Review on Diffuser Augmented Archimedes Wind Turbine

Naveenkumar [1], Santhosh Kumar[2], Thangavelu[3], Vigneshwar[4], Dr. S.Benjamin Lazarus[5]
[1, 2, 3, 4, 5] Department of Mechanical Engineering
[1, 2, 3, 4, 5] The Kavery Engineering College, Salem, Tamil Nadu, India

Abstract*- Wind energy is most of the promising renewable energy source. In general, moderate to high-speed winds, typically from 5m/s to about 25m/s are considered favorable for most wind turbines in India. But in rural areas, wind speed is near about 3m/s to 6m/s and this wind turbine is applicable for low wind velocity. In wind turbine technology, the turbine blades play an important role as it directly comes in contact with the wind. This article presents a review on the Archimedes Wind Turbine. This is used to develop small wind turbine used for enough power generation for at low wind speed of 3m/s to 6m/s. A spiral wind turbine gives an inherit advantage of the spiral curves to provide a gradual change in curvature from straight section to a curved section. When the spiral blade catches the wind, rotating force is generated due to the aerodynamic properties caused by Magnus Effect. This type of turbine is better than normal type more effective, cheaper the construction cost and it can withstand high wind velocity*

Keywords- Wind speed, Wind turbine blade, Angle of attack, Tip Speed Ratio, CFD Analysis, Power coefficient.

I. INTRODUCTION

Wind as a source of renewable energy receives a great attention as an increasingly viable solution to one of the most important issues of our time, that is, pollution free electricity for sustainable living. The continued dependence on depleting fossil fuel sources or nuclear power has the potential to wreck the world's economy and security. With highly efficient, solid and reliable wind turbine, wind power offers a solution to meet energy needs and environmental care. Wind power represents one of the most promising sources of renewable energy and currently wind is more economically feasible than solar or biomass for electricity generation.

The wind energy is firstly used to produce mechanical energy and the system used to change the kinetic energy of the wind into mechanical energy is called windmill. The term wind turbine is the updated version of the term windmill. Wind turbine refers to the system which converts the wind energy into electrical energy. Wind has considerable amount of kinetic energy when blowing at high speeds. This kinetic energy when passing through the blades of the wind turbines is converted into mechanical energy and rotates the wind blades and the connected generator, thereby producing electricity. Here the Archimedes wind turbine is discussed. The spiral allowed better measurement of a circle's circumference and thus its area. In micro wind turbine, diffuser is used to create pressure drop after rotation of blades so high velocity output can be obtained.

II. TYPES OF WIND TURBINE

Broadly wind turbines are classified into the two main categories as

a. Horizontal axis wind turbines (HAWT)
b. Vertical Axis Wind Turbines (VAWT)

III. ARCHIMEDES WIND TURBINE

Archimedes spiral wind turbine, as new concept structure which using the Archimedes spiral principles, is one of the HAWT, but different from traditional HAWT that uses the lift force to take power from wind energy, the Archimedes spiral small wind turbine is mainly depended on the drag force. Wind turbine system that consists of a diffuser shroud with a broad-ring brim at the exit periphery and a wind turbine inside it, for a given turbine diameter and wind speed. This is because a low-pressure region, due to a strong vortex formation behind the broad brim, draws more mass flow to the wind turbine inside the diffuser shroud and significant increase in the output power of a micro-scale wind turbine was obtained.

Aerodynamic shape optimization is one of the main research fields which are directly related to power production of a wind turbine. In wind turbine, involute spiral shaped blades are mounted on fixed shaft as stator and moving blades are mounted on moving shaft. So, air impinged on fixed blades so moving blades are rotating. So, pressure reduction occurs in the diffuser and due to pressure drop air is sucked just like an exhaust nozzle of gas turbine and velocity of wind turbine is increasing by increasing power output of system.

Figure 1. Archimedes Wind Turbine.

IV. LITERATURE REVIEW

Timmer and Toet set one model in the DNW wind tunnel at TU Delft with 0.14m radius and 3mm wall thickness to investigate the aerodynamic characteristics. In their report, utilized the selective laser sinter method in order to update the Archimedes wind turbine pattern and explore the major potentials and optimum of the wind turbine power output the maximum power coefficient was measured at the optimum tip speed ratio. In 2009, the Archimedes spiral wind turbine model was improved by TU Delft. As a result, their finding had showed the maximum efficiency of that model was 12% while effects generated an angle of 20 degree or more were positive to its efficiency.

Lu et al. developed a design method of the Archimedes spiral wind turbine blade and performed a numerical simulation using ANSYS CFX v12.1 in 2012. CFX, one of the analysis programs on fluid mechanics of CFD, which is idealized according to Reynolds Averaged Navier-Stokes Equation and the Finite Volume Method of Governing Equation. The Shear Stress Transport model has been used in order to predicting the separation of flow accurately. It ensemble average velocity fields of the overall flow field on the central of the Archimedes spiral wind turbine at three different wind speeds, through the unsteady numerical simulation study. When there is no drag torque, the pure blade's rotating speed is influenced by inlet velocity, and the predicted blade's rotating speed approach 500rpm while the inlet velocity is 4.5m/s. The analysis of the obtained results shows the interaction between the mean flow at the rotor downstream and the induced velocity due to the tip vortices.

