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Design of Low Head Hydrokinetic Turbine

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ABSTRACT

Vertical axis Darrieus water turbine, very suitable for use in river flow in the utilization of the kinetic energy. Darrieus H-type hydrokinetic turbines are electromechanical energy converters that generate electricity from harness kinetic energy of flowing water to generate electricity. The design water speed is 1.5m/s , tip speed ratio 4 and the final power output is designed to be 100W through water turbine. The designed water turbine has 3 blades. Electricity is generated by using Darrieus H-type hydrokinetic turbine. Blade design is made of fiber and the chord length of 0.0742m. The diameter and the height of turbine are 0.354m and 0.531m with two circular end plates. Steel shaft has 7.85mm in diameter. Hydrofoil NACA 0018 is chosen based on max C_L/C_D ratio at angle of attack 10′. The design hydrokinetic turbine can be used for pico hydro generation in rural communities non-connected to electricity. This research can provide to generate the electricity Darrieus hydrokinetic Turbine with low cost and local materials.

KEYWORDS: *Darrieus water turbine, Hydrokinetic turbine, Power, Tip speed ratio, NACA*

1. INTRODUCTION

Nowadays, renewable energy such as bio fuel energy, wind energy, solar energy, geothermal energy, biomass energy and hydropower energy is very important. Firstly, renewable energy technologies are clean energy that has a much lower environmental impact than conventional energy technologies.

Small scale hydro power generation is one of the types of renewable energy. Hydrokinetic energy conversion is one of these concepts to produce electricity from the runoff water in river, canal and hydropower channel. The kinetic energy conversion in the river is most valuable research. Hydrokinetic energy conversion has no requirement of large civil structure that why it can easily install in river and marine environment.

The working principle of water turbines are group into two, namely the impulse turbine and reaction turbine. Impulse turbine is a high head low flow rate pelton turbine and reaction turbine is a low head high flow rate propeller turbine.

2. Classification of Hydrokinetic Turbine

Hydro turbine like a windmill is a rotary engine operating in the water, and it converts hydrokinetic energy to mechanical energy. Unlike the turbines used in the large hydro dam, which produce large amounts of energy from potential energy of waterfall, the turbines used in the low head power applications are different. A general classification of these turbines based on their physical arrangements. Based on rotation of the axis of shaft with respect to the flow of water hydrokinetic turbines are classified into three types such as horizontal axis, vertical axis and cross flow. The vertical axis turbines are similar as wind turbine. The horizontal axis turbines have axes parallel to the fluid flow and employ propeller type rotors. Horizontal axis turbines are common in tidal energy converters and are very similar to modern wind turbines from concept and design point of view. Cross flow turbines are less efficient than axial flow turbines, however, cross flow turbines have many potential advantages for marine applications. Hydrokinetic turbines can be used both in rivers or oceans. The cross flow turbines have rotor axes orthogonal to the water flow but parallel to the water surface as shown in Figure 1.

(a)H- Darrieus (b) Squirrel cage Darrieus

(c) Savonius (d) Darrieus

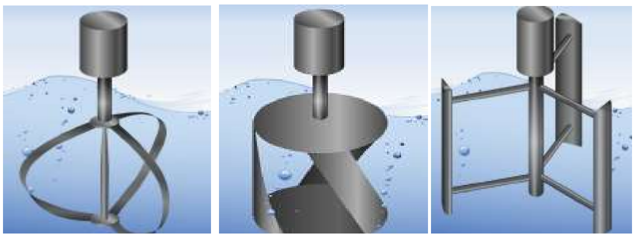
Figure1. Vertical axis kinetic turbine

2.1. Darrieus Turbine

Darrieus type turbines are used in many hydrokinetic projects. Darrieus cross-flow turbine is the most generally used system, and this makes the turbine rotate by converting the potential energy of the water into kinetic energy. This turbine has the advantage of high efficiency, but the construction cost for a dam or waterway is high and can cause significant environmental problems. In this way such small hydropower systems do not require a dam to be built.

Darrieus turbine was patented in France in 1925 and in the US in 1931 by Georges Jean Marie Darrieus. Three hydrofoils are attached to a central axis which they rotate around. The lift force created can pull the blades of the turbine around at a speed greater than the current flow. Darrieus water turbine has become popular in harnessing tidal power.

Darrieus turbine mainly consists of two or more hydrofoil blade. Darrieus turbine is a lift driven turbine and savonius turbine is a drag driven turbine. Types of Darrieus turbines are as shown in Figure 2.



