Design & Analysis of Rotor which Produce the Electricity

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Abstract— A major difficulty encountered by a horizontal axis water turbine is the limit of aerodynamic torque that it can withstand at high water speed. A novel strategy is proposed to improve the operational capability of a prototype scale system by decreasing its water speed for power generation. The paper is focused on the research of design and development of rotor which works on the slow flowing water at 2 mph.

Key words: Rotating Blades, Shaft, Generator, Bearing, Rotating Drum, Gear System

I. Background

In many areas of the world, the need for energy and/or energy dependence is critical concerns. In an attempt to address these problems, a great deal of effort has been focused on clean renewable energy generation. However, each of the conventional approaches has its own drawbacks, resulting in an ongoing need for better energy-generation solutions.

II. Introduction

The use of renewable energy resources is becoming an important factor in meeting the energy needs while significantly reducing the environmental impacts. Solar power, hydropower and water resources technologies, for example, continue to decrease in costs and increase in efficiency, while removing commercially adverse environmental effects. Many traditional renewable energy production technologies, however, require large amounts of capital and / or real estate for execution. For example, under the rotor (turbine) it may need to be usually built and / or sited in fast flowing water. So various researchers have tried to improve the design of the Hydro-Rotor blade and increase their efficiency and eliminate design problems.

III. Illustration

A. Various Designs of Hydro- Microturbines

K. Sornes [1] in his paper have discussed about various types of blade design. The axial flow turbine and cross flow turbine being two most common small scale concepts of hydro-kinetic turbine. The axial concept has a rotational axis of rotor which is parallel to the incoming water stream. The cross flow concept on the other hand, has a rotational axis of rotor which is parallel to water surface. The advantage of cross flow turbines over axial flow turbine is that they can rotate un-directional even with bi-directional flow. Cross flow turbine can be divided into two groups, namely Vertical axis (Axis vertical to water plane) and In-plane axis (Axis on the horizontal plane of water surface). From which we are going to discuss namely six traditional types of blade design.

In cross flow turbine the water passes through the turbine transversely, or across the turbine blade. It provides additional efficiency. Cross flow turbines are often constructed as two turbines of different capacity that share the same shaft [1]. The different types of Cross-flow turbines are explained below.

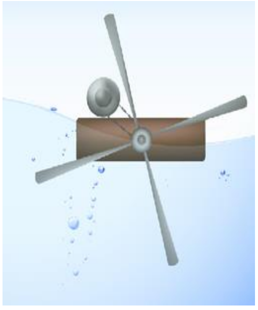


Fig. 1: In-plane axis [2]

J. Khan [2] in his research paper have discussed about In-plane axis. In-plane axis is better known as floating water wheels. These are mainly drag based devices and inherently less efficient than their lift based counter parts. The large amount of material usage is another problem for such turbines. Darrieus turbines with In-plane axis may also fall under this category. But such systems are left common and suffer from bearing and power take off problems.

Fig. 2: Squirrel cage Darrieus [3]

G. J. M. Darrieus [3] has presented two major types of Darrieus mechanisms. They differ on how they handle the centrifugal force impose on the blade of the turbine, one is called Squirrel cage variant which consists of two disks at top and bottom with the airfoil running straight up and down between their rims. This allows the centrifugal force to be handled by the relatively sturdy construction of the disks. The advantage of turbine is to be able to progressively get into rotation. The disadvantage of it is the low reynold number.

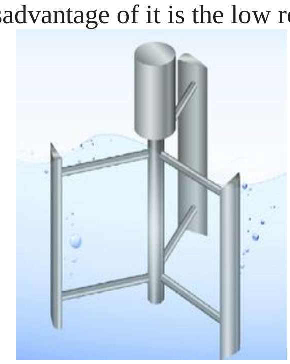


Fig. 3: H-darrieus [4]

S. Roy et al [4] in his work have described about H-darrieus turbine. H-Darrieus are breed of vertical axis wind turbine designed by George Darrieus in 1920's. They are capable of producing much power than most typical wind turbine. H-Darrieus rotor is a lift type device having two or three blades designed as airfoils. The blades are attached vertically to centre shaft through support arms. The support to vertical axis helps rotor to maintain its shape. One major disadvantage of H-type Darrieus turbine is that since lift forces drives them that must be brought to a minimum speed before the forces generated as sufficient to propel the turbine. The starting torque coefficient is zero and at low tip speed ratio it is even negative. Therefore, a special motor is required to start the rotor. With increase of height to diameter ratio, velocity magnitude difference from inlet up to rotor increases up to height to diameter ratio 1.0 and then decreases loss of performance for turbine with increases of height to diameter ratio. It can be concluded that velocity difference from inlet up to rotor is responsible for power stroke of blades during its clockwise direction. The Tip Speed Ratio of H-Darrieus turbine is high, hence, it rotate faster [5].

