Analytical Evaluation of Solar Enhanced Magnus Effect Wind Turbine Concept

Krishan Chand\(^1\), Naushad A. Ansari\(^2\), Abhishek Sharma\(^3\)*, Yashvir Singh\(^4\), V.R.Mishra\(^5\), Vinay Goel\(^6\)

\(^{1,2}\)Delhi Technological University, New Delhi, INDIA
\(^{3,5,6}\)G. L. Bajaj Institute of Technology & Management, INDIA
\(^4\)Department of Mechanical Engineering, Sir Padampat Singhania University, Udaipur, Rajasthan, INDIA
\(*\)Corresponding author E-mail: absk2001@gmail.com

Abstract

Environment degradation and non-biodegradability are the major problems associated with mineral-oil based lubricants. Non-edible vegetable oils are one of the suitable substitutes for the mineral oils. In this study, pongamia oil was used as the lubricant to check its feasibility for the tribological behaviour. TiO\(_2\) nanoparticles are added to the pongamia oil on a weight-percentage basis. The variation of TiO\(_2\) nanoparticles concentration with pongamia oil was evaluated for the coefficient of friction and wear analysis. Minimum coefficient of friction and wear was observed at 0.1% concentration which gets further increased at 0.2% concentration. The smooth surface of the pin was observed at 0.1% nanoparticles concentration with the comparison to base pongamia oil.

Keywords: Betz limit; spinning cylinders; Magnus effect; power extraction.

1. Introduction

As with the fast extinction of resources future of the world depends upon the renewable sources of energy and the wind and solar energy are currently the main sources of renewable energy [1,2]. To increase the efficiency of energy that can be extracted, many research works are going on. But there is also a limitation with the use of these energies, that if the wind is available then we can extract wind energy and if sunlight is present then we can have solar energy, then what will happen if we have no wind or sunlight [3]. So, our research provides co-existence of both the energies. As if the wind is not present then we can use the solar energy from the solar panels provided on the spinning cylinder and if no sunlight then we can use the wind energy. The use of spinning cylinders instead of conventional blades make it possible to provide the solar panels on the cylinders [5]. The use of solar panels on spinning cylinders cause no effect the aerodynamic efficiency, as they are just used as form of energy to generate the power [6].

As the novel turbine needs the power to rotate its cylindrical blades. As the air cause a drag force on the blades, so we have to calculate the torque according to the varying condition and when there is condition of no wind and we have to use the sunlight then the different alignment of cylindrical panels is done to have the direct sunlight and have maximum amount of energy. So, in further study the various derivation and equation are given to calculate the various required parameters and the performance is analysed on depending upon the various conditions [7]. The various forces acting due to the rotation of rotating cylinder is in (fig.1). the figure also represents the various velocity components at spinning cylinder [8]. There are also various challenges are faced in deciding the structure for the best efficiency, so, various formulas are used to calculate the various parameters.

![Fig. 1: Various velocity components at the spinning cylinder cross section.](image)

development of flow direction given by Eq. 3.

2. Methodology

Assumption are taken for the aerodynamic analysis of wind turbine that flow is invariable and incompressible [9]. So by using equations 1&2

\[
C_t = \frac{T}{R \sqrt{V}} = \frac{2\pi R C W_C}{R \sqrt{V}} \frac{2\pi R C W_C}{V} = \frac{R C W_C}{V}
\]  

(1)

\[
\theta_{stagnation} = \arcsin \left( \frac{R C W_C}{V} \right)
\]  

(2)

Since at the same time the cylinder is also spinning about its axis which leads to the formation of velocity triangle and enables us to calculate the governing flow direction given by Eq. 3.

\[
v_{\infty} = \left[ v_{wind}^2 + w_f^2 + \frac{R C W_C}{V} \right]^{1/2}
\]  

(3)

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
As there is a downward force and newton’s third law states that “to every action there is an equal and opposite reaction” so, there is an upward lift force in reaction to the downward force and that lift force is calculated by Eq.4 and 5.

\[ dM = dL \cos \beta = \rho \frac{D}{2} \pi r_t \theta \]

\[ r_t = dL \cos \beta \]

The moment is integrated over the span to calculate the overall torque and the power generation. But for integration we have to consider some points like, first the number of cylinders. Second, the actual speed of wind and due to expansion of stream tube in turbine it become less than the wind speed and using Eq. number 6 to 8.

\[ v_{\text{wind}} = v_{\text{wind}}(1 - a) \]

So, the power extracted

\[ w_{\text{gen}} = M \omega_t \]

\[ = N(\omega_c R_c^2)(\omega_t R_t^2) \frac{\pi}{2} v_{\text{wind}} (1 - a) \]

Another method to calculate the power extraction is decrease in kinetic energy, as, the rate of decrease in kinetic energy in stream tube is equal to the by Eq. 9.

\[ w_{\text{extracted}} = \frac{1}{2} (\pi R_t^2) v_{\text{wind}}^3 (1 - a)^2 4a \]

now equate the above two equations to form a polynomial to get the value of “a”

\[ a^2 - a + \frac{N \omega_c \omega_t R_c^2}{2v_{\text{wind}}^2} = 0 \]

The value power coefficient for turbine in term of “a” can be calculated by

\[ c_p = 4a(1 - a)^2 \]

After this we put the different values of “a” like 1/3 in above equation to study the different outcomes. But the value must return in betz limit. Betz limit means that no turbine can capture more than 16/23 or (59.23%) of the kinetic energy [10]. So, including the betz limit another limitation is the union of stagnation points at certain rotational speed. As our motive is to extract energy instead of producing the lift so there is a limitation of the speed. the union of two point in inviscid fluid is possible when stream velocity \( v_{\text{wind}} \) is equal to tangential speed on cylinder surface \( (\omega_t R_c) \).

