Design and Fabrication of a Turbine having NACA 2415 Blades and Feasibility Study of its Application in Cooling Tower

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Abstract. In modern world, energy is a blessing, but its production is a problem with many human and economic ramifications. Comparing with others, solar and wind energies are much popular but have their own problems, primarily cost. Some of experiments are at MIT’s Media Laboratory are happening with cheap alternative energy sources. Wind energy is more efficient according to research, than solar energy. Mathematically it is proven, with the help of a 3 square meter turbine where velocity of wind is 36 km per hour and with 30% of total efficiency about 300 watt can be obtained. The main contents of this project and thesis include the design, construction and calculating the performance of aerofoil shaped turbine blade. To construct the aerofoil shaped turbine three blades and a wood-hub are used. A shaft is fitted with hub with 5 cm diameter; a metallic gear is there for supporting the other end. In addition, gearing system is there to make the speed of output shaft are more high. A24 volt generator is also connected to the output shaft. The primary output was 6 watt & can apply this output power in various purposes like to run energy saving lamp, to charge mobile battery & other charge storage battery. A model has been used for simulation since the site of the actual turbine was not feasible for collecting effective data. The model was tested at different wind speeds and rpm of the rotor with respect to the amount of electricity produced.

1. Introduction
In today’s world, energy from renewable sources have a special attention in the field of growing concern about sustainable energy supplied and protection of the environment from adverse effect done by fossil fuel utilization. Presently, the pattern for both consumption and requirements of energy, which is related to population increase, economic growth, development, etc. are essentially
unsustainable [1]. The tremendous increase in oil import burden and other effects in shortage of power are some of the critical issues that the world is facing today.

Vast amount of carbon-dioxide with other greenhouse gases are being dumped into the atmosphere by burning fossil fuel, causing global warming [2]. It is clear that any effective strategy to control global warming should involve effective use of energy and environment friendly technologies [3]. A windmill is practically designed to convert the wind-energy into useful forms for the use of rotating blades. Turbines and windmills have been used in America since colonialism [4]. Windmills were used initially for grinding, but later it has been used for production of electricity. Human being has been using wind as energy for a long time. As example, for sailing boats, ancient Egyptians used wind. Use of wind in windmills was the most significant one [5].

Wind turbine, wind generators are called the most modern generation of wind mills and are used in generation of electricity. These windmills are designed and manufactured for converting the wind energy into electricity energy. The statistical data on wind turbines demonstrate that the largest turbines have capacity to generate about up to 6MW of power, where modern fossil fuel power plant can generate from 500 to 1,300MW [6].

Especially in industry the exhaust air which is coming from the cooling tower fan has sufficient velocity but this energy is normally unused. If we can utilize this air velocity sufficient amount of electricity will be generated and then can apply this power in various purposes [7]. So, we will apply the windmill principle here. To run wind turbine efficiently the required velocity of air is needed about 7ms-1 but the exhaust air velocity range of cooling tower fan exists between (3.1-12.9) ms-1 [8]. So, it is feasible to produce electricity by this process.

2. Design Criteria

There were several types of basic components to setup this experimental design:
2.1. Turbine Blade
Aero foil shaped turbine blade was used because to minimize friction, to reduce shock load and retain its inertia at low air velocity. For using aero foil shaped turbine it is possible to capture maximum air and increase the efficiency of the system.

2.2. Parabolic Hub
A parabolic shaped hub was used in the arrangement because it will reduce the energy lose in hub. It will also increase the efficiency of system.

2.3. Gear Arrangement
To increase speed of output shaft a gear arrangement was used in the arrangement. The ratio of the gear arrangement was 1:2.5.

2.4. Bearing
A bearing is a means positioning one part with respect to another in such a way that a relative motion is possible. Bearing supports the revolving shaft or a moving part with relative motion and to serve the machine fairly.

