Power Generation Characteristics of a Crossflow Turbine and a Single Shaft Coupled of Two Crossflow Turbines

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Abstract. This study evaluate the power generation capability of two different configurations of crossflow turbine used on conversion of the hydro potential energy of small river to electrical energy. First one is the 12 blades single crossflow turbine while second one is the 12 blades and 24 blades crossflow turbine coupled in a single shaft (double crossflow). The turbines are coupled with an ac single-phase permanent generator to form a small hydro power generation unit. This small hydro power unit is then installed in a small river in Cipancar, Sumedang, West Java for field experimental study. The objective is getting the power generation characteristics of those two different configurations of crossflow turbines. Results of the field experimental study show that the single shaft coupled of two crossflow turbines/double crossflow configuration gives higher torque and power than configuration of single 12 blade crossflow configuration. The highest torque and power generated is 59.9 Nm and 135.1 W respectively at 21.53 rpm and depth of dip 0.24 m.

Keywords: crossflow turbine · double crossflow · power generation · small hydro

1 Introduction

Remote area in Indonesia commonly has a lot of small rivers. Small river saves small amount of hydro energy potential. Converting this small hydro energy potential requires two conditions i.e. low-speed hydro turbine and low-speed generator [1, 2]. Moreover, the low-speed generator should be generator with permanent magnet excitation instead of generator with external excitation source. The low-speed hydro turbine requires to convert hydro potential energy of the small river to rotational mechanical energy. Futhermore, low-speed generator requires to convert rotational mechanical energy to electrical energy.

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The crossflow horizontal shaft, or shortly crossflow, is popular choice as it is one kind of low-head hydro turbine. Low-head hydro turbine works on low-speed, thus suitable for application in a small river having low-speed of water flow. Crossflow turbine is a popular choice for use in a small hydro power unit. Crossflow turbine has number of blades that directly contact and move along with the water flow. All blades in crossflow system are supported by a wheel firmly attached to the shaft of turbine. These will deliver motion of blades to the turbine shaft. The shaft is supported two bearings at two end sides of the turbine. The bearing house is firmly attached on concrete floors constructed at both river sides where the turbine is going to be installed [3].

Ac permanent magnet generator is one kind of low-speed generator. Two different types of ac permanent magnet generator are axial flux permanent magnet (AFPM) generator and radial flux permanent magnet generator [4, 5]. AFPM generator is a suitable choice for use in small hydro power generation unit such has pico-hydro and micro-hydro [6–11]. Conventional radial flux permanent magnet generator is a also a choice for use in small hydro power generation unit, particularly the one developed through modification of squirrel cage single-phase ac induction motor [12–15]. In fact, a single-phase ac induction motor can be easily operated as an ac induction generator, just by rotating its rotor faster than synchronous speed [4]. However, capacitor need to be installed to maintain and regulate the output voltage generated [12]. Thus, the easiest way is through modification of a squirrel cage single-phase ac induction motor. [13–15].

In this paper, a small hydro power generation unit constructed mainly by coupling of crossflow turbine and ac single-phase permanent generator is analyzed. The ac single-phase generator is developed through modification of a squirrel cage single-phase ac induction motor. The small hydro power unit is installed in a small river located at Cipancar, a village in Regency of Sumedang, West Java. Analysis is focused on power generation characteristics of the small hydro power unit works on two different configurations of crossflow turbine i.e., single crossflow (using only a 12 blades crossflow turbine) and double crossflow (using 12 blades and 24 blades crossflow turbines coupled in a single shaft). The power generation characteristics can be used as considerations for suitable applications.

2 Methodology

The power generation characteristics of a small hydro power unit was studied when works with single crossflow and double crossflow turbine, three major steps are taken. These three major steps are studying location where the turbines are installed, calculating parameters necessary for turbine installation such as debit of water, rotation speed and pulley transmission ratio and installing the turbines followed by running test to collect data necessary for analysis. Detail explanation about the steps is given in points below:

- First step is studying location where the two different crossflow turbine configurations are going to be installed. A small river in Cipancar, Sumedang, West Java has been selected. A waterway and concrete structure, in which the small hydro power unit is going to be installed, have been constructed. Measurement of waterway and concrete structure dimension as well as velocity of water flows along this waterway are taken.

