Study of Vortex Induced Vibrations for Harvesting Energy

Gaurao Gohate
Student
Department of Mechanical Engineering
DBACER, Nagpur, India

Saurabh Bobde
Professer
Department of Mechanical Engineering
DBACER, Nagpur, India

Abhilash Khairkar
Student
Department of Mechanical Engineering
DBACER, Nagpur, India

Sameer Jadhav
Student
Department of Mechanical Engineering
DBACER, Nagpur, India

Abstract

Today, India is stepping towards becoming a global super power. This implies that, it is leading the list of developing countries in terms of economic development. Hence its energy requirement is going to increase manifold in the coming decades. To meet its energy requirement, coal cannot be the primary source of energy. This is because coal is depleting very fast. It is estimated that within few decades coal will get exhausted. The next clean choice of energy is solar power, but due to its lower concentration per unit area, it is very costly. India is having fifth largest installed wind power capacity in the world. As the regions with high wind speed are limited, the installation of conventional windmill is limited. Windmills that would provide safe, quite, simple, affordable and work on lesser wind speeds are need of the hour. The Bladeless Windmill is such a concept which works on the phenomenon of vortex shedding to capture the energy produced. Generally, structures are designed to minimize vortex induced vibrations in order to minimize mechanical failures. But here, we try to increase the vibrations in order to convert vortex induced vibrations into electricity. The paper studies the scope and feasibility of the bladeless windmill.
Keywords: Bladeless Windmill, Vortex Induced Vibrations, Vortex Shedding, Renewable Energy Sources

I. INTRODUCTION

The concept of wind energy dates back to nearly 7000 years ago [1]. Wind power technology is many centuries old. Alexander used windmills to cater water from wells. The first wind powered electricity was produced by a Machine built by Charles F. Bob in Cleveland Ohio in the year 1888[1]. Electricity can be generated in many different ways. In every way a fuel is used to turn a turbine, which drives a generator to produce electricity. The turbines are designed in which wind is the fuel, which drives the turbine. It is free and clean source of energy. Wind power is one of the most mature renewable energy technologies with over 74000 MW installed globally [1]. In the late 1800 Dane developed the first wind turbines to produce commercial electricity [1]. The types of windmill are vertical axis wind turbine and horizontal axis wind turbine [fig 1].

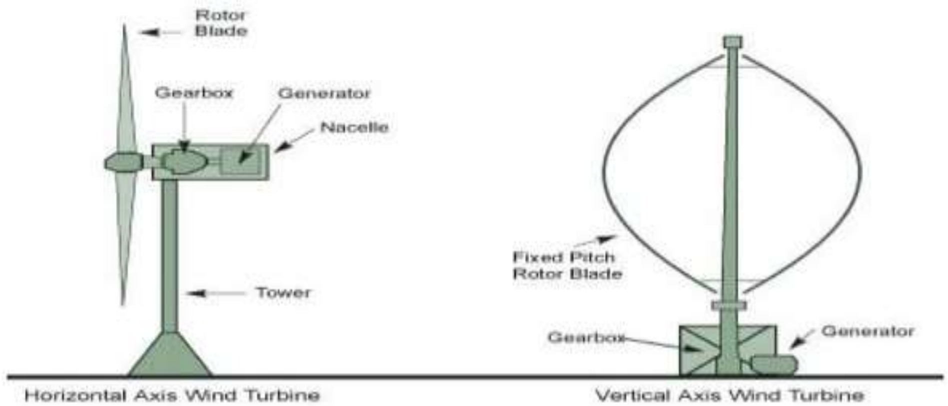

Fig. 1: Vertical and horizontal windmills

Energy is the key factor in a country's development. In the year 2013, India had the 5th largest installed wind capacity globally, during present year; India added installed capacity of 17644 MW as on June 2012 [1]. India's total estimated potential is 48,561 MW with Karnataka, Gujarat, and Andhra Pradesh as the leading states [1].The construction of windmill is shown in [fig 2].The various parts are rotor, nacelle, drive train, hub, controller, generator, foundation, and mainframe.

