IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 10, December 2014.
www.ijiset.com
ISSN 2348 – 7968

Performance of the Counter Rotate Rotor of a Newly Vane Designed HAWT

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Abstract
A horizontal axis wind turbine model having divided vanes has been designed, fabricated the prototype and tested in a real condition wind speed. This paper presents a study on the performance of a wind turbine with two counter rotating rotors (CRWT). The characteristics of the two counter-rotating rotors are on a 4-Bladed in primary and 2- Bladed in secondary rotor. The prototype is tested in a real wind condition with the low wind speeds varying between 2 m/s and 10 m/s. The power coefficient of the turbine model with single rotor which have 4-blade is 0.18 and increase the power coefficient to 0.22 when use two rotors counter rotate.

Keywords: *HAWT, Power coefficient, divided vane, Performance analysis*

1. Introduction

The wind systems that exist over the earth's surface are a result of variations in air pressure. These are in turn due to the variations in solar heating. Warm air rises and cooler air rushes in to take its place. Wind is merely the movement of air from one place to another. There are global wind patterns related to large scale solar heating of different regions of the earth's surface and seasonal variations in solar incidence. There are also localized wind patterns due the effects of temperature differences between land and seas, or mountains and valleys.
Wind speed generally increases with height above ground. This is because the roughness of ground features such as vegetation and houses cause the wind to be slowed.
The power in the wind is proportional to:
• The area of windmill being swept by the wind
• The cube of the wind speed
• The air density - which varies with altitude

The formula used for calculating the power in the wind is shown below:

$$P = \frac{1}{2}\rho A V^3 \quad (1)$$

where, P is the power in watts (W), ρ is the air density in kilograms per cubic metre (kg/m^3), A is the swept rotor area in square metres (m^2), V is the wind speed in meters per second (m/s).
The fact that the power is proportional to the cube of the wind speed is very significant. This can be demonstrated by pointing out that if the wind speed doubles then the power in the wind increases by a factor of eight. It is therefore worthwhile finding a site which has a relatively high mean wind speed.
Although the power equation above gives us the power in the wind, the actual power that we can extract from the wind is significantly less than this figure suggests. The actual power will depend on several factors, such as the type of machine and rotor used, the sophistication of blade design, friction losses, and the losses in the pump or other equipment connected to the wind machine. There are also physical limits to the amount of power that can be extracted realistically from the wind. It can been shown theoretically that any windmill can only possibly extract a maximum of 59.3% of the power from the wind (this is known as the Betz limit).[1,2] In practice, the maximum power coefficient of conventional horizontal axis wind turbines having a single rotor is about 40-50% due to some losses such as viscous loss, three dimensional loss, and transmission loss. Over the past few decades, many different concepts and blade designs of a wind turbine have been proposed to improve the maximum power coefficient [3].
In order to calculate the maximum theoretical efficiency of a thin rotor (of, for example, a wind mill) one imagines it to be replaced by a disc that withdraws energy from the fluid passing through it. At a certain distance behind this disc the fluid that has passed through flows with a reduced velocity. The assumptions is:

1. The rotor does not possess a hub, this is an ideal rotor, with an infinite number of blades which have 0 drag. Any resulting drag would only lower this idealized value.

2. The flow into and out of the rotor is axial. This is a control volume analysis, and to construct a solution the control volume must contain all flow going in and out, failure to account for that flow would violate the conservation equations.

3. This is incompressible flow. The density remains constant, and there is no heat transfer from the rotor to the flow or vice versa.

So, modifying the formula for 'Power in the wind' we can say that the power which is
produced by the wind machine can be given by:

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

where, PM is power (in watts) available from the machine, Cp is the coefficient of performance of the wind machine.
Solidity is usually defined as the percentage of the area of the rotor, which contains material rather than air. Low-solidity machines run at higher speed and tend to be used for electricity generation. High-solidity machines carry a lot of material and have coarse blade angles. They generate much higher starting torque (torque is the twisting or rotary force produced by the rotor) than low-solidity machines but are inherently less efficient than low-solidity machines. The wind pump is generally of this type. High solidity machines will have a low tip-speed ratio and vice versa.
There are two primary physical principles by which energy can be extracted from the wind; these are through the creation of either lift or drag force (or through a combination of the two).
The difference between drag and lift is illustrated by the difference between using a spinnaker sail, which fills like a parachute and pulls a sailing boat with the wind, and a Bermuda rig, the familiar triangular sail which deflects with wind and allows a sailing boat to travel across the wind or slightly into the wind
Drag forces provide the most obvious means of propulsion, these being the forces felt by a person (or object) exposed to the wind. Lift forces are the most efficient means of propulsion but being more subtle than drag forces are not so well understood.
The basic features that characterize lift and drag are:

