# Hydrokinetic Renewable Energy Application in Bangladesh


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***The burning of fossil fuels to generate electricity has been around for some time in society. The method of using fossil fuels has proven to be reliable, however has side effects that effect the environment negatively. An alternative to burning fossil fuels is using renewable energy such as solar and hydrokinetic turbines. This paper discusses applications of vortex-induced autorotation bladeless turbines and bladed turbines for hydrokinetic power generation from rivers in Bangladesh. Bangladesh is a South-Asian country which is a delta surrounded by water bodies. Has a coastline of 580 km. The country consists of the Ganges (Padma), Brahmaputra (Jamuna), and Meghna Rivers and their tributaries which occupy 79 percent of the country. The Ganges (Padma) has an average velocity of 0.5185 m/s pre-monsoon, 1.185 m/s during monsoon and 0.4974 m/s Post-monsoon while the maximum velocity of the river is 2.7 m/s and the Padma river has a minimum velocity of 0.37 m/s. The Brahmaputra (Jamuna) river has an average velocity of 0.75 m/s and the river has a maximum velocity of 1.42 m/s and a minimum velocity of 0.65 m/s. The Jamuna river has an annual average velocity of 0.95 m/s and a maximum velocity of 1.55 m/s. The minimum velocity of the river is 0.67 m/s. It is important to develop ways to make power from the rivers making them cost effective and sustainable as more than 70% of the people in Bangladesh do not have access to electricity. We examined bladeless and bladed turbine models in a custom flow tank available in the Fluid Lab of Mechanical Engineering Program of SUNY New Paltz. The 5-to-6 cm turbine models were designed using SolidWorks and 3d-printed using PLA. The open flume tank was used to run simulation of rivers in Bangladesh by mimicking the flow speed and turbulence. Power production and rotation of the turbine are measured using digital multimeter and rotation sensor, respectively.***



***Keywords— Autorotation, renewable energy, bladeless turbines***


## I. INTRODUCTION

Bangladesh is a South-Asian developing country which is a Delta surrounded by multiple bodies of water with a coastline of 580km. The country consists of the Ganges (Padma), Brahmaputra (Jamuna), and Meghna Rivers and their tributaries which occupy 79% of the country. The Ganges (Padma) has an average velocity of 0.5185 m/s pre-monsoon, 1.185 m/s during monsoon and 0.4974 m/s post-monsoon, while the maximum and minimum velocity of the river are 2.7 m/s. and 0.37 m/s, respectively [1]. The Brahmaputra (Jamuna) river has an average velocity of 0.75 m/s and the river has a maximum velocity of 1.42 m/s and a minimum velocity of 0.65 m/s. The Jamuna river has an annual average velocity of 0.95 m/s and a maximum velocity of 1.55 m/s[2]. The minimum velocity of the river is 0.67 m/s[1].

Electricity consumption is on the rise in Bangladesh due to its economic development and population growth. New buildings and cities demand large electric power supply for industry, commerce, and transportation. With the rapid increase in energy demands, the country has relied on coal powered powerplants with the help of private and government owned companies because coal is cheap and easily accessible. However, coal is non-renewable resource which goes through an irreversible process and is detrimental to the environment. It is important to develop ways to make power from the rivers making them cost effective and sustainable as more than 70% of the people in Bangladesh do not have access to electricity. Furthermore, it will be more efficient to use off-grid electricity for different states of Bangladesh as per the country's topography and geographical location.

The alternative to fossil fuels is categorized as renewable energy which include various sources such as solar power, wind power and hydropower. Renewable energy is defined as "any naturally occurring, theoretically inexhaustible source of energy, such as biomass, solar, air, tidal, wave, and hydroelectric power, that is not derived from fossil or nuclear fuel" [3]. Renewable energy is attractive because it is a clean and environmentally friendly. It provides alternatives to traditional power generation methods for unique applications such as electricity and transportation in isolated societies.