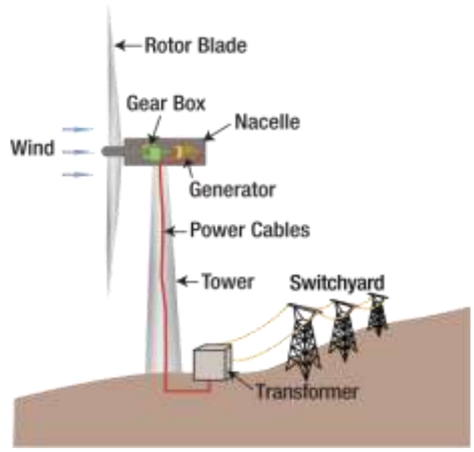

Fig. 2: various parts of windmill

A. Problem Identification:

But utilization of wind energy with the help of conventional windmills is very costly. To find the answer to the above question survey of established literature was done. The problems related to conventional windmills were studied.

- It was found that huge investment is the most significant problem for erection of windmills.
- Conventional windmill requires places where wind speed is more. Such places are limited. Hence windmills working on lesser wind speeds are need of the hour.
- The cost of manufacturing different parts of windmill is very high. A typical windmill will cost $3000-$8000 per kilowatt [4].
- So also the transportation of such huge parts is very costly and risky. If during transportation components get damaged then again cost increases.
- Designing of windmill blades is also a big task.
- The size of the assembled windmill is also very large. The conventional windmills occupy lots of space. The commercial turbines can be 160m high [5].
- Area of installation is 60 acres per megawatt of capacity of wind farms [6].
- Also they prove fatal to birds [2].
- They produce low frequency sound which is not good for human health [2].

B. Possible Solution:

Hence there is a need to find cheap and safe alternatives to conventional windmills. The concept of bladeless windmill is far less costly and also has less maintenance cost. The bladeless wind mill has lesser moving parts as compared to the conventional windmill. Also it will require lesser wind speed. It requires less space and also is safe for birds. The bladeless windmill is based on the phenomenon of vortex shedding effect. In fluid dynamics, **vortex shedding** is an oscillating flow that takes place when a fluid such as air or water flows past a bluff (as opposed to streamlined) body at certain velocities, depending on the size and shape of the body [3]. Instead of capturing energy via the rotational motion of a turbine, the windmill takes advantage of what's known as vorticity, an aerodynamic effect that occurs when wind breaks against a solid structure. The structure starts to oscillate, and captures the energy that is produced. This technology works by placing cylindrical bodies in normal to wind flow. Flow over this cylinder will generate an irregular vortex pattern which creates alternating high lift forces on the body and pushing it up and down perpendicular to fluid flow. The alternating movement of this body will produce fluctuating kinetic motion which can be converted into electricity [8].

Fig. 3: Proposed Model

C. *Study of Vortex Induced Vibrations [8]:*

1) *VIV Theory:*

VIV is a result of vortex shedding phenomenon which generally occurs nearly on any bluff body when submerged into fluid flow. Normally, irregular vortex shedding will occurring flow behind the body resulting in the fluctuating pressure differential which produces lift force perpendicular to the direction of the flow. The oscillating motion on the body is due to alternating lift forces.

2) *Reynolds Number:*

In general, flow parameter that affects the behaviour of vortex shedding has been observed to be the Reynolds number of flow as

$$Re = (U\,D)/\nu \qquad (1)$$

U is the free-stream velocity, D is the cylinder diameter and ν is the fluid kinematic viscosity. The regime that is targeted in this project is known as the "fully turbulent vortex street", with Reynolds number in the range of (300<Re<3x10^5).

3) *Strouhal Number:*

The Strouhal Number, St is a non-dimensional parameter
that describes the vortex shedding frequency to the oscillating
flow mechanism.

$$St = (f_s\,D)/U \qquad (2)$$

Where, f_s is vortex shedding frequency.

Strouhal number will be used as a constant value in this project as the Reynolds number falls in the middle of constant Strouhal number region which is 0.2 for subcritical flow as shown in Fig. 4.

4) *Lock In Phenomenon:*

A phenomenon known as "lock in" is a condition when the vortex shedding frequency becomes close to the natural frequency of the body. It has the potential to enlarge the amplitudes of bodies' oscillation which is similar to linear resonance.