• Drag is in the direction of air flow
• Lift is perpendicular to the direction of air flow
• Generation of lift always causes a certain amount of drag to be developed
• With a good aero foil, the lift produced can be more than thirty times greater than the drag
• Lift devices are generally more efficient than drag devices

There are two main families of wind machines: vertical axis machines and horizontal axis machines. These can in turn use either lift or drag forces to harness the wind. The horizontal axis lift device is the type most commonly used. In fact other than a few experimental machines virtually all windmills come under this category.
There are several technical parameters that are used to characterize windmill rotors. The tip speed ratio is defined as the ratio of the speed of the extremities of a windmill rotor to the speed of the free wind. Drag devices always have tip-speed ratios less than one and hence turn slowly, whereas lift devices can have high tip-speed ratios (up to 13:1) and hence turn quickly relative to the wind.
The maximum power that can be extracted from the wind is about 59% of the available energy, if the velocity change across the rotor, according to Betz theory [4], is 2/3. But in practice, the energy in the wake behind a single rotor is not very small. Part of this energy can be extracted further by installing a second rotor in the wake. At the same time, the maximum energy that can be extracted by two rotors of same diameters is increased from 59% to 64% of the available energy that is the Betz limit for two rotors. As the wake behind the first rotor is rotating in the opposite direction to the rotational direction of the rotor, the second rotor is advisable to rotate in the same direction as the wake in order to extract efficiently the available energy in the wake. [5]
A counter-rotating wind turbine having two rotors rotating in opposite direction on the same axis has been proposed as a new concept to enhance the maximum power coefficient of the wind turbine. Using classical momentum theory, Newman found that the maximum power coefficient of a wind turbine having two rotors without any losses increased to about 64% [4]. Recently, based on this result, the counter-rotating wind turbine has been studied extensively to obtain more power from the wind than that obtainable from a conventional wind turbine having a single rotor [6, 7].
Despite these efforts, it has been still difficult to optimize the aerodynamics of the rotors to obtain the maximum power coefficient. This is because complex phenomena are induced by the aerodynamic interactions of the two rotors in the counter-rotating wind turbine, unlike in a conventional wind turbine having a single rotor. In addition to the design parameters of a single rotor, design parameters such as the differences of pitch angles, rotational speeds and radii of the two rotors need to be considered to improve the aerodynamic performance of the counter-rotating wind turbine. Furthermore, the effects of these additional design parameters on the aerodynamic performance of the counter rotating wind turbine have yet to be fully understood, so the design becomes more complicated. Therefore, a preliminary study investigates the effects of design parameters on the aerodynamic performance of the counter-rotating wind turbine to obtain the optimized design of the counter-rotating wind turbine yielding the maximum power coefficient and compares the

optimized design with that of a conventional wind turbine having a single rotor. [8]

The advantages of Contra-rotating propellers have been found to be between 6% and 16% more efficient than normal propellers.[6] However they can be very noisy, with increases in noise in the axial (forward and aft) direction of up to 30 dB, and tangentially 10 dB.[2] Most of this extra noise can be found in the higher frequencies. These substantial noise problems will limit commercial applications unless solutions can be found. One possibility is to enclose the contra-rotating propellers in a shroud. It is also helpful if the two propellers have a different number of blades (e.g. four blades on the forward propeller and five on the aft).

The efficiency of a contra-rotating prop is somewhat offset by its mechanical complexity and the added weight of such complex gearing that makes the aircraft heavier, thus some performance is sacrificed to carry it. Nonetheless, coaxial contra-rotating propellers and rotors are moderately common in military aircraft.