(a)Darrieus (b) Gorlov (c) H-Darrieus

Figure2. Darrieus turbine and Savonious Tubine

3. DESIGN CONSIDERATION OF H- DARRIEUS TURBINE

Power equation of hydrokinetic turbine is similar to wind turbine since both systems involve fluids and either air-foil or hydrofoils. Power equation for hydrokinetic turbine is given as;

$$P_t = \frac{1}{2} \rho A V^3 C_p \qquad (1)$$

Where, P is the power, ρ is the density of water, A is cross sectional area of water flow through turbine, C_p is the turbine power coefficient and it can be defined as;

$$Cp = \frac{P_t}{P_w} \qquad (2)$$

The available water power;

$$P_w = \frac{1}{2} \rho A V^3 \qquad (3)$$

Where, V is water velocity.

3.1 Blade Profile

Blade profile shape can have a significant impact on performance due to the pressure forces that develop when subjected to an incident flow. Some of the blade design parameters include chord length, leading edge profile, trailing edge profile blade thickness-to-chord ratio, location of maximum thickness, and blade camber. The blade chord line connects the leading edge of the blade to the trailing edge of the blade. Blade camber refers to the position of the mean thickness of a blade along its length. For a symmetric, uncambered blade, the camber line and the chord line are co-linear. Traditionally, vertical axis turbine blades have been designed with the common NACA 4-digit series symmetrical profiles due to the availability of the lift and drag data for a large range of Reynolds numbers. In terms of lift generated, symmetric hydrofoils NACA0018 is chosen optimum blade hydrofoil.

3.2 Number of Blade

The number of blade is directly proportional to solidity. For any turbine, as the number of blade increase, the chord length of a blade must be decreased to maintain a desired solidity ratio. Conversely, for constant chord length, the solidity of the overall device will increase number of blade increase. If allowing solidity to increase, increasing number of blade should result in increased starting torque, a lower operating tip speed ratio and lower overall power performance. Increasing number of blade while maintaining solidity constant had mixed result: for flat plate blade, C_p was relatively unchanged from 3to 12 blades, but for hydrofoil – shaped blades, the power coefficient substantially decreased. This suggests that both number of blades and blade solidity may be responsible for the shift in power performance. The operating point at which this begins to impact the design depends on number of blades, size, chord length, and rotational speed.

3.3 Solidity Ratio

Solidity ratio refers to the amount of turbine swept area that is solid material versus which is void space. The definition used in the present study considers the amount of blade material as measured on a chord basis relative to the circumferential sweep area of the blades, as given by Equation.

$$\sigma = \frac{nc}{D\pi} \qquad (4)$$

Where, n is number of blade, c is chord length.

Darrieus turbine, the best solidity for obtaining maximum power was 0.2-0.3.

3.4 Tip Speed Ratio

Tip speed ratio is the ratio of the blade speed to water speed. The tip speed ratio is an extremely important factor in water turbine design. The blade tip speed, depends on the blade hydrofoil profile used, the number of blades, and the type of water turbine. The natural tip speed ratio of the Darrieus turbine were found 3-5 in all resources used. Another important concept relating to the power of Darrieus hydro turbine is the optimal tip speed ratio, which is defined as the ratio of the velocity of the blade tip to the free stream water velocity. The tip speed ratio is dimensionless factor defined by using the Equation;

$$\lambda = \frac{R\omega}{V_w} \qquad (5)$$

3.5 Aspect Ratio

Aspect ratio (AR) refers to the ratio of turbine height to diameter, as in Equation;

$$AR = \frac{H}{D} \qquad (6)$$

Aspect ratio has also been defined for a Darrieus turbine as ratio of blade length to chord length.

$$AR_B = \frac{l}{c} \qquad (7)$$

Where, l is the spanwise length of the blade

4. DESIGN OF H-DERRIEUS TURBINE

Given data: $P_e = 100W$
$V = 1.5\ m/s$
$\rho = 1000 kg/m^3$
$C_p = 0.35$
$\eta_g = 90$

The swept area can be calculate by this equation.

$$P_t = \frac{1}{2} \rho A V^3 C_p \eta_g \qquad (8)$$

$A = 0.1881\ m^2$

The swept area of the turbine rotor is H-type and vertical axis. So, the diameter and height of the turbine rotor are related as follows:

$A = D \times H$ (9)

The aspect ratio of the Darrieus turbine is 1.5.

Thus, the height of the turbine is 1.5 times of the diameter.