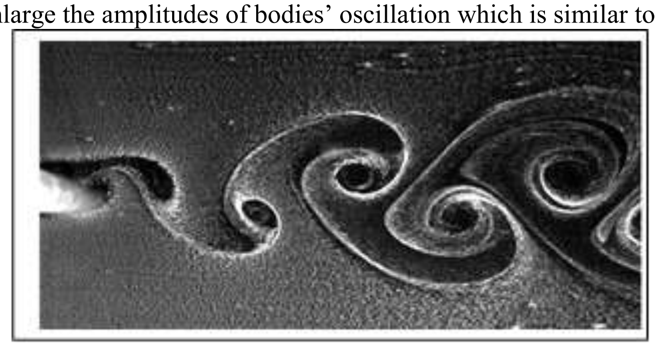

Fig. 4: Vortex shedding periodic pattern

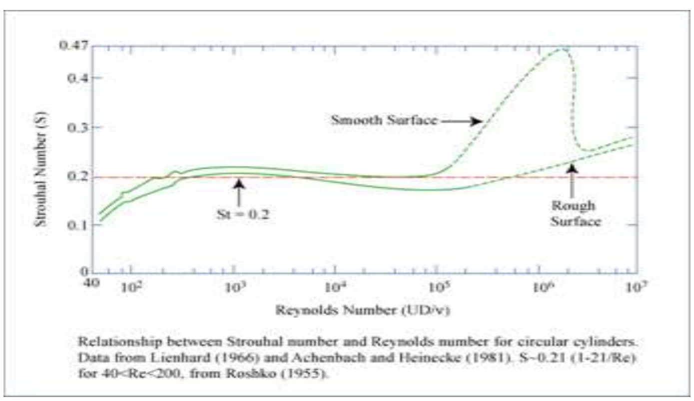

Fig. 5: Vortex shedding periodic pattern

II. METHODOLOGY

This section will show the result for one cylinder length. The Reynolds Number targeted here is within the range of ($300<Re<3x10^5$) which is known as fully turbulence. At this range Strouhal number is about 0.2 for smooth surfaces, which correspond to the fully turbulence vortex range. The cylinder and flow parameters investigated are listed in Table I.

Table - 1

Wind velocity	*Mass of cylinder*	*Density of fluid*	*Kinematic viscosity of fluid*
2.88m/s	*1.55kg*	*1.145 kg/m^3*	*0.15*10^{-5} m^2/s*

The values in the given table are considered on the following basis:

- Wind speed study in locale [7]

A report by Indian Metrology Department was studied which gave the idea of wind speed and its direction. The wind speed in Nagpur ranges from 0.72 m/sec to 3.66 m/sec where as the average speed is 2.88m/sec. The wind speed is more in the evenings. Mostly north easterly winds are present. So Nagpur does not fall in high wind speed category area. Hence, windmills working efficiently in low wind speed areas are necessary.

- Mass of cylinder was calculated by using density of polycarbonate fibre sheet and its volume. The density of the sheet to be used for construction is 1005 kg/m^3 while the height is 1.8m and diameter is 0.2m.
- Density of fluid i.e. air is taken as 1.145 kg/m^3
- Kinematic viscosity of air is taken as $0.15*10^{-5}$ m^2/s at temperature of 20^o C.

III. CALCULATION

Method & calculation of natural frequency of cylindrical body:

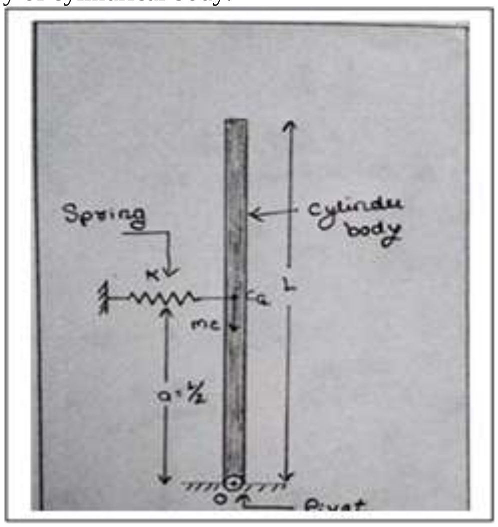

Fig. 6: Torque method

The natural frequency of the body is calculated by using torque method.

$$wn = \sqrt{\frac{(K\ L^2\ -2Mc \times g\ L\ )\ /\ 4}{I}} \qquad (3)$$

$$fn = \frac{1}{2\pi}\sqrt{\frac{(K\ L^2\ -2Mc \times g\ L\ )\ /\ 4}{I}} \qquad (4)$$

Where,
I –Moment of inertia of cylindrical body about perpendicular axis rotating its one end.

$$I = \frac{1}{3}\ Mc \times\ L^2 \qquad (5)$$

K – Spring stiffness.
L - Length of cylindrical mast.
Mc – Center of mass of cylindrical
g - Acceleration due to gravity.