The required torque for spin can be calculated by Eq. 12 and Eq. 13.

\[ C_T = \frac{T}{2v_{\text{wind}}^2 R_c^2} = \frac{2 \pi}{\sqrt{R_c}} (\lambda^{0.5} - 0.522 \lambda^{2.5}) \]

Where

\[ R_e = \frac{v_{\infty} 2 R_c}{\nu} \]

the result from above equation are valid between the Reynolds number from 200 to 10000 and the value of torque coefficient decrease with increase in Reynolds number. Today the value of Reynolds number in present study reaches upt0 10^6 but in comparison value of torque coefficient is very less and due to the lack of data the same torque coefficient is multiplied by three times and used. The rotational speed of blades and no. of blades are multiplied to get the final amount of power required for the spinning of blades. Now, about the solar energy the solar panel used are generally of rectangular shape and they have the area \( 2g x R_c \). As there are various effects of the rotation of turbine and spinning of the cylinder. Normally it makes sure that that one portion of solar cell receive the sunlight in normal direction and further the angle of incidence of sunlight for different portion of cell changes with the rotation of turbine and spinning of cylinder on which the solar cells are provided. For photo voltaic in standalone position then it is required to know about the amount of solar radiation incident on the inclined surface. for the other type round panel to simplify the calculations the dodecagon type panel is used (dodecagon means the polynomial having 12 sides) which act PV panel having fixed tilt and various fixed azimuth angles. The device used to measure and provide azimuth angle is a single axis tracker system. As given in Fig.1. If it is assumed that the efficiency of a flat type panel is provided correct tilt and azimuth angle is “1” by taking 120 no. of cells in panel, the efficiency of the dodecagon type PV panel can be calculated as;

Where as the round panels covering the blade surfaces efficiency is calculated it is estimated about 0.3.

3. Results and Discussion

So, we calculate the coefficient of performance for the following data. The number of blades is 3, the rotor period is 3 seconds ant the wind speed is taken as 15m/s. Fig.3 shows the various result. Overall it is seen that the thicker cylinder can achieve higher efficiency at lower wind speed. The range of lower wind speed is 3-3.5m/s and at this low wind speed the wind turbine generates the minor amount of power.

Figure 3: Variation of coefficient of power with cylinder spin velocity at different cylinder radii

As, the cylinder radius also effects the power of coefficient and for the conventional turbine the Cp is taken as 0.35 and with the increase in cylinder radii the surface area increases so, amount of solar radiation incident increase as a result the solar energy increase. In Figure 4 an example is shown for 15m and wind speed of 3m/s.

Figure 4: solar and wind components of power generation at low wind speed
To make a comparison with a conventional wind turbine, a sample case is formed for a wind speed of 15 m/s, rotor radius of 10 m, and a rotor period of 3.33s. Under these conditions at sea level the approximately 260 kW power is generated by conventional turbine having aerodynamic efficiency of 0.4, while under the same conditions the Magnus wind turbine when run at settings to reach the Betz limit and to unite the stagnation points provide 385 kW power. Further change the number of blades, cylinder radius and cylinder rotation rate according to the design limit leads to increase in aerodynamic efficiency. Figure 5 shows the variations.

Figure 5: Variation of settings for maximum efficiency in a Magnus effect wind turbine.

Figure 6 shows the power required to spin the cylinder. Considering the same values, the net power output from the turbines showing Magnus effect lies between 323-352 kW which is about 63-92 kW more than the power output from conventional wind turbine. so, the net increase is about (24-35) %.

In cylindrical blades the $C_l$ value decreases with radial position in the rotational plane and the overall speed of the cylinder cross-section is going on increasing as a result stagnation points also move far from each other. Figure 7 shows the angular separation variation of stagnation points along the span and with the increase in separation between the stagnation points, the suction peaks on either side of the cylinder rotate along the span. That leads to change in the flow in the span wise direction which in turn effects the overall aerodynamic efficiency of the turbine.

Figure 7: Variable angular separation of different stagnation points along the span.

It is seen that betz limit can be reached without much increase in rotation rate of cylinder. As it is shown if Fig.8 that at wind speed of 5m/s the maximum efficiency limit can be achieved when the cylinder radius axed 0.5m without increasing the rotational speed or lower rotational speed.

Figure 8: Betz limit reaching condition and stagnation points union at 5 m/s wind speed.

4. Conclusion

On the basis of above discussion and observation we can conclude that:-
1. Instead of normal blades the spinning cylinders are used.
2. These turbines use magnus effect and provide high aerodynamic efficiency closer to betz limit at low rotational speed.
3. These novel turbines provides the sizing benefit; these turbines can be employed easily in urban areas for small power generation as compares to conventional turbines.
4. Overall increase of 35% in power generation is estimated.
5. Minor power from alternate source (wind or solar) can be used for the rotation in turn to increase the power output from the other source.

References


