Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 3159-0040
Vol. 2 Issue 6, June - 2015

Electricity Generation From Windmill And Its Performance Analysis

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***Abstract*— Windmill is a clean source of energy that has much lower environmental impact than conventional energy technologies. As the world is getting hotter by the emission of greenhouse gasses due to the use of fossil fuel, wind power is a well proven and cost-effective technology for the generation of electricity. This paper shows the design criteria and the performance analysis of a prototype windmill for small power generation. Also it shows that for a wind of 36 km per hour with a 3 square meter turbine of total efficiency 30% it obtain about 300 watts. To construct the windmill three blades of GI sheet, a hub of MS sheet are used. A metallic shaft of 2 cm diameter is fitted with hub in one end which is supported with two bearings on a round sheet metal. The total system is constructed in such a way so that it can revolve 360 º angles. A tail is connected to the round plate. The total system is fitted on a post of about 20 feet height. There is also gearing system to increase the speed of output shaft. A 9 volt generator is connected to the output shaft. A manual clutch system is kept between input shaft gear and output shaft gear so that when the blades rotate more than the maximum limit of generator shaft rotation then it can disengage the gear assembly.**

Keywords—Electricity, windmill, rotor, gear assembly, generator

I. Introduction

Wind is quite simply moving air, and is generated by the sun, which heats the surface of the earth at different rates. During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more rapidly over land than over water. As long as the Sun keeps heating the Earth and as long as this process continues to occur, there shall be wind. The wind has been used by the human race as a source of energy for a long time [1, 2]. As long as 5,000 years ago the ancient Egyptians used the wind to power there sailing boats. The next significant use of the wind by man was for windmills [3].

A windmill is a machine that is powered by the energy of the wind. It is designed to convert the energy of the wind into more useful forms using rotating blades. The term also refers to the structure it is commonly built on [4]. In America windmills and turbines have been used since the days of colonization. Initially they used windmills for grinding, but later they used windmills to produce electricity, even today it is still seen the evidence of them using wind mills on remote ranches and farms.

Wind has been used for centuries to propel ships and the wind routes were well known and used by explorers such as Magellan and Columbus [4, 5]. Wind power was used as a source of mechanical energy on land for thousands of years. The Babylonians constructed windmills for irrigation as early as 1700 BC and Europeans were using windmills by 1000 AD. The Dutch used windmills to drain the land and used eight basic types. Dutch settlers introduced windmills to the United States in the early 1600's. Daniel Halliday invented a new style of windmill, which many believe encouraged the rapid settling of the American West. More than 6.5 million windmills were sold in the US between 1880 and 1935. They were used to pump water, grind grain and cut lumber. Some small electrical generating systems were used to produce direct current by 1900. Cheap electricity was introduced in the 1940's and most of the wind powered generating systems in rural areas were considered obsolete and fell into disuse [5, 6].

The first wind powered electricity was produced by a machine built by Charles F. Brush in Cleveland, Ohio in 1888. It had a rated power of 12 kW (direct current - dc). Direct current electricity production continued in the form of small-scale, stand-alone (not connected to a grid) systems until the 1930's when the first large scale AC turbine was constructed in the USA. There was then a general lull in interest until the 1970's when the fuel crises sparked a revival in research and development work in North America (USA and Canada) and Europe (Denmark, Germany, The Netherlands, Spain, Sweden and the UK). Modern wind turbine generators are highly sophisticated machines, taking full advantage of state-of the-art technology, led by improvements in aerodynamic and structural design, materials technology and mechanical, electrical and control engineering and capable of producing several megawatts of electricity. During the 1980's installed capacity costs dropped considerably and wind power has become an economically attractive option for commercial electricity generation. Large wind farms or wind power stations have become a common sight in many western countries [7, 8, 9].

II. Types of Windmill

There are two types of wind machines Horizontal axis and Vertical Axis

A. Horizontal-axis

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator. Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount [10].

Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind, and because in high winds, the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines [11].

B. Vertical-axis

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable. VAWTs can utilize winds from varying directions.

