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Design and Modelling of a Two Stage Savonius Wind Turbine

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Abstract

This paper will focus on the basic design and technical equipments to build a low cost Savonius wind turbine that can be used to generate electrical power or water pumping. The turbine consists of vertical axis, self-starting, low tip speed ratio and high torque type for smoothen movement and equilibrium of motion for rotor multi stages must be employed.

An attempt is made to explain the design of a two stage Savonius wind turbine ofopen type with overlap for the blades and suitable spacing, for a good design we can get lift force on suction surface of blade in addition to drag force on the pressure surface of the same blade at same time.

Keywords: Savonius wind turbine, low cost wind turbine, power generation, water pumping, low wind.

1. Introduction

The Savonius wind turbine is to spin becauseof the different pressureon both upstream and downstream and the turbines extract much less of the wind's power than other similarly-sized lift-type turbines. The swept area of a rotor may be near the ground, if it has a small mount without an extended post, making the overall energy extraction less effective due to the lower wind speeds found at lower heights.

2. Power and Rotational Speed of a SavoniusRotor

The maximum power in watts (W) of a Savonius rotor can be calculated from the below equation.

$P_{max} = 0.18 * H * D * V^3$(Watt) (1)

Where: H=The height (m)

D= The diameter of the rotor (m)

V= The wind speed in meters per second (m/s)

The rotational speed in revolutions per minute (rpm) of a the rotor is calculated using the below equation

$N = \frac{60.\lambda.V}{\pi.D}$(rpm) (2)

Where: λ = factor called tip-speed ratio

The tip-speed ratio λis a characteristic factor of specific windmill. Its value ranges between 0. 5 and 14. It is obtained by dividing the speed of the tips of the blades by the wind speed. In a Savonius rotor λis approximately equal to unity (λ ≈ 1).

3. The Power Coefficient C_p Analysis

The relation between the power coefficient C_p and the wind speed can express on the basic theory of the wind turbine. Basically the power of the rotor that can extract from the wind (P_w), is less than the actual available wind power (P_a)in order to calculate the performance of this wind turbine. Practically, when the turbine is placed in a wind tunnel, the power can be extracted from the wind and can be found by the following steps:

1. Find the average of wind speed through the rotor area is $(V_1+V_2)/2$ where V_1 and V_2 are the inlet and outlet wind speed in m/sec respectively
2. Define the mass of the airflows passing through the S-rotor area (A) per second in stream tube.
3. $\dot{m}=\rho A(V_1+V_2)/2$ (3)
4. – And according to the kinetic energy, $KE=1/2mV^2$ (4)
5. – The power extracted, $P=1/2\rho A(V_1^2-V_2^2)$ (5)

Substituting the mass of air to this formula the power that rotor can be extracted from the wind is

$P_w=\rho/4(V_1^2-V_2^2)(V_1+V_2)A$ (6)

When swept area A = H (2d-e) = H * D(m^2) (7)

Similarly, if the S-rotor generates the electricity, the power that the rotor can extract from the wind is

$P_w = E * I$(Watt) (8)

The available power, P_a from the wind is

$P_a=1/2\dot{m}V_1^2=1/2\rho AV^3$ (9)

Where$\dot{m} = \rho AV_1$ (10)

ThereforeP_a=1/2$\rho A V_1^3$ (11)

The power coefficient C_p is given by

$$c_P = \frac{P_w}{P_a} \quad (12)$$

The power coefficient C_p and the torque coefficient C_m are related to each other. The power coefficient C_p can be calculated by the equation $C_p = C_m X$ (13)

Where X=$R\omega/V$ (14)

where R= radius of rotor (m)

ω = circumferential velocity of the rotor (radian/sec) the driving torque M is given by

$$M = 0.5 \rho C_m R A V^2 \quad (15)$$

According to Canadian experiments the best results for the torque and power are obtained for the rotor constructed with a parameter e/d = 1/6 and the maximum power coefficient reaches 0. 3

Where : e= overlap distance (mm)

d = chord of blade (diameter of scooper) (mm)

ρ = density of air (kg/m^3)

4. The Innovation Design of Savonius Rotor

The innovation design of Savonius rotor is consist of combination of two stages vertical axis Savonius type rotor, where each stage has two blades of curvatureprofile shown in figure 2. The design of the Savonius rotor blade is shown in Figure 3. While Table 1 shows the detail dimensions ofthe Savonius rotor. The material proposed for the Savonius rotor blade in this paper is metal sheet.

Velocity of wind leaving the turbine

To calculate the velocity of wind leaving the turbine a plane should be created at a distance away of the rotor, the distance in this paper is 2 m after the center of rotation downstream side to outlet direction, the dimension of this plane is the same of swept area of rotor.

5. Results and Discussions

The goal of this research to find the optimum design of Savonius wind turbine are tested under different boundary condition(Table 2) of wind speed and Tip Speed Ratio equal to 0. 8. The analysis is done by using ANSYS 12. 0 CFX software. In this paper the inlet and outlet wind speed take the base to calculate power produced and power coefficient of the rotor.