Methods that use solar and wind as sources have already been developed to be efficient. On the other hand, there has been still scopes for improvement in methods that utilize water currents. The current project reflects on an innovative design for power harvesting of kinetic energy from flowing water through vortex-induced autorotation. The water-based power generation is still dominated by hydropower technology that relies on the potential energy from water. The hydropower requires dams, which function to collect gravitational potential energy from the water at a height. Dams are expensive to build and often cause environmental damage as the construction has to take place in natural rivers. To harness the energy, either reaction or impulse turbines may be used to generate the electricity. Another method is harnessing energy from the flowing river, by using the kinetic energy from the rivers current. The hydrokinetic energy harvesting has become an attractive topic for investigation as the technology promises a minimum infrastructure requirement and a low impact on freshwater life [4]-[6]. Hydrokinetic technology is still developing unlike wind turbine that is already mature and has a low cost of energy harvesting [7]. Vortex-induced autorotation of objects on Vertical Axis Autorotation Current Turbine (VAACT) to generate power would be discussed in this paper.

An object rotating is properly categorized as autorotating when, “one or more stable positions exist at which the fluid flow exerts no torque on the resting body” [8]. An autorotating body requires an initial strong impulse to produce continuous rotational motion. The autorotating bladeless turbine model introduced in the current project was motivated by works on vortex induced oscillations and autorotation of bodies exposed to fluid flow by Skews [9] and Araneo et al. [10]. Skews studied the autorotation of polygonal prisms in air flow and found that triangular shape prisms worked the best among other prisms [9]. Motivated by the work of Skews, Areneo et al. suggested a cross-cylinder model where two short cylinders, having diameter equals to length, are merged in orthogonal manner to form a bladeless turbine model [10]. In the current project, the proposed bladeless turbine is compared to Savonius turbine model that has been studied as hydrokinetic power generators. The Savonius turbine used by Rostami and Fernandes [11] to study effects of inertia and flap on autorotation applied for hydrokinetic energy harvesting.

Two turbine models studied in this project represent turbine with and without blades. The bladeless turbine is represented by a triangular prism with curved side surfaces, instead of flat surfaces. This symmetric 3D-printed turbine model has an edge-to edge distance of 3.7 cm, a mass of 12.7 grams, and an infill density of 10%. The triangular turbine was designed based on the finding by Skews [9] for its curved surface and being three sided rather than four sides which allowed the turbine for a lower moment of inertia which meant that the force needed to rotate the turbine would be less than that of the four-sided turbine. The bladed turbine model is represented by Savonius turbine with four blades. The blades are arranged radially at a 45-degree angle and all are equidistant from each other. Tests will be performed to observe amount of power generation by these designs in a small-scale water flow.

The bladed turbines use drag and lift forces generated by the water flow interacting with the blades to rotate about its axis. On the other hand, the bladeless turbine relies on rotational motion induced by vortex shedding trailing on the back of bodies exposed to fluid [10]. Both designs discussed in the current paper demonstrate the vortex-induced rotational modes and rotational oscillation modes, instead of the lateral oscillation modes.

In this paper we will discuss the turbine models, specification of the flow tank, how the speed was accumulated, and detailing methods involved in for each experiment and compare both the turbines and their data and results will be discussed and lastly the application of these turbines in the rivers of Bangladesh.

## II. Method

All of the tests in this study were carried out with 3D printed turbines that were created with SolidWorks CAD software. The bladeless turbine is a 3-sided equilateral triangular shape modified with curves with dimensions of 3.7 x 3.7 x 5 $cm^3$ and a mass of 12.7 g. The curves that were added to the triangle side surfaces resulted in larger surface area exposed to water shear stresses. This feature increased the forces and torques operating on the turbine, allowing it to produce more rotation and power. The second turbine was a bladed Savonius turbine, measuring 6.2 cm in diameter and 6.5 cm in height. The model weighs 29.2 g. Four blades were arranged at 45-degree angles relative to the radial axis and placed equidistant from one another. Both turbine models were printed using Polylactic Acid (PLA) with a low infill printing setting of 10%. The models were lowered into the water about 7 cm and was placed 38 cm from the entrance of the channel of the custom water tank. The water fills the observation chamber to a depth of around 15 cm. The transparent chamber's width and length are 15 and 60 cm, respectively. Both chamber walls have holes drilled into them to allow perforated C-bars to be screwed to them. Similar C-bars were put all across the chamber to secure the construction of the motor case.