Fig. 4: Darries turbine [6]

L. J. Hagen et al [6] in his research paper has summarized about Darries turbine. It was patented by Georger Jean Marie Darrieus, in 1931. Darrieus turbine is a vertical axis turbine. High rotating opened is achieved by the curvature of the blade. It is powered by phenomenon of lift. There are major difficulties in making Darrieus turbine and making it self- starting. In Darrieus blade the airfoils are arranged to that they are symmetrical and also zero rigging angle. There is a problem in this turbine the angle of attack change of the turbine spins, so that each blade generator max torque at two points on its cycle.

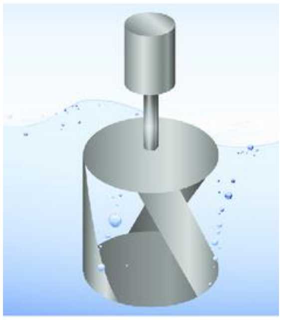


Fig. 5: Gorlov turbine [7]

A. M. Gorlov [7] has patented information about Gorlov turbine also known as "cross flow helical turbine". It is similar to Darrieus turbine. Gorlov reported from experimentally testing that maximum efficiency for Gorlov turbine is around 35%

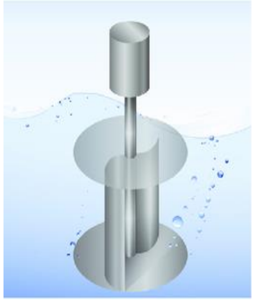


Fig. 6: Savonius turbine [8]

I. Dobreva et al [8] in his paper have briefed about Savonius turbine. It generates high torque at low speed. The maximum power coefficient is larger when rotation direction is water is clockwise for clearance ratio greater than 0.73.

B. *Recent Trend*

There are various modification done in rotor (turbine) to improve certain parameters such as efficiency, tip speed ratio, self-starting ability, torque etc. For example, hybrid of Darrieus and Savonius turbines are available. But here it was such as Savonius turbine using some modification is that taking horizontal axis because of the waves is horizontal direction

The Waterotor is ideal for the world's energy requirement through renewable way because it transforms the energy in slow-moving rivers and ocean currents to electrical power, thereby making a continual available 24 hours a day to people.

Waterotor is unique in that its highly developed design can extract a very high level of energy (Coefficient of Power) from very slow flowing water about 2 to 10 MPH. Waterotor stands alone by extracting 30 % of slow moving water energy and converting this energy to electricity at these very slow water flow speeds.

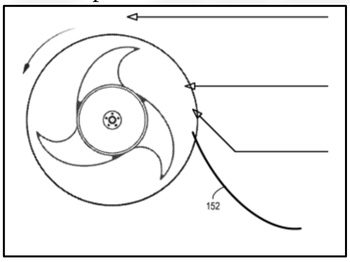


Fig. 7: rotor with deflector

A water flow deflector may guide water into the vanes. The deflector or frontal stator may have trailing edge close to the blades of the vanes and above a stagnation point associated with the system.