The swept area is the section of air that encloses the turbine in its movement, the shape of the swept area depends on the rotor configuration, this way the swept area of a straight-bladed vertical axis wind turbine the swept area has a rectangular shape while for a HAWT is circular shaped and is calculated using:

$$A = \pi r^2 \qquad (3)$$

The number of blades has a direct effect in the smoothness of rotor operation as they can compensate cycled aerodynamic loads. For easiness of building, four blades have been contemplated. The solidity σ is defined as the ratio between the total blade area and the projected turbine area. It is an important nondimensional parameter which affects self-starting capabilities. [11]

2-The proposed design of VAWT impeller

The present rotor type horizontal axis turbine design consisting of two rotors separated by an appropriate distance, the front rotor has four vanes with angles of 90˚ between each blades. There is invention of the blade type horizontal axis wind turbine patented in USA, US7396208 B1. 09.02.2006 (Fig. 1). This wind turbine designed with divided blade rotor. The rotor blade is presented with an integral tip portion from which two diverging blade portions extend to separate respective roots. The blade may have conventional airfoil sections, or may be made from flat or curved sheet material. The two rotor blade portions may have dissimilar angles of incidence. Leading edge holes or slots are located behind the leading edge of the blade. The two blade portions may have distinct angles of incidence.

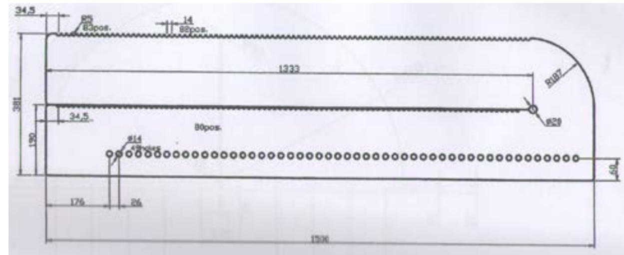

Figure (1): The invention blade

Counter-Rotating Open Rotors are currently being investigated as a potential alternative to high-bypass turbofan engines, offering the possibility to reduce fuel consumption and CO2 emissions. They are made of two propellers rotating in opposite direction around the same axis. The front rotor rotating with clockwise and consist of four blade, the rear rotor which rotating counter clockwise designed with two blade as shown in fig. (2). the upstream propeller induces energy of rotation to the fluid which is recovered by the downstream one, increasing the aerodynamic efficiency. [10]

Figure (2), Counter Rotating Open Rotor

3-The Prototype tests in a real condition

The object of the wind turbine test is verifying the ability of performance design, to get real data. The wind turbine testing fabricated with dimensions presented in Fig. 2, where r= 1.5 m, b = 0.38 m and the thickness =0.003m. The analyses considered power output test, the range of the wind speed in real condition is between 2 m/s and 10 m/s. The digital anemometer model HV935 TF Instrument INC was used to measure the wind speed.

The practical results show that the power coefficient of this model with single rotor 4-blade is 18%, and the power coefficient for the system model with two rotor is about 22%. The results test of output power varies the wind velocity shown in fig. (3)

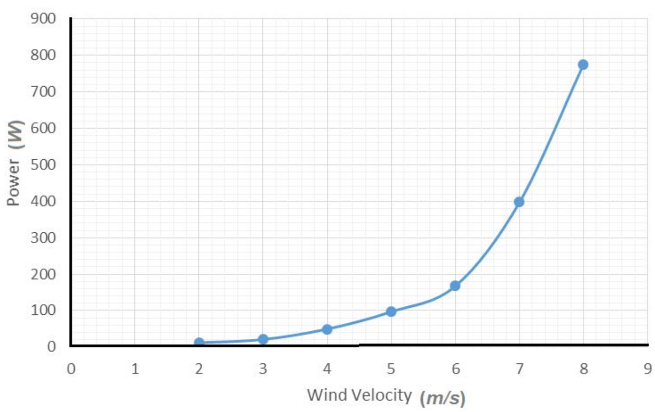

Figure (3) Power output VS wind velocity

Despite the single rotor with invention blade have a low power coefficient 18%, because the efficiency depending on many factors the attack angle (in this case use 12°) and the orientation system to the wind direction (problem in the design of the tile, which the system rotate around himself). The counter rotates of the two rotor increase the power coefficient to 22%.

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