Figure 1 shows the water flow tank, which was designed to convey about 12800 gph of water via the transparent viewing room of 15x15x60 $cm^3$. The system is fitted with a 3-hp centrifugal pump that may be controlled by a Variable Frequency Drive (VFD) in order to achieve such a flowrate. The VFD provides either manual or automatic control of the flowing fluid at frequencies ranging from 20 to 55 Hz. The maximum average flow speed achievable is around 60 cm/s. To lessen the intricacy of the flow and provide uniform flow, a converging chamber was built at the observation chamber's entrance. The closed-loop flow tank was custom-built and constructed as a senior design project within the Division of Engineering of SUNY New Paltz sponsored by the Vibration Institute [12]. To mimic natural flows of Bangladeshi rivers, a 5-cm wide wooden ruler is placed on the channel to provide a non-symmetric obstacle to the flow. Beside creating non-symmetric flow pattern, such placement has been shown to increase autorotation and power production of vortex-induced bladeless turbines [10].

The axle linked to the turbine model was coupled to the short shaft of a 0.5-V DC motor, which is used as an electric generator, through a hard plastic tubing with an internal diameter of 2 mm. The DC motor was then mounted in a 3D-printed enclosure suspended above the flowing water by a frame secured on the tank walls. A wire connection from the DC motor is linked to a Dawson Digital Multimeter to collect quantitative data from the autorotating turbine. This multimeter is equipped with a USB connection and compatible software that allows users to process the data acquired in Excel. At intervals of about 0.5 seconds, the software records measurements. All measurements were obtained in 180-second intervals, for a total of about 90 seconds. During the test, the voltage and current were measured separately, but each data was collected for the same time period of 90 second. Each data was collected when the flow achieves steady state. The data was imported into Microsoft Excel for further analysis. The time-averaged of the absolute current and voltage data were used for the power estimation calculated using the Watt’s Law shown below in equation (1). The maximum current and voltage data were used to estimate Maximum possible power produced by the turbine model. (clockwise and counterclockwise rotations from the tri-curve turbine yielded negative and positive readings, respectively and counterclockwise for the bladed turbine for a positive readings). The absolute value readings' averages were then calculated. Finally, Watt's Law was used to calculate the amount of energy and power harvested:

$$\bar{P} = \bar{V} \times \bar{I} \qquad (1)$$

where $\bar{P}$, $\bar{V}$, and $\bar{I}$ are the average power, average voltage and average current, respectively.

The average power is the product of average voltage and current measurements taken for the same sampling rate but various flow rates. For lengthy periods of time, it was expected that the turbine's movement patterns would not drastically change at each flow speed increment. While the true power generated may not exactly match the observed power, the discrepancy between the true and observed power is assumed to be negligible, and the correlations between flow speed increments remain valid. Above all, the experiment was designed to look at the possibility of autorotation and power generation between blade and bladeless turbines for the best fit for Bangladeshi rivers as pump frequency and average flow speed increased.

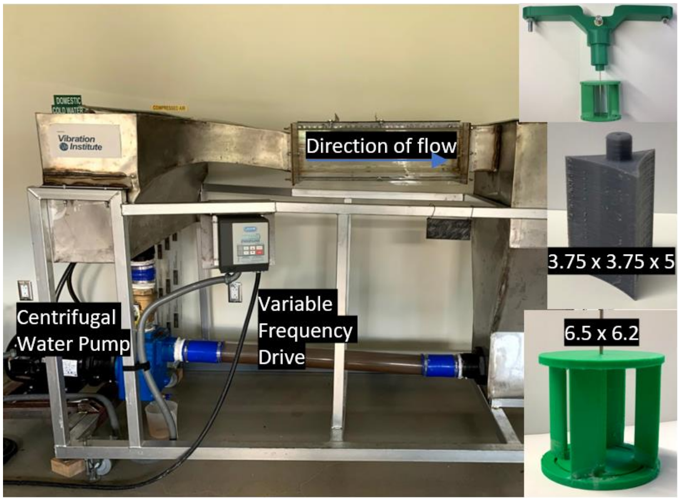


*Figure 1. Water flow tank used for the experiment and the 3D printed turbine models (Tri-curve and 45 degree Savonius turbine) used in the tests. Also shown is the DC motor and water-proof case assembly used in the experiment. The shown dimensions are in centimeters.*