IV. THEORY AND DESIGN

Wind power, Pw is defined as the multiplication of mass flow rate, ρAV and the kinetic energy per unit mass, ½mV²[9]. The wind power is denoted by the equation of:

$$\therefore P_w = \frac{1}{2} m v^2 = \frac{1}{2} (\rho A v) v^2 = \frac{1}{2} \rho A v^3$$

Where, Mass flow rate, m= ρav

Kinetic energy, K.E= $\frac{1}{2} m v^2$

The swept area for Savonius Wind Turbine is calculated by multiplication of rotor diameter, D and the rotor height, H [10]. The larger the swept area, the larger the power generated.

$$A = D.H$$

Where, D= Rotor diameter
H= Rotor height

The water power in Equation (1) represents the ideal power of a water turbine, as in case of no aerodynamic or other losses during the energy conversion processes. However, there is not possible for all energy being converted into useful energy. The ideal efficiency of a water turbine is known as Betz limit. According to the Betz limit,[9] there is at most only 59.3 % of the wind power can be converted into useful power. Some of the energy may lose in gearbox, bearings, generator, transmission and others [11]. The maximum power coefficient, Cp for Savonius rotor is 0.35. Hence, the Cp value used in this project is 0.35 and the power output, P with considering the power efficiency is:

$$P = 0.15\ \rho A V^2$$

Aspect ratio is a crucial criterion to evaluate the aerodynamic performance of Savonius rotor. [12] Suggests the Savonius rotor is designed with rotor height twice of rotor diameter and this lead to better stability with proper efficiencies.

$$AR = \frac{H}{D}$$

Tip speed ratio, λ is defined as the ratio of the linear speed of rotor blade ω.R to the undisturbed wind speed, V [13]. ω is the angular velocity and R represent the radius revolving part of the turbine. The maximum tip speed ratio that Savonius rotor can reach is 1. High tip speed ratio improves the performance of wind turbine and this could be obtained by increasing the rotational rate of the rotor.

$$\therefore \lambda = \frac{\omega R}{V}$$

Where, ω = angular velocity
R = radius revolving part of turbine

Solidity is related to tip speed ratio. A high tip speed ratio will result in a low solidity [16]. Solidity as the ratio of blade area to the turbine rotor swept area. For HAWT, the solidity is defined as[9]

$$\therefore \sigma = \frac{nd}{R}$$

Where, n = number of blade
d = chord length (diameter of each cylinder)
R = radius of wind turbine

Where n is the number of blades, d is the chord length or can be defined as the diameter of each half cylinder, and R is radius of water turbine. Many researchers have proved that the higher the number of blades, the higher the performance of most wind turbine.

Parameter	Value
Power generated	2.688 watt
Swept area	0.24 m^2
Rated wind speed	0.4 m/s
Aspect ratio	1:0.4
Solidity	0.417
Diameter-Height	480mm-500mm
Number of blades	3

Table 1: shows the design parameters used in this research.

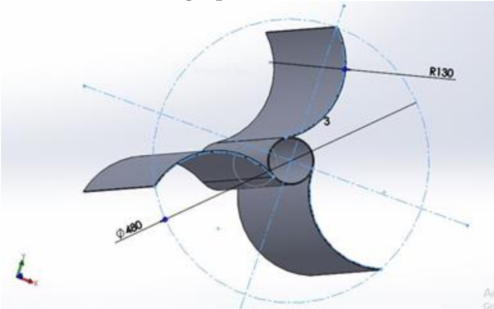


Fig. 8: savonius rotor blade

The design of the Savonius rotor blade is shown in Figure 8, while Table 1 shown the detail dimension of the Savonius rotor blade. The material proposed for the Savonius rotor blade in this paper is Acrylonitrile butadiene styrene (ABS) plastic. Since the manufacturing process and material cost are not considered in this paper, the material is chosen based on the material properties. Table 2 summarizes the general properties of the ABSP and also rotor blade for this research.

Parameter	Value
Swept area, A	0.24 m^2
Rotor Diameter, D	480 mm
Rotor Height, H	500 mm
Chord length, d	210 mm
Overlap distance, e	70 mm
Blade thickness, t	2 mm
Elastic Modulus(ABSP)	2 GPa
Poisson's Ratio(ABSP)	0.394 N/A
Mass Density	1000 kg/m^3
Tensile Strength(ABSP)	30 MPa
Yield Strength(ABSP)	45 MPa

Table 2: specification and dimension of material

V. SIMULATION AND ANALYSIS

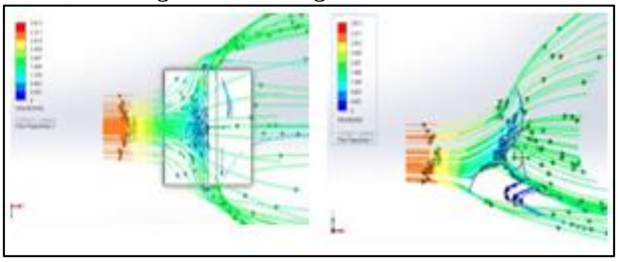
In this paper, two kinds of simulation and analysis were done i.e. Computational Fluid Dynamics (CFD) Analysis and Structural Analysis by using Solid Works Flow Simulation and Solid Works Structural Simulation/Cosmo.