With a vertical axis, the generator and gearbox can be placed near the ground, so the tower doesn't need to support it, and it is more accessible for maintenance. Drawbacks are that some designs produce pulsating torque. Drag may be created when the blade rotates into the wind.

It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten the service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and these can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence [12].

The most modern generations of windmills are more properly called wind turbines, or wind generators, and are primarily used to generate electricity. Modern windmills are designed to convert the energy of the wind into electricity. The largest wind turbines can generate up to 6MW of power (for comparison a modern fossil fuel power plant generates between 500 and 1,300MW). With increasing environmental concern, and approaching limits to fossil fuel consumption, wind power has regained interest as a renewable energy source. It is increasingly becoming more useful and sufficient in providing energy for many areas of the world. One area where turbines have become feasible is in the Midwestern United States, due to great amounts of wind [13].

III. Performance parameters of windmill:

A. Tip Speed Ratio (TSR):

$$TSR = \frac{\text{Tip speed of blade}}{\text{Wind speed}} \quad (1)$$

Typical TSR for slow running is 1 to 4 and for fast running 5 to 7

B. Lift coefficient:

$$C_L = 2 \times \pi \times \text{Blade angle in radians} \quad (2)$$

$= 2 \times 3.141 \times 0.26 = 1.64$ [25^0=0.26 radians]

C. Power:

Power = $0.6 \times C_p \times N \times A \times V^3$

Where, C_p= Rotor efficiency. It can be taken 0.4 to 0.48

N =Generator efficiency. It is about 0.7

A = Swift area by rotor.

V=Wind speed.

D. RPM:

$$RPM = \frac{V \times TSR \times 60}{6.28 \times R} \quad (4)$$

Where, V= Wind speed

TSR = Tip Speed Ratio

R= Radius of rotor

E. Blade chord:

$$\text{Blade chord} = \frac{5.6 \times R \times R}{i \times CL \times r \times TSR \times TSR} \quad (5)$$

Where, R = radius at tip

r = radius at point of computation

C_L = lift coefficient

i = number of blades

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Vol. 2 Issue 6, June - 2015

IV. DESIGN CALCULATION:

The design of windmill is based on the following criteria

A. Tip Speed Ratio (TSR):

$$TSR = \frac{\text{Tip speed of blade}}{\text{Wind speed}}$$

Typical TSR for slow running is 1 to 4 and for fast running 5 to 7

B. Number of blade:

The two blades were not strong enough to withstand harmonic vibrations. It was also true that harmonic vibrations would affect two and four blade windmills similarly. Since this was discovered study went into three blade windmills because they were discovered to be sturdier and less likely to be harmed by the harmonic vibrations. Best number of blade is 3 for smooth and steady rotation.

C. Angle of attack (Blade angle):

Typical blade angle is 4^0 with flight direction but most used blade angle is 15^0. Sometimes 30^0 or 45^0 blade angles are used but higher blade angle produce more vibration.

D. Wind speed:

Typically windmill works efficiently at a wind velocity of 20 mile/hour.

Based on the above criteria the power, rpm, blade chord of the windmill, the wind velocity is 7 mile/ hour.

Wind speed V= 7 mile/h = 11.27 Km/h = 3.13 m/s (For Rajshahi, Bangladesh)

Diameter = 206 cm = 2.06m

Radius r = 1.03 m

Area $A = \pi r^2 = 3.14 \times 1.03^2 = 3.79\ m^2$

Let TSR = 2, C_p = 0.4, N = 0.7

We know

Power = $0.6 \times C_p \times N \times A \times V^3 = 0.6 \times 0.4 \times 0.7 \times 3.79 \times 3.13^3$ =19.52 watt

$$RPM = \frac{V \times TSR \times 60}{6.28 \times R} = \frac{3.13 \times 2 \times 60}{6.28 \times 1.03} = 54 \text{ rpm}$$

Blade chord at the tip of the blade

$$= \frac{5.6 \times R \times R}{i \times CL \times r \times TSR \times TSR} = \frac{5.6 \times 1.03 \times 1.03}{3 \times 1.64 \times 1.03 \times 3 \times 3} = 11 \text{ cm}$$

Blade chord at the center of the blade = 15 cm
Blade length = 90 cm

Blade width at hub = 15 cm

Blade width at tip = 11 cm

Hub diameter = 24 cm

Rotor diameter = 206 cm

Blade angle = 25^0 with flight direction

RPM obtained = 54 rpm

Power obtained = 19.52 watt

The blades and hub are constructed according to these dimensions. Some figures concerned with blade and hub are given below.

