | 120                  | 841.6                  | 6.41                 | 13.13         |
| 6  | 125                  | 1015.7                 | 9.71                 | 19.1           | 6  | 125                  | 885.7                  | 7.39                 | 14.53         |
| 7  | 130                  | 1040.1                 | 10.33                | 19.53          | 7  | 130                  | 911.5                  | 8.16                 | 15.43         |
| 8  | 135                  | 1055.9                 | 10.84                | 19.75          | 8  | 135                  | 940.8                  | 8.85                 | 16.11         |
| 9  | 140                  | 1097.3                 | 11.43                | 20.07          | 9  | 140                  | 993.6                  | 9.52                 | 16.71         |
| 10 | 145                  | 1134.9                 | 12.05                | 20.44          | 10 | 145                  | 1021.2                 | 9.91                 | 16.8          |

Figure 4 shows that the flow rate of the two-inlets was about twice the one-inlet for the first until the fourth valve opening condition. The graph shows that the rational speed and the power increase as the increase in flow rate.

Figure 5 shows the value of the power generated for each condition when the valve opened fully. It shows that the highest power was generated when the water flowed with the two-inlets pipe and using the original impeller.

The experiment shows that PAT technology can be implemented in a low head waterfall with a minimum budget of approximately USD 600. However, the test result indicates that the generated power was still low. It needs more improvement and further research, especially in the generator.
Figure 4. The comparison result of the original and modified impeller for (a) rotational speed for one-inlet; (b) rotational speed for two-inlets; (c) generated power for one-inlet; (d) generated power for two-inlets.

Figure 5. The comparison of the maximum performance of each impeller.

5. Conclusion
In this research, the actual performance of the PAT in four conditions was investigated. A commercial pump, the Grundfos NF 30-18 was modified into a turbine and generator. Four test conditions were performed namely one-inlet with the original impeller, one-inlet with the modified impeller, two-inlets with the original impeller and two-inlets with the modified impeller. It was found that the PAT rotational speed and the power improved as the flow rate increased. The highest generated electrical power and PAT efficiency were 12.05 Watt and 20.44%, respectively, that was achieved when two pipes were used as the inlets to the PAT.
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