Arens and Williams conducted numerical analysis on Darrieus VAWTs to characterize the flow field in the rooftop area of buildings with different shapes and geometrical proportions in 1977. In their study, the feasibility of the rooftop installation of Darrieus VAWTs was evaluated and the analyses were combined in an energy-oriented study. The effects of the pitch angle and blade camber on the flow characteristics and performance of a small-size Darrieus VAWT system driven at a uniform wind speed (10 m/s) were investigated using a simulation model.

In 2005, Hirahara et al. studied on very small wind turbine system with 500 mm as a diameter of blades. Through their experimental study, they mentioned that the maximum power coefficient employed in their study showed approximately 40 % at 2.7 as a tip speed ratio. Quasim et al. have studied for the power coefficient on cavity shape vane vertical axis wind turbine model through wind tunnel experiment. Through their experimental study, they mentioned that the frame of vertical axis wind turbine may affect the power coefficient.

Herbert et al. reviewed the wind resources assessment models, site selection models and aerodynamic models including wake effect in the year of 2007. They also discussed that the differences exist in performance and reliability evaluation models, various problems related to wind turbine components (blade, gearbox, generator and transformer) and grid for wind energy system.

Howell et al. would like to provide the performance coefficient prediction on small vertical axis wind turbine through experimental and numerical study in 2010. They mentioned on dynamic behavior of the over tip vortex as a rotor blade rotating through each revolution. These studies reported the effects of the blade geometry on the power curve, the turbine's rated power related to its swept area, the total electricity production, and the pay-back period.

Ragheb et al. discussed the Betz limit for horizontal and vertical axis wind turbine systems in 2011. And they also mentioned that the wind turbine must be designed to operate at their optimal wind tip speed ratio in order to extract as much power as possible from the wind stream.

Scheurich and Brown investigated numerically the aerodynamics of VAWTs in unsteady wind conditions using the vorticity transport model in 2013. The inherent unsteadiness in the blade aerodynamic loading because of the continuous variation of the angle of attack on the blades is shown to be larger than that are induced by the unsteadiness in the wind conditions. Edwards et al. reported 2D PIV measurements and 2D CFD simulation of the performance and flow physics and of a small-scale VAWT. They found that the most significant CFD-PIV differences are observed in predicting flow reattachment.

In 2015, Ho Seong Ji and Joon Ho Baek are reviewed the aerodynamic performance study on small wind turbine, in which they analyzed the lower wind speed condition similar with local wind condition for urban such as between 3 ~ 6 m/s, the highest output power and power coefficient can be observed in the case of 0° wind condition than angle of attack change. From this sense, to provide the highest efficiency to the household user, the automatic yawing system for the Archimedes wind turbine with easily facing to the approaching wind direction seems to be most effective. In the lower wind condition similar with urban normal wind condition, the angle of attack can be relatively estimated an important parameter for the Archimedes spiral wind turbine employed.

In January 2015, Arman Safdari and Kyung Chun Kim are analyzed the aerodynamic and structural evaluation of horizontal Archimedes spiral wind turbine. The investigation of the obtained results determined the straight interaction between the mean flow at the rotor downstream and the induced velocity due to the tip vortices. The finding exposed the presence of important vortex constructions downstream the hub and near the root of the blade. Some unpredictability of the helical tip vortices is also distinguished. Because of these fluctuations, the instantaneous velocity field is very rich with the evidences.

V. PARTS DESCRIPTION

The various parts used in the turbine which are used to specific applications to run the turbine are listed below.

a) Spiral blade
b) Archimedes Rotor
c) Hollow shaft & frame
d) The Yawing System
e) Generator
f) The Safety Feature

a) Spiral blade

The Archimedes rotor blade is a flat surface elongated to give it depth and, therefore its shape perceived to have volume. From a sheet of paper one can obtain the spatial form of an Archimedes rotor blade by turning and simultaneously stretching out a cutout of the plane between a circle with radius R and a flat spiral. Here the blade material used is galvanized iron sheet of 1mm thickness, because of its easy availability & less cost.