From this relation, we get natural frequency of cylindrical.

Shedding frequency calculations:

$$St = Fs * D/\ U \qquad (2)$$

Diameter (D) = 0.2 m
Strouhal No = 0.2
Velocity of fluid (U) =2.8 m/s
Therefore shedding frequency is 2.8 Hz.
Resonance or Lock-in condition:-
For achieving resonance, we equate the natural and vortex shedding frequency.

$$\sqrt{\frac{(K\ L^2\ -2Mc \times g\ L\ )\ /\ 4}{I}} = fs \qquad (6)$$

For designing a spring to sustain the high stress develop in resonance condition .It is necessary to calculate the value of spring stiffness under resonance condition.

$$K = \frac{4\ I\ fs^2 \times 2\pi\ +2\ Mc \times gL}{L^2} \qquad (7)$$

$$K = 215.57\ N/m$$

Lift force developed at the upper end of the cylinder and coefficient of lift force C is assumed to be 0.6 based on previous study.

$$F = 0.5\,\rho\,U^3 D\,L\,C \qquad (8)$$

Density of fluid =1.145 Kg/m^3
Diameter of cylinder (D) = 0.2 m
Velocity of fluid (U) = 2.8 m/s
Length of cylinder (L) =1.8 m
Therefore, Lift force F is 2.714 N.
The oscillation produce by the vortex shedding is converted in to rotary motion and then into power.

$$P = \frac{2\,\pi\,N\,T}{60} \qquad (9)$$

For converting oscillatory motion into rotary motion we used slider crank mechanism. There are two gear meshing having module is 6. The number of teeth on larger gear is 40 and smaller gear is 10.
The torque transmitted at the smaller gear is 3.81 N-m and at the speed of 480 rpm.

IV. Results

Depending upon the length of the mast, we get the mechanical power output as shown in table 2.
This can be converted into electricity by using a D.C. generator of suitable specifications.

Table – 2

Sr. no.	*Length (L) m*	*Frequency (Fn) Hz*	*Torque (T)N-m*	*Speed (N) RPM*	*Power (P)Watt*
1	*1.8*	*2.8*	*3.81*	*480*	*191.5*
2	*4*	*3.1*	*12.2*	*620*	*792.1*
3	*6*	*3.6*	*27.8*	*730*	*2125.7*
4	*10*	*3.9*	*39.9*	*890*	*3718.70*

V. CONCLUSION

The VIV application in generating alternative energy is a viable solution of the current energy crisis. Although some technologies based on solar energy sources are currently being developed, they are costly. Further research on maximizing VIV phenomenon will be done to increase energy extraction rate based on the geometries of cylinder. Different design of VIV system will be numerically and experimentally researched to trigger more rigorous vortex shedding activities thus enhancing energy generation. VIV also has the potential to be integrated with the other renewable energy technologies such as solar, wind and tidal.

References

[1] P. Srinivasa Rao, Dr. K. Vijaya Kumar Reddy, Dr. P. Ravinder Reddy. International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 3, May-Jun 2013, pp.194-200
[2] Common concerns about wind power Published May 2011 by the Centre for Sustainable Energy ISBN 978-0-9568981-1-1
[3] https://en.wikipedia.org/wiki/Vortex_shedding
[4] http://www.windustry.org/how_much_do_wind_turbines_cost
[5] http://www.windustry.org/how_big_are_wind_turbines
[6] http://www.aweo.org/windarea.html
[7] INDIA METEOROLOGICAL DEPARTMENT CLIMATE OF NAGPUR. By Dr. P. K. Nandankar, P. L. Dewangan, Mrs. R.V. Surpam, Regional Meteorological Centre, Airport, Nagpur (M.S.)
[8] Application of Vortex Induced Vibration Energy Generation Technologies to the Offshore Oil and Gas Platform: The Preliminary Study World Academy of Science, Engineering and Technology International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:8,No:7, 2014