Then, debit and hydro energy potential can be calculated using two formulas below [16]:

$$Q = Av \tag{1}$$

$$P_{hydro} = \frac{1}{2}\rho v^3 A \tag{2}$$

with Q (m^3/s) is debit of water flow, A (m^2) is cross-sectional area of water flow, v (m/s) is velocity of water flow and > (kg/m^3) is specific mass of water.

- Regarding power generation of the two different crossflow turbine configurations, parameters to be calculated are debit of water flow and turbine rotation speed. To calculate these parameters, the 12 blades dan 24 blades turbine dimension data are needed. Having calculate the turbine rotation speed, pulley ratio and belt length can be determined. The pulley-belt method is selected to transmit turbine shaft power to generator shaft. Formulas used to determine pulley ratio and belt length are expressed in Eqs. (3) and (4) below [16]:

$$\frac{d_1}{d_2} = \frac{n_2}{n_1}. \tag{3}$$

$$L = \sqrt{4C^2 - (D-d)^2} + \frac{1}{2}(D\theta_D + d\theta_d) \tag{4}$$

with d_1 (m) is diameter of pulley 1, d_2 (m) is diameter of pulley 2, n_1 (rpm) is rotation of pulley 1, n_2 (rpm) is rotation of pulley 2, L (m) is length of belt, D (m) is diameter of larger pulley, d (m) is diameter of smaller pulley, C (m) is distance between two pulley centers and θ (°) is the angle contact between belt and pulley.

- After designing pulley and belt, the crossflow turbine can be connected to the ac single-phase permanent magnet generator to form a small hydro power unit. Then, the small hydro power unit is installed on the waterway and concrete structure for field experimental test. In general, two different field testing for the small hydro power unit are conducted i.e., the one with single crossflow turbine (using only a 12 blades crossflow turbine) and the one with double crossflow turbine (using 12 blades and 24 blades crossflow turbines coupled in a single shaft). For each field experimental test, the dip of turbine varied and rotation as well as torque/power generated are measured. The data the analyzed to determine power generation characteristics of each crossflow turbine configuration.

3 Result and Discussion

3.1 Constructing the Small Hydro Power Generation Unit

The waterway and concrete structure are shown in Fig. 1. Height, wide and length of the waterway and concrete structure are 1 m, 1 m and 7 m respectively.

Table 1 presents the measurement data and calculated of water flow velocity. The average velocity of the water flow is found to be 1.43 m/s.

Fig. 1. Waterway and concrete construction in which small hydro power generation unit is installed.

Table 1. Measurement data for water flow velocity.

No.	Time elapsed (s)	Distance traveled by test object (m)	Water flow velocity (m/s)
1	3.18	5	1.57
2	3.88	5	1.29
3	3.55	5	1.41
4	3.42	5	1.46
5	3.55	5	1.41
6	3.62	5	1.38
7	3.35	5	1.49
8	3.44	5	1.45
9	3.45	5	1.45
10	3.64	5	1.38

Using dimension data of the waterway and verlocity of water flow, the result showed in Table 1, hydro power potential in waterway can be calculated using Eqs. (1) and (2). Note that water height is taken as 0.3 m. This is the maximum height of water allowed to flow in the waterway. The calculation results are presented in Table 2. The average hydro power potential is found to be 700.34 W.

Figure 2 show two single crossflow turbines, one with 12 blades and the other with 24 blades. Meanwhile, Fig. 3 show a configuration of double crossflow turbine constructed

Table 2. Calculated hydro power potential of the waterway.