A. Computational Fluid Dynamics (CFD) Analysis

The purpose of this simulation is to obtain the pressure different between the concave and convex surface. The pressure difference between the concave and convex blade surface of the Savonius rotor induced drag force that turns the blade. The pressure difference was obtained by implementing Computational Fluid Dynamics (CFD) analysis on Solid Works Flow Simulation. The two flow types in this paper were external flow and internal flow analysis. Both analyses were static analysis. The engineering goals for the internal analysis and the external analysis are two Surface Goals and four Global Goals. The two Surface Goals are dealing with total pressure, for both concave and convex surface. The four Global Goals are deal with total pressure, velocity, normal force and force.

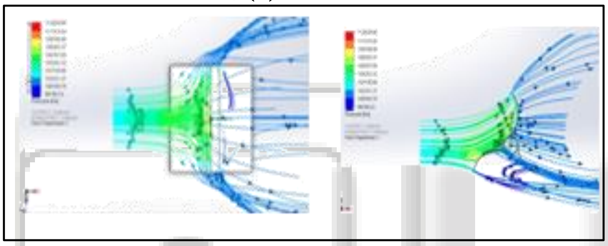
B. External flow analysis

The flow type of Savonius rotor blade is considered as external flow since it involves a solid model which is fully surrounded by the flow. The fluid flow is not bounded by outer surface, but bounded only by the Computational Domain boundaries. The Computational Domain is firstly defined to 7m x 7m x 9 m, which means that the Savonius rotor is enclosed by this region and the volume is fixed within this fluid flow field. The Computational Domain can be set in different size, however, the bigger the Computational Domain, the longer the meshing and solution time.



(a) (b)

Fig. 9: flow pattern on external flow of velocity (a) top view, (b) left side view



(a) (b)

Fig. 10: flow pattern on external flow of pressure (a) top view, (b) left side view

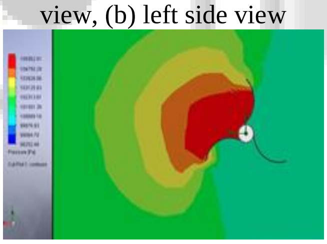


Fig. 11: External flow distribution pressure.

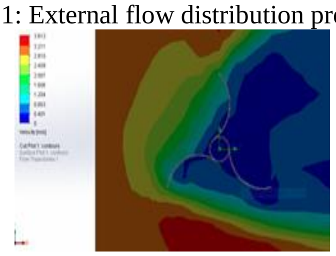
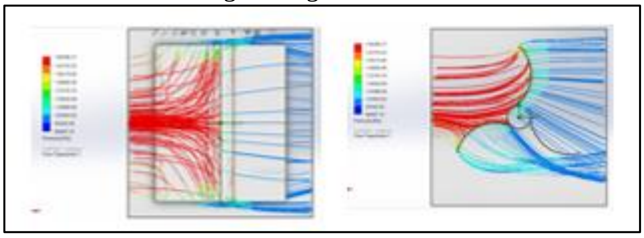


Fig. 12: External flow distribution velocity

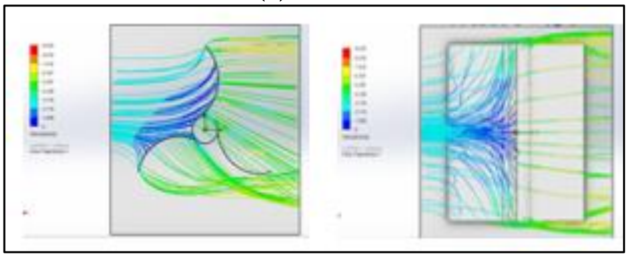
1) Internal Flow Analysis

In this analysis, the wind enters the wind tunnel with the size of 10m x 25m x 8m, flow through the Savonius rotor blade, and then exits through the outlet that is set to environmental conditions. The Savonius rotor blade is placed in the middle of wind tunnel. In internal analysis, the Computational Domain is automatically enveloped the model wall, which is the wind tunnel size for this paper. The lids are used to apply boundary conditions which introduce to inlet velocity and outlet condition as shown in Figure 6. The lid thickness for an internal analysis is usually not important for the analysis. However, the lid should not be so thick until the flow pattern is affected downstream in some way. If the lid is created to be too thin, this will make the number of cells to be very high. For most cases the lid thickness could be the same thickness used to create the neighboring wall [14]