$H = 1.5\ D$

$A = D \times 1.5\ D$

$D = 0.3541\ m$

$H = 1.5 \times 0.3541 = 0.5312\ m$

4.1. Design of Blade

The blade thickness and shape is determined by the hydrofoil used, in this case it will be a NACA hydrofoil, where the blade curvature and maximum thickness are defined as percentage of the chord.

Thus, chord length of hydrofoil can be calculated the following equation 4,

$$\sigma = \frac{nc}{D\pi} \quad (10)$$

Solidity ratio = 20%

$c = 0.0742\ m$

Can get the value of linear velocity from the equation of tip speed ratio. The tip speed ratio is the ratio of the blade speed to the velocity of water.

Tip speed ratio is 4, the velocity of water is 1.5m/s.

$\omega R = 1.5 \times 4 = 6\ m/s$

$\omega = 33.89\ rad/sec$

The speed of turbine can be calculated by the following equation.

$$\omega = \frac{2\pi N}{60} \quad (11)$$

$N = 320\ rpm$

The relative velocity is the square root of the sum of the square of water velocity and linear velocity. So, the following equation;

$$u_{rel} = \sqrt{v_w^2 + (\omega R)^2} \quad (12)$$

$= 6.2\ m/sec$

4.2 Selecting of Airfoil

To select the hydrofoil, the Reynolds number as it is an important parameter in selecting the hydrofoil. The calculation of Reynolds number is as from this equation.

$$Re = \frac{U_{rel}\ \rho\ C}{\mu} \quad (13)$$

$= 515600$

In the above Reynolds number calculation, the constant value of viscosity of water (μ) is taken as 8.9×10^{-4}.

Hydrofoil selection for a Darrieus blade is limited to symmetrical profiles. Symmetrical hydrofoils are used in the Darrieus because lift is must be produced from both sides of the blade. In order to get the optimum design, the ratio of must be as high as possible.

NACA 0018 is selected for this design as it will provide the optimum design condition for constructing the blade of this Darrieus H Type hydrokinetic turbine.

4.3. Thickness of Airfoil

As the hydrofoil is NACA 0018, so the maximum hydrofoil thickness to chord length ratio is 18%. The thickness (T) of the hydrofoil can be calculated as follows:

$T/C = 18\%$

when, $C = 0.0742\ m$

$T = 0.18 \times C$

$= 0.0134\ m$

So, Darrieus H-type hydrokinetic turbine of thickness of hydrofoil blade is 13.4mm.

4.4. Calculation of Power Output

Darrieus Cross-Flow Turbine works converting the kinetic energy of water into electrical energy.

Power extraction from water from the equation 3.

$$P_w = \frac{1}{2} \rho A V^3$$

$= 317\ W$

The turbine power output from this equation,

$P_t = P_w \times C_p$ (14)

$= 111W$

C_p = power coefficient = 0.35

The mechanical power is obtained after considering about the mechanical losses. The following is the calculation of the mechanical power output.

$P_m = P_t \times \eta_m$ (15)

$= 88.9\ W$

$\eta_m = 80\%$

After considering the generator losses, the generator power output is the required power output and it is described in the following:

$P_g = P_m \times \eta_g$ (16)

$= 80\ W$

$\eta_g = 90\%$

If the device was inserted into free flowing water averaged 1.5 m/s for a 24 hour day, then the total energy produced for the whole day from this equation.

$E_t = P_t \times time$ (17)

$= 2.67\ kWhr$

Table1 Result Data

Sr.	Parameters	unit
1	Aspect ratio	1.5
2	Tip Speed ratio	4
3	Swept Area	$0.1881\ m^2$
4	Diameter	0.354 m
5	Height	0.531 m
6	Turbine speed	320 rpm
7	Relative velocity	6.2 m/sec
8	Thickness of airfoil	0.013 m
9	Chord length	0.0742 m

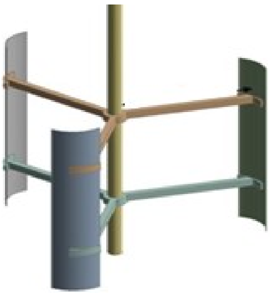


Figure3. ISO View of Darrieus Turbine

5. CONCLUSIONS

The electrical power output is designed to be 100W through the vertical axis Darrieus H-type turbine. In this research, the prototype is implemented to run at about 1.5 m/s water velocity. The blade which is made of fiber has 0.3541m in diameter, 0.5312m height.

The results of lift and drag coefficient for Profili Software are 1.0889 and 0.0170. In this paper, symmetrical hydrofoil is selected for Darrieus H-type turbine by considering torque to get high efficiency. In the design the process of the blade, it can be constructed by locally in rural communities or near them for reducing turbine total cost.

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