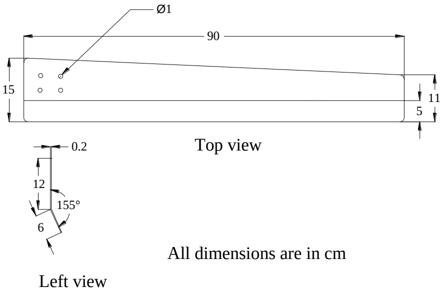

Fig 1: Designated blade views of a windmill

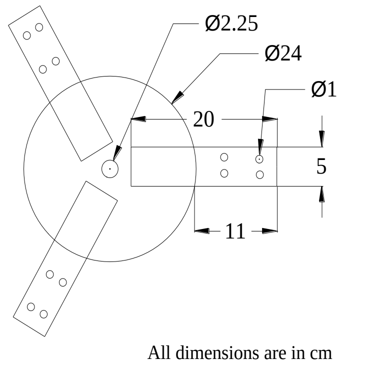

Fig 2: Hub of a windmill

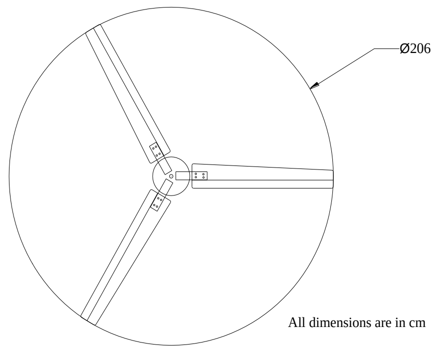

Fig 3: Blade and Hub assembly

V. EXPERIMENTAL SETUP

At first to measure the wind speed the digital anemometer was placed at blade height of the windmill. The wind speed reading was displayed directly on the screen of the anemometer. The voltmeter was connected in parallel and at the same time the ammeter was connected in series to the generator. The reading of voltage and current were taken directly from the voltmeter and ammeter screen respectively. The rotor speed was measured by tachometer. Power was calculated from voltage and current. For experimental setup the Digital anemometer, Voltmeter, Ammeter, Tachometer apparatus are also needed. The complete setup of the windmill is shown below.

Fig 4: Shaft to Generator

Fig 5: Rotating base Assembly

Fig 6: A Complete Windmill

VI. RESULT

The resulted power will be increased when the wind speed and the rpm of the turbine are increased as shown in Figure 4.

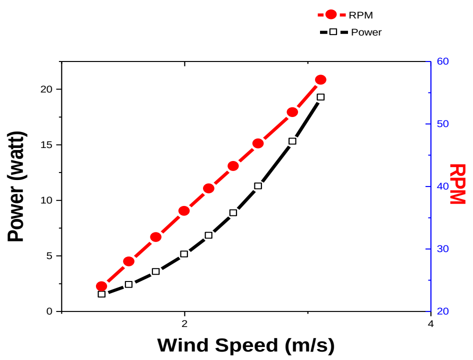

Fig. 7: The effect of rpm vs wind speed on the generated power

From performance test graph it’s clear that power increases with respect to wind speed, rpm also increases. Power increases at the geometric rate but rpm increases at the algebraic rate. But for much more wind speed power and rpm may fall due to vibration. Hence it needs to run a wind mill at an optimum wind speed.

The power variation i.e. the current is a function of the wind speed as shown in Figure 8 and Figure 9.