(a) (b)

Fig. 13: flow pattern on internal flow of pressure (a) top view, (b) left side view



(a) (b)

Fig. 14: flow pattern on internal flow of velocity (a) left side view, (b) top view

Above shows the meshing of the model and pressure distribution along the water tunnel, observed from the top. The maximum pressure is indicated by the red color region whereas the minimum pressure is in the blue color region. Figure 13 also shows that the concave surface experience higher pressure than convex surface. The maximum and minimum pressure found in this analysis is 149.286 kPa and 90.487 kPa respectively.

C. Comparison of external and internal flow analysis

Both external and internal flow analysis shows different results. From the view of pressure distribution, both analyses have shown that the pressure is higher on the concave surface and lower on the convex surface [15]. However, the pressure differences of both analyses are not same. Internal flow analysis has higher pressure differences than external flow analysis, which are 322.15 Pa and 262.65 Pa respectively. This explained by the velocity vector in Figure 4 and Figure 7.

Since the Savonius rotor was set at static position, when the water reached on the blade, it was not turning as in real world condition and hence blocked the wind flow. From Figure 9, the velocity vector plot shows that the wind which blocked by the Savonius rotor blade are tend to flow in the direction that bias from the water flow in the external flow analysis. The water was not completely flow through the rotor blades. However, the water was completely passed through the Savonius rotor blades as shown in Figure 11. This is because the Savonius rotor is bounded by the water tunnel wall. The water which blocked by the blade is reflected to the water tunnel wall and then passes through the Savonius rotor blades. Hence, in the static analysis, the result of internal flow analysis is more accurate and precise

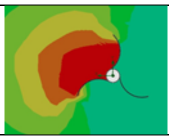
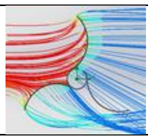
Aspect	External Flow Analysis	Internal Flow Analysis
Pressure Differences	112.829KPa	149.286KPa
High Pressure Region	Concave surface	Concave surface
Low Pressure Region	Convex surface	Convex surface
Vector Plot		
Flow Pattern	The wind flow is blocked by the Savonius rotor blades and bias from the wind direction. Since there is no wall boundary, the wind flows out from the Computational Domain. The wind is not completely flow through the rotor blades.	The wind flow is blocked by the Savonius rotor blades and bias. However, the Savonius rotor is bounded by the wall of wind tunnel. Hence, the wind is completely flow through the rotor blades.

Table 3: shows the comparison summary of the external and internal flow analysis.

VI. Satisfaction of Waerotor

- Operates in slow-moving water; as lower than 1.5 mph
- Mobile, requires no bottom fixtures or foundation, only simple anchoring
- Strong yet simple structural integrity (‘drum like’)
- High coefficient of power (high-energy output vs. size)
- Environmentally friendly (no high speed spinning blades)
- Broadens a competitive market from very low to high water flow speeds
- Most cost effective (simple to build and fully scalar)

VII. Conclusion

- As an emerging renewable energy solution, comparative information on River Current Turbine systems is invaluable. This work attempts to summarize the state-of-the-art of hydrokinetic turbine technology.
- Advantages and disadvantages of various turbine rotor models have been discussed. From the survey, it is evident that the hybrids made for increasing the performance of non-conventional turbines can give better output as compared to conventional turbines.
- From the entire traditional the horizontal axis turbine has the maximum efficiency and vertical have the minimum efficiency.
- Waterotors (horizontal axis turbine) are truly based on their design, their configuration, etc. Large-scale waterotors requires high precision blades, high accuracy, which is difficult to manufacture. So designs of rotor blades are difficult and hence expensive.

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