## III. RESULTS

The flow speed of the water in the tank was collected using measuring tools at varying increments of the pump frequency. A Vernier Flow Rate Sensor was utilized in the flow tank to find the flow speed. The sensor can detect speeds up to the velocity of 4 m/s and can be used in room temperature liquid. The accuracy of the device is $\pm$1%. The accuracy of the device is +1 percent. The frequency of the pump can be adjusted using the digital VFD to vary the water flow speed in the chamber. The free Vernier's Logger Pro software was used to obtain the flow speed readings from the flowmeter. The data was then imported to an Excel spreadsheet, where it was further processed and plot in Figure 2. This figure shows the expected linear relationship between the average flow speeds and the pump frequency. The triangular symbols mark the speed data of free stream. It was found that the average speed and pump frequency can be related as $y = 0.0141x - 0.0705$ . The $R^2 = 0.9867$ indicate a minimum deviation of the data from this equation. Also shown in Figure 2 (circle and rectangular symbols) are plots of average water speeds when the wooden obstacle is placed upstream the flowmeter at distances of 10 and 20 cm. The trends of both data set are clearly linear with gradient higher than that of the free stream. This is expected as the obstacle would reduce the channel cross section area and hence increase the speed upstream the flowmeter. The distance from the flowmeter does not effect the average speed.

The pump frequency can be related to non-dimensional Reynolds numbers, which are typically used for flow characterization, calculated as follows:

$$R_e = \frac{\rho V D}{\mu} \quad (2)$$

Here, the ρ, V, D and μ are the fluid density, average fluid speed, turbine diameter, and fluid viscosity, respectively. For water, the density and viscosity are 998 kg/m$^3$ and 9.8x10$^{-4}$ Pa.s, respectively.

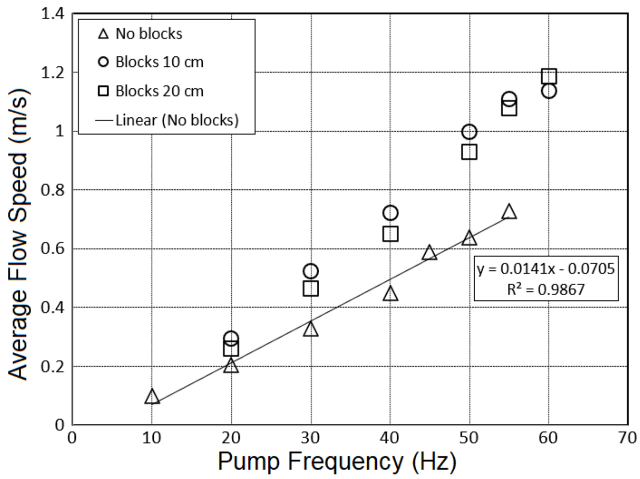


*Figure 2. Relationship between pump frequency to the average flow speed (left axis) without upstream blockage (triangle), and with blockages at 10 cm (circle) and 20 cm (square) distances from the turbine location upstream*

The study was carried out to simulate Bangladeshi rivers and assess the potential for hydrokinetic turbine application in Bangladesh. Testing bladeless turbines and measuring rotation and power production provided the inspiration for comparing power and maximum power for bladeless vs bladed turbines. Observing the turbines during 10 cm blockage testing, it was discovered both turbines remained relatively motionless when the flow speed is below 50 cm/s (pump frequency <30 Hz). The tri-curve demonstrated some movement (wiggling, small oscillation) between 30 and 35Hz (or about 50 cm/s). Beyond this speed, the turbine demonstrates clockwise and counterclockwise rotations. It can be estimated that the critical water speed associated with the initial autorotation for the tri-curve is about 50 cm/s. Using a representative diameter of 5 cm, this speed corresponds to approximately Re of 25K. For the Savonius turbine, it was observed that at pump frequency > 30Hz (slightly lower than that of the tri-curve turbine) the turbine exhibited autorotation and would rotate in one direction.

Figure 3 below illustrates the computed average power generated and maximum power potential from flowing water for the Tri-curve and Savonius Turbine. The average power is computed based on the average current and voltage over the sampling period of 90 seconds. On the other hand, the maximum potential power output $W_{max}$ is the product of maximum current and maximum voltage during the sampling period.