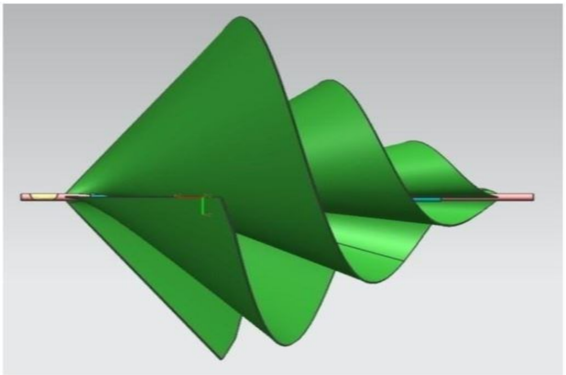

Figure 2. Side-view of Archimedes spiral wind turbine blade

b) Archimedes Rotor

The Archimedes Rotor has the characteristics of both. The blade is constructed from flat sheets, can work under a large margin of error, produces very low noise (<42 Db) and is lightweight. All are characteristics of a resistance type rotor. In contrast, the Archimedes Rotor tip speed ratio is greater than 1, and its efficiency is extremely high, characteristic of the lift type.

c) Hollow shaft & frame

The hollow shaft material used is mild steel, because of its easy availability & less cost. The frame is also made up of mild steel, because of its easy availability & less cost.

d) The Yawing System

The blade’s shape also ensures that the blade automatically turns itself into the most optimum wind direction. Methods for finding the optimal wind direction are unnecessary even when the airflow to the rotor is blocked unexpectedly.

e) Generator

The generator is a high voltage generator and can achieve up to 400 volts. The advantage of such a high voltage generator is the relatively higher efficiency and lower copper losses that occur during transport of the energy through the copper power cables. In addition, the risk of overheating is reduced to a minimum.

f) The Safety Feature

The Archimedes wind turbine has several safety features to ensure safe operation. Both the generator and the brakes have an automatic mode and a manual mode. The controller sets an upper limit to the number of rotations per minute. This prevents the rotor from spinning too fast. The mill can also be stopped manually by means of the generator, the so-called emergency stop. An electrical brake is installed at the back of the machine, which is governed by a controller that measures the actual wind speed. When the wind speed exceeds a certain value this electrical brake kicks in. Only when the wind speed reaches a lower limit will this break kick out again. This governor thus prevents wind gusts to spin the mill too fast. This brake too can be activated manually in order to stop the machine..

VI. DESIGN CALCULATION

i) Spiral blade modeling

First step in modeling is determining parameter of Archimedes spiral that will determined rotor shape. The term used is:

$$b = \frac{D - 2a}{\alpha_1 + \alpha_2}$$

a, b – Archimedean spiral parameters.
D – Rotor diameter.
$\alpha 1$ – Outermost angle of spiral.
$\alpha 2$ – Angle diametrically opposed to the outermost angle of spiral.
Archimedes spiral in Polar coordinates:

$$r = a + b\theta$$

Archimedes spiral in Descartes coordinates:

$$x = r * \cos(\theta)$$
$$y = r * \sin(\theta)$$

r – Radius of blade.
θ – Angle of blade.

ii) Tip speed ratio

Tip speed ratio of wind turbine is an essential parameter to how efficient that turbine will perform.

TSR = (speed at blade tip) / (wind speed)

$$TSR = \frac{R \times \omega}{V_{in}}$$

R – Radius of the rotor.
ω – Rotor rotational speed in rad/s

iii) Power available in the wind

$$P_w = \frac{(A \times \rho_{air} \times v^3)}{2}$$

A– Cross sectional dimension of wind turbine.
ρ_{air} – Density of air in kg/m^3.
v – Wind velocity in m/s.

iv) Power of wind turbine

$$P_t = 0.5 \times \eta_{wt} \times \rho_{air} \times v^3$$

η_{wt} – Wind turbine efficiency.

v) Efficiency of rotor

$$\text{Efficiency} = \frac{P_w}{P_t}$$

vi) Turbine rotational speed

$$N = \frac{(\lambda \times {}^{v}/_{R})}{(60/2\pi)}$$

λ – Tip Speed Ratio.

V. CONCLUSION

The major conclusions from the literature are as detailed below.

The Archimedes wind turbine turns and accelerates internally by which an optimal lift and transfer of kinetic energy is realized. In this the air flow isn't blocked due to the spiral unlimited orbit shape. The forward force is relatively seen reduced and is towards zero and is bend to a sideway force. Within the wind turbine the wind accelerates in almost all directions.

The design of wind turbine, due to arrangement of the diffuser around the spiral blades, increases the velocity of wind at outlet. Due to pressure reduction occurring in the diffuser and since air is sucked the velocity of wind turbine is increasing by increasing power output of system.

By using this type of wind turbine 2-5% velocity can be increased other than conventional wind turbine. Despite friction of bearings and obstruction on account of its frame, the Archimedes Rotor is able to extract 88 % of the theoretically viable energy from the wind.

The efficiency of the rotor blades has been measured by way of computer simulations, wind tunnel tests and field tests at around 52% (for an existing system). This means that 52% of the available kinetic energy in the wind is converted into rotational movement. The theoretically maximum achievable efficiency is 59 %, the so-called Betz Limit.

The spiral wind turbine designed is ideal to be located on top of a home to generate electricity, powered by wind. It will be more obvious in many circumstances, such as around buildings, because the wind turbine operates at low wind speeds. Small-size wind turbine like AWT has been designed in fields such as mobile communication base stations, city road lighting, offshore aquaculture and sea water purification in several countries.

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