Table 1. specification of the rotor

Parameter	Value
Number of stage	2
Number of blade/stage	2
Diameter (D)	2000 mm
Height of one stage	2500 mm
Total Height (H)	5008 mm
Swept Area (A)	10, 016, 000 mm^2
Aspect ratio	0. 52
Mid. Separation disc thickness	4 mm
Top and bottom discs thickness	2 mm
Top and bottom discs diameter	2100 mm
Tip speed ratio (λ)	0. 8
Rated wind Speed (V)	3, 5 and 7 m/sec

Table 2. Rotor speed at different boundary conditions of wind speed and Tip Speed Ratio

		λ(0. 8)
V (m/s)	3	22. 93
	5	38. 22
	7	53. 50

Table 3 The power produced

Description	Case 1	Case 2	Case 3
$\mathbf{V_{in}}$ (m/s)	3	5	7
$\mathbf{V_{out}}$ (m/s)	2. 011	3. 346	4. 695
$\mathbf{P_{available}}$(watt)	159. 975	740. 625	2032. 275
$\mathbf{P_{turbine}}$ (watt)	73. 564	341. 282	933. 963
Theoretical power produced (watt)	48. 6	225	617. 4
Increase of power generated(%)	51. 3	51. 6	51. 2

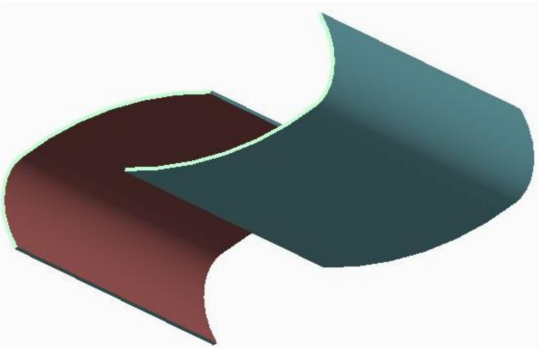

Figure 1. The suggested rotor scooper

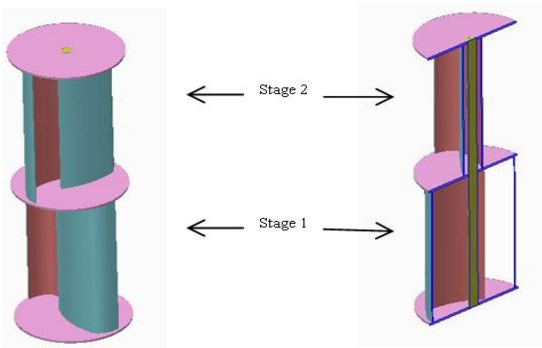

Figure 2. The model of two stage and cross section

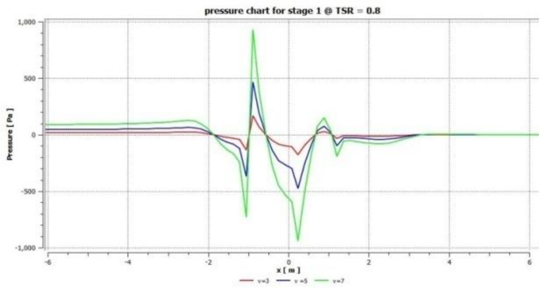

Figure 3 pressure chart for stage 1

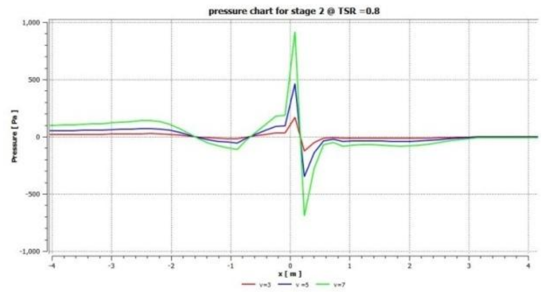

Figure 4 pressure chart for stage 2

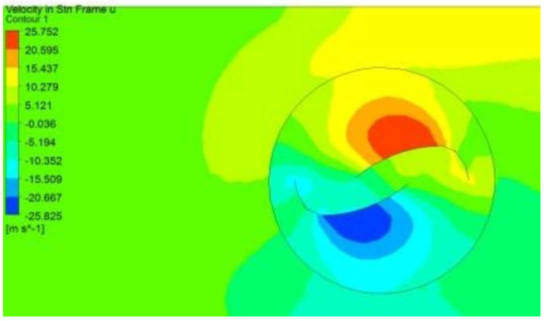

Figure 5 velocity contour for case 2 at stage1

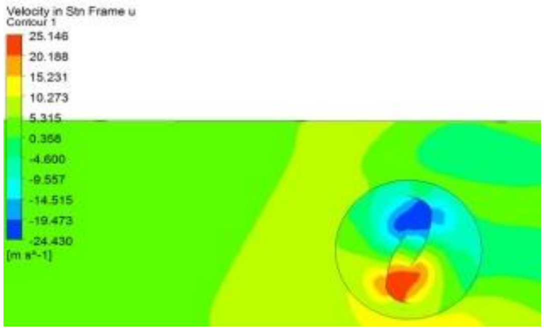

Figure 6 velocity contour for case 2 at stage 2

6. Conclusions

Among three cases the velocity of 5 m/s and Tip Speed Ratio equal to 0. 8 gave the best result because of high value of increment of power produced compering to other cases. The outlet velocity was 3. 346 m/s at a distance 2 m from the center of rotation leads to power produced by the rotor of 341. 28 watt for maximum power available in wind stream is 740. 62 watt. At temperature of 25^{o}C, the density of air was 1. 185 kg/m^3 so the power coefficient was 0. 46.

7. References

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