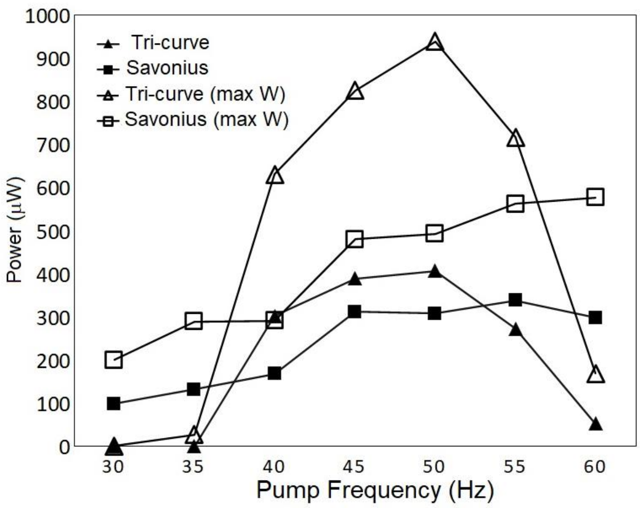


*Figure 3. Average power (closed symbols) and maximum power (open symbols) vs pump frequency for both turbines*

Results indicate that the turbines demonstrate different characteristics. The bladeless turbine shows a local maximum while the bladed turbine shows power that function with flow speed. The power production of Savonius turbine increases with flow speed (or pump frequency). The Tri-curve, on the other hand, follows the Savonius turbine's pattern until the pump frequency reaches 50 Hz, after which the power generation begins to decline. At 50Hz, the Tri-curve provided the greatest power out of the two turbines, 407.35 $\mu$W (micro Watt). The Savonius turbine, on the other hand, produced a maximum output 338.24 $\mu$W at 55 Hz. The Tri-curve's highest maximum power potential is 938.7 $\mu$W at 50 Hz, while the Savonius Turbine's maximum power potential is 577.72 $\mu$W at 60 Hz. The graph shows that as the pump frequency is increased, the Savonius turbine can produce greater power, although more study is necessary.

Figure 4 graphs the calculated efficiency of the Tri-curve (rectangle symbol) and Savonius (triangle symbol) turbines with respect to the pump frequency. The efficiency here is defined as the ratio of average power production to the maximum possible power production, formulated as follows:

$$\eta = \frac{W_{power}}{W_{max}} \quad (3)$$

Here $\eta$ represents the efficiency of the turbine, $W_{power}$ represents the power produced by the turbines based on average current and voltage. The maximum potential power output $W_{max}$ is the product of maximum current and maximum voltage during the sampling period.

It can be seen in Figure 4 that as the pump frequency increases from 30 Hz to 35 Hz, the efficiency for both turbines decreases from the baseline efficiency at 30 Hz. The Tri-curve displays a surge in efficiency after the pump frequency of 35 Hz, as shown in the graph. Following that, the efficiency continues to decline until the pump frequency reaches 55 Hz, at which point it declines substantially. For the Tri-curve, the efficiency graph follows closely the trend of the power curve that shows local maximum. Further investigation is needed to determine the cause of the local characteristics.

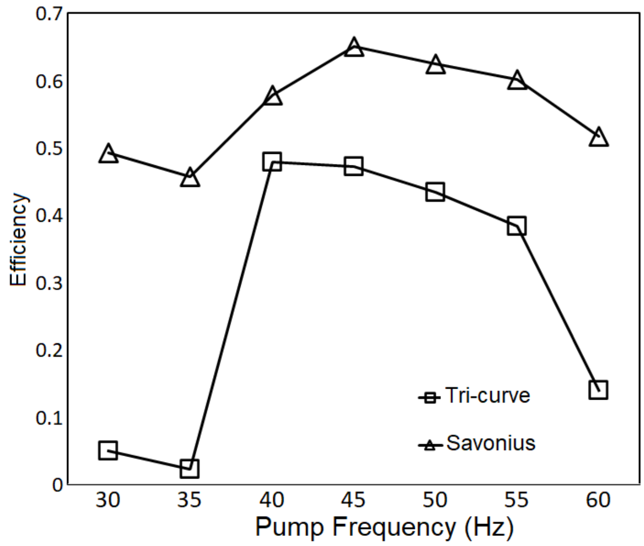


*Figure 4. Efficiency vs pump frequency for the Savonius turbine (triangle) and Tri-curve turbine (square).*

Unlike the Tri-curve, the Savonius Turbine's efficiency is predictable and consistent. The efficiency is always greater than 40%. The efficiency of the Savonius turbines improves between the pump frequency of 35 Hz and 45 Hz, as shown in the graph, before dropping. The efficiency reduction, on the other hand, is not as significant as the Tri-curve. The predictability of the Savonius turbine is what is desired from a turbine, as more efficient the turbine is, the closer it produces to its maximum power output. This also shows how effective the turbine would be when the river's velocity rises.