No.	Height of water flow (m)	Debit of water flow (m^3/s)	Hydro power potential available (W)
1	0.3	0.75	932.33
2	0.3	0.62	514.01
3	0.3	0.68	669.91
4	0.3	0.70	749.99
5	0.3	0.68	669.91
6	0.3	0.66	632.11
7	0.3	0.72	798.71
8	0.3	0.70	736.22
9	0.3	0.70	730.16
10	0.3	0.66	622.55

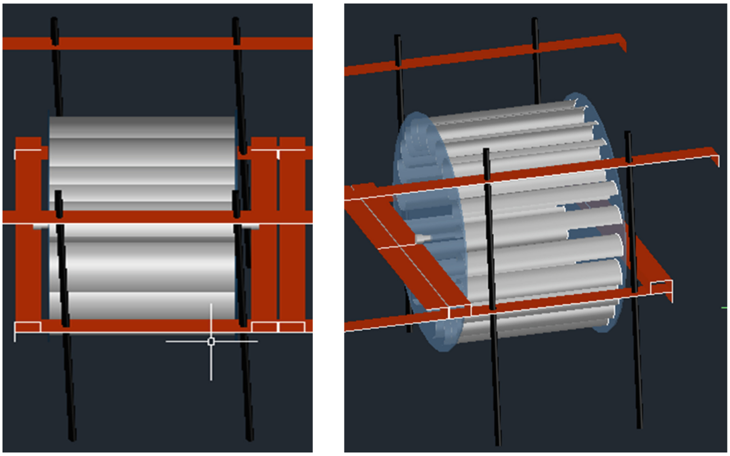

Fig. 2. A 12 blades crossflow turbine and a 24 blades crossflow turbine.

by a 12 blades crossflow turbine and a 24 blades crossflow turbine coupled in a single shaft. Length of each blade of the crossflow turbine is 0.5 m. The blade diameter of 12 blades crossflow turbine is 0.1 m, while the blade diameter of 24 blades crossflow turbine is 0.12 m. Each turbine has a diameter of 0.75 m. Using this data, turbine rotation speed for average velocity of the water flow 1.43 m/s can be calculated as 36.41 rpm.

After obtaining rotation speed of the turbine, next step is calculating the pulley and belt needed to couple the crossflow turbine and ac single-phase permanent magnet generator to form a small hydro power unit. It is known that the ac single-phase permanent with magnet generator has 10 permanent magnet poles. Therefore, its nominal rotation

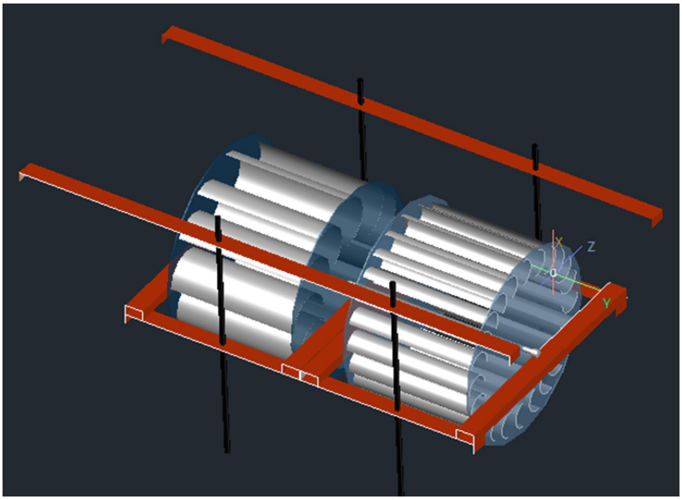

Fig. 3. A double crossflow turbine consisted of a 12 blades crossflow turbine and a 24 blades crossflow turbine.

speed is 600 rpm to generate output voltage with frequency of 50 Hz [17]. Then using Eq. (3) pulley ratio is found as 1:16. Because the ratio is too high then two-level pulley configuration is chosen. If each pulley (pulley level 1 and pulley level 2) is designed to have the same ratio, then the calculated pulley ratio is equal to 1:4. To avoid slippage, pulley ratio of 1:5 is chosen. If diameter of the large pulley is 0.3 m, diameter of small pulley is 0.06 m, distance between two pulleys for pulley level 1 is 0.5 m and distance between two pulleys for pulley level 2 is 0.4 m then length of belts for pulley level 1 and pulley level 2 are going to be 1.44 m and 1.17 m respectively.