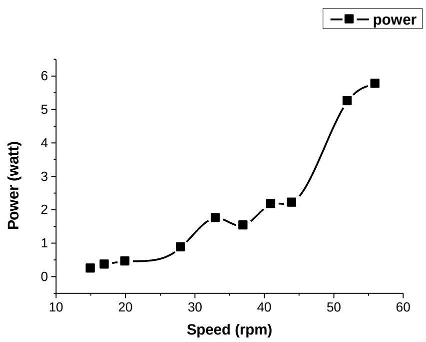

Fig 8: Power vs Speed

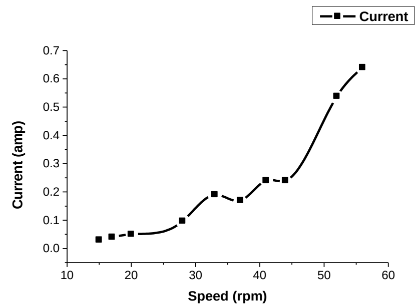

Fig 9: Current vs Speed

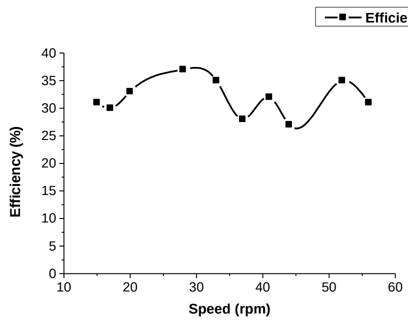

Fig 10: Efficiency vs Speed

From graphs Figure 8, Figure 9, and Figure 10, it is clear that efficiency curve fluctuate with respect to speed. Same as earlier graph power also increases as current increases with respect to speed.

VII. CONCLUSIONS

The windmill is designed for about 54 rpm. But practically it is running above the designed rpm and there have a good prospect of windmill at Rajshahi, Bangladesh. We suggest the following changes which can improve the performance of the windmill.

- To generate electricity by normal generator it needs about more than 1000 rpm but windmill shaft rotates at about 60 rpm. It is possible to increase the speed at generator by using a speed up gear box but it is costly and losses some amount of power due to friction.

- Additionally if gear box is used it will be very hard for the blade to overcome the initial torque.
- Hence it is essential to develop special types of generator which can produce electricity at lower rpm and eliminate the gear box.

APPENDIX -1

SAMPLE CALCULATION:

Calculation of Power, RPM and Blade chord for a 206 cm diameter rotor at wind speed about 3.13 m/s (Measured by an anemometer)

Data:

Wind speed V= 3.13 m/s (For Rajshahi region, Bangladesh)

Diameter = 206 cm = 2.06m

Radius, r = 1.03 m

Area, $A = \pi r^2$ = 3.14×1.03^2 = 3.79 m^2

Let TSR = 2

C_p = 0.4

N = 0.7

We have from equation (3)

Power = $0.6 \times C_p \times N \times A \times V^3 = 0.6 \times 0.4 \times 0.7 \times 3.79 \times 3.13^3$ =19.52 watt

Also, we have from equation (4)

RPM = $\frac{V \times TSR \times 60}{6.28 \times R}$ = $\frac{3.13 \times 2 \times 60}{6.28 \times 1.03}$ = 54 rpm

Table 1. Data for various wind speed

Parameters	1	2	3	4	5	6	7	8	9
Wind Speed (m/s)	1.33	1.55	1.77	2	2.2	2.4	2.6	2.88	3.11
Power (watt)	1.5	2.38	3.54	5.12	6.81	8.84	11.24	15.28	19.25
Rpm	23.94	27.9	31.8	36	39.5	43.2	46.8	51.8	57

APPENDIX -2

SAMPLE CALCULATION:

Data from multi-meter

Generator voltage = 9 V

Current for 28 rpm = 0.097 amp

∴ Power = V×I = 9×0.097 = 0.873 watt

Efficiency = $\frac{0.873}{2.38}$ × 100 % =37 %

Table 2. Current, Power and Efficiency for various speeds

Parameters	1	2	3	4	5	6	7	8	9	10
Speed (rpm)	28	33	52	20	44	56	17	37	15	41
Current (amp)	0.097	0.19	0.538	0.05	0.24	0.64	0.04	0.17	0.03	0.24
Power (watt)	0.873	1.75	5.25	0.45	2.21	5.77	0.36	1.53	0.24	2.17
Efficiency (%)	37	35	35	33	27	31	30	28	31	32

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