Figure 5 below represents the total rotation time for the Tri-curve and the Savonius turbine, which are represented by filled squares and filled circles, respectively. The rotation time represents the time period when the turbine produces either positive or negative current during the sampling time.

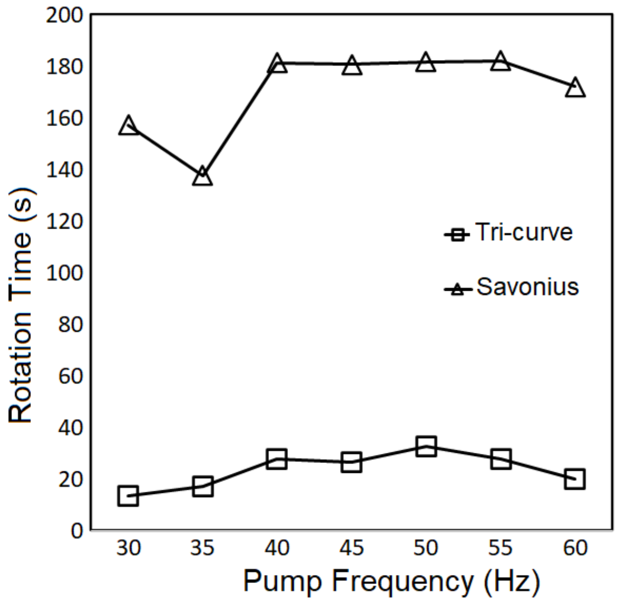


*Figure 5. Total rotation time vs pump frequency for the Savonius turbine (triangle) and Tri-curve turbine (square) undergoing water flow.*

Note that the maximum rotation time for the turbines would be 180 seconds as that is the sample size of the experiment performed. Figure 5 indicates that the Savonius turbine rotates more than tri-curve. The Savonius turbine rotates continuously up to its maximum sampling time of around 180 seconds. This occurs for almost all flow speeds. The rotation time drops between 30 Hz to 35 Hz, but then it spikes up to 180 seconds after 35 Hz. The tri-curve turbine, on the other hand, manages to rotate for only about 30 seconds during the sampling time. Due to its bladeless and full symmetrical nature, the turbine mostly demonstrates rotational oscillations and occasionally short-time rotations and flips in its direction.

The large-scale power production of turbine prototypes may be estimated using the power coefficient formulation defined as $C_P = \frac{W}{\rho\, n^3\, D^5}$ , where $\rho$ is the fluid density, $n$ is the revolution per minute, and $D$ is the diameter of the turbine [15]. Assuming that the power coefficients, fluid density, and revolution per minute for both the turbine model and prototype are equal, the output of the prototype can be calculated as follows:

$$W_p = \left(\frac{D_p}{D_m}\right)^5 W_m \quad (4)$$

where $W_p$ and $W_m$ are the power by the prototype and model, respectively and $D_p$ and $D_m$ are the diameters of the prototype and model, respectively. The formulation indicates that a-20 times scale-up would multiply the model's power by 3.2e6 times larger. Figure 6 below depicts the expected power for the scaled-up Tri-curve and Savonius turbines for the average velocities tested in our project. The velocities are correlated to the pump frequencies via the relationship presented in Figure 2 for the case of flow with upstream obstacle.

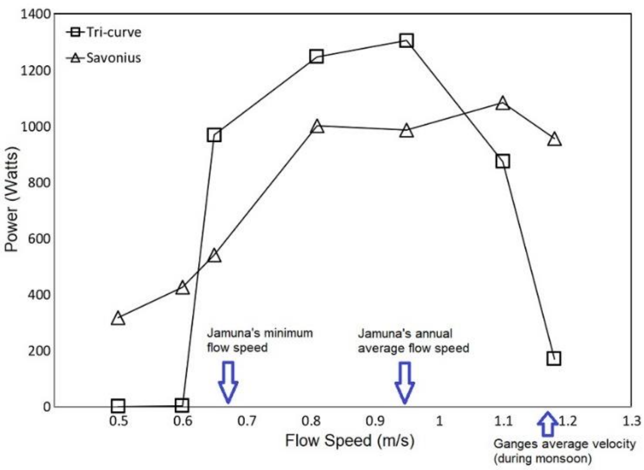


*Figure 6. Expected power vs flow velocities for the Savonius turbine (square) and Tri-curve (filled circle) undergoing water flow.*

Figure 6 indicates that the Savonius produces power that increases with the flow speed. On the other hand, the Tri-curve produces only produces high power for a certain flow range.