3.2 The Small Hydro Unit Field Testing Field Experimental Test of the Small Hydro Power Generation Unit

Figure 4 show the small hydro power unit installed in the waterway. The small hydro power generation unit is tested under two different conditions. The first one is small hydro power generation unit with single crossflow turbine (using only a 12 blades crossflow turbine). The second one is small hydro power generation unit with double crossflow turbine (using 12 blades and 24 blades crossflow turbines coupled in a single shaft). For each test condition, dips of crossflow turbine configurations are varied for 0.12 m, 0.18 m and 0.24 m. The results are presented in Table 3 and Table 4. Table 3 gives data for small hydro power generation unit with single crossflow turbine while Table 4 gives data for small hydro power generation unit with double crossflow turbine.

To get better understanding about the capability of this small hydro power unit with single and double crossflow turbines, data in Table 3 and Table 4 can also be presented in graph shown by Fig. 5.

Fig. 4. The small hydro power generation unit installed in the waterway.

Table 3. Data for small hydro power generation unit with single crossflow turbine.

Turbine dip (m)	Rotation (rpm)	Torque generated (Nm)	Power generated (W)
0.12	22.00	25.50	58.71
	17.45	29.32	53.56
	16.43	29.64	50.98
	15.19	35.06	55.73
0.18	22.78	15.94	38.00
	18.70	22.31	43.67
	16.89	25.50	45.07
	16.09	29.96	50.46
0.24	24.14	12.75	32.21
	19.95	19.12	39.92
	18.25	22.31	42.61
	17.23	26.13	47.12

Table 4. Data for small hydro power generation unit with double crossflow turbine.

Turbine dip (m)	Rotation (rpm)	Torque generated (Nm)	Power generated (W)
0.12	25.39	31.87	84.69
	20.85	50.99	111.30
	19.61	54.18	111.19
	18.59	57.37	111.61
0.18	26.75	33.15	92.79
	22.55	49.72	117.37
	20.74	54.18	117.62
	19.72	57.37	118.41
0.24	27.65	34.42	99.63
	24.48	50.99	130.66
	22.67	56.09	133.08
	21.53	59.92	135.05

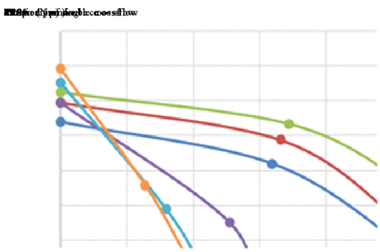

Fig. 5. Comparison of power generation from small hydro power unit with single and double crossflow turbines.

Small hydro power generation unit with double crossflow turbines experiences less decrease of rotation as load increases. The deeper dip of the turbine, the less decrease of rotation as load increases. Vice versa, small hydro power generation unit with single crossflow turbines experiences significant decrease of rotation as load increases. It also shown that highest torque and power are 59.92 Nm and 135.05 W respectively at 21.53 rpm, achieved by double crossflow turbine configuration with depth of dip 0.24 m. Meanwhile, lowest torque and power are 25.50 Nm and 58.71 W respectively at 22.00 rpm, achieved by single crossflow turbine configuration with depth of dip 0.12 m.

4 Conclusion

Two different configurations of crossflow turbine have been successfully constructed and tested to harness hydro potential energy of a selected small river. The single crossflow (using only a 12 blades crossflow turbine) configuration give higher speed but lower torque/power. The double crossflow (using 12 blades and 24 blades crossflow turbines coupled in a single shaft) takes the advantage of crossflow turbine with less or greater number of blades. The double crossflow configuration able to give higher torque and power at higher speed. The highest torque and power generated is 59.9 Nm and 135.1 W respectively at 21.53 rpm and depth of dip 0.24 m.

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