## IV. Conclusion

In this project, the results indicate that increasing the pump frequency, and hence the flow speed increases power generation. For the bladeless Tri-curve turbine, the increase of power with flow speed occurs over a range of flow speed. On the other hand, the Savonius turbine shows consistent power growth over the speed. Given the turbines' efficiency, power generation, and rotation time, it can be deduced that the Savonius turbine is a superior choice than the Tri-curve turbine. Given the power generation of both turbines even at small geometric sizes, it may be deduced that hydrokinetic turbines could be used on a wide scale in Bangladesh's rivers. Furthermore, as shown in Figure 5, having a higher fluid flow speed does not always entail to more turbine rotations and rotational duration. There are numerous aspects that contribute to the creation of electricity from hydrokinetic energy, and this experiment demonstrated that, regardless of the type of turbine used, hydrokinetic turbines could be used efficiently to produce electricity using a variety of shapes of turbines.

## References


[1] Iskandar Haiyat Mahmud, Afeefa Rahman, Anika Yunus, and Probir Kumar Pal, "A Study on Seasonal Variation of Hydrodynamic Parameters of Padma River", Journal of Modern Science and Technology, Vol. 5, No. 1, September 2017

[2] Maruf Dustegir, Md Islam, Shammi Haque, Munsur Rahman, and Anisul Haque, "Simulation of Flow Field Along the Jamuna River in Bangladesh", International Conference on the Status and Future of the World's Large Rivers at New Delhi, India, April 2017

[3] "Renewable energy | Definition of Renewable energy at Dictionary.com.".Available: https://www.dictionary.com/browse/renewable-energy. [Accessed: 19-Sept-2021].

[4] L. I. Lago, F. L. Ponta, and L. Chen, "Advances and trends in hydrokinetic turbine systems," Energy Sustain. Dev., vol. 14, no. 4, pp. 287–296, 2010.

[5] M. Sood and S. K. Singal, "Development of hydrokinetic energy technology: A review," Int. J. Energy Res., vol. 43, no. 11, pp. 5552–5571, 2019.

[6] M. J. Khan, G. Bhuyan, T. Iqbal, J. E. Quaicoe, M. T. Iqbal, and J. E. Quaicoe, "Hydrokinetic Energy Conversion Systems and Assessment of Horizontal and Vertical Axis Turbines for River and Tidal Applications: A Technology Status Review," Appl. Energy, vol. 86, no. 10, pp. 1823–1835, Oct. 2009.

[7] H. Anuta, P. Ralon, M. Taylor, and F. La Camera, "Renewable power generation costs in 2018," Int. Renew. Energy Agency, Abu Dhabi, 2019.

[8] H. J. Lugt, "Autorotation," Annu. Rev. Fluid Mech., vol. 15, no. 1, pp. 123–147, Jan. 1983, doi: 10.1146/annurev.fl.15.010183.001011.

[9] B. W. Skews, "Autorotation of many-sided bodies in an airstream," Nature, vol. 352, no. 6335, pp. 512–513, 1991, doi: 10.1038/352512a0

[10] J. Araneo, B. J. Chung, M. Cristaldi, J. Pateras, A. Vaidya, and R. Wulandana, "Experimental control from wake induced autorotation with applications to energy harvesting," Int. J. Green Energy, vol. 16, no. 15, pp. 1400–1413, 2019, doi: 10.1080/15435075.2019.1671413.

[11] A. B. Rostami and A. C. Fernandes, "The effect of inertia and flap on autorotation applied for hydrokinetic energy harvesting." 2014

[12] R. Wulandana, "Open Water Flume for Fluid Mechanics Lab," Fluids, vol. 6, pp 242, 2021

[13] S. Singha and K. P. Sinhamahapatra, "Flow past a circular cylinder between parallel walls at low Reynolds numbers," Ocean Eng., vol. 37, no. 8–9, pp. 757–769, 2010.

[14] N H Al Mamun, M Q Islam, D G Infield, and A K M Sadrul Islam, "Zero Head Water Turbine for Small Scale Electricity Generation in Bangladesh"

[15] Y.A. Cengel, & J.M. Cimbala, "Fluid Mechanics Fundamental and Applications (1st ed.). McGraw Hill, 2006