2.5. DC Motor
A 24 volt DC motor was connected to the output shaft as generator to generate electricity. When the shaft of generator is rotated by external source the flux is cut by the conductor and voltage induced if the system is closed current will flow.

The design of aero foil shaped turbine is based on the following criteria:

2.6. Number of blade (Three)
The most expected number of blades are 3, as smooth and steady rotation is required. Besides, two blades were not strong enough to withstand harmonic vibrations. On other hand, harmonic vibrations would affect two and four blade windmills similarly. After it 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. [9]. It was experimentally proved that

• When one blade was used then it captured 10% less energy than two blades.
• When two blades were used it captured 5% less energy than three blades.
• When three blades were used balance of rotating mass smooth & steady rotation was obtained.

• When four blades were used in this case more vibration was occurred.

2.7. Angle of attack (angle of blade 25°)
Usual angle is 4° with direction of flight, though most used blade angle is 25°. Sometimes the angles of 30° or 45° were used but higher blade angle produced more vibration [10].

2.8. Speed of Wind
Windmill typically worked efficiently when the wind has velocity is 20 miles/hour. Considering the above criteria of the rpm, blade chord of the windmill at a wind velocity of 7 miles/ hour (Measured by means of anemometer) was designed using the theory.

3. Design of Blade & Methodology:
At first the wind speed was measured by an anemometer (digital), which was placed at blade-height of the wind turbine. The reading of wind speed was displayed on the anemometer. The voltmeter and the ammeter were connected in parallel and series respectively to the generator. Rotor speed was measured by tachometer. Voltage and current reading were taken from the voltmeter and ammeter screen respectively. From voltage and current power was calculated.

The mean camber line coordination be determined by the following equations which have been taken from an article of ‘aerospace web organization’ for every single number of x-coordinates.

\[ y_c = \frac{m}{p^2} \left( 2px - x^2 \right) \]

\[ y_c = \frac{m}{(1-p)^2} \left[ (1-2p)2px - x^2 \right] \]

From x=p to x=c

From x=p to x=c

Here,
Airfoil length(chord), c=15cm (assume)
Highest camber position (along chord), p=40% of c
Highest camber, m=2% of c
Highest airfoil thickness, t=15% of c.
The thickness of above & below mean line can be determined by the following equation for each of the x coordinates.

\[ \pm y_t = \frac{t}{2} \left( 0.2969\sqrt{x} - 0.1260x - 0.351x^2 + 0.284x^3 - 0.1015x^4 \right) \] (1)

Table 1. Data of upper and lower surface value for designing NACA 2415 model

| x/c  | y/c  | x/c  | y/c  |
|------|------|------|------|
| 0.1  | 0.99 | 99.8 | -0.18|
| 1.53 | 2.97 | 99.17| -0.24|
| 4.56 | 4.87 | 96.76| -0.5 |
| 9.11 | 6.58 | 92.83| -9   |
| 15.03| 7.97 | 87.53| -1.43|
| 22.13| 8.93 | 81.02| -2.02|
| 30.16| 9.38 | 73.53| -2.7 |
| 98.85| 9.3  | 65.3 | -3.5 |
| 47.81| 8.75 | 56.59| -4.2 |
| 56.82| 7.87 | 47.69| -4.8 |
| 65.59| 6.75 | 38.89| -5.3 |
| 73.84| 5.48 | 30.53| -5.6 |
| 81.31| 4.17 | 22.77| -5.7 |
By using table 1 to design NACA-2415 model turbine blade **Design FOIL** was used.

|     |     |     |     |
|-----|-----|-----|-----|
| 87.76 | 2.9 | 15.86 | -5.5 |
| 92.99 | 1.79 | 9.99  | -4.9 |
| 96.85 | 0.91 | 5.34  | -3.9 |
| 98.22 | 0.059 | 2.07  | -2.6 |
| 99.2  | 35  | 0.3   | -0.6 |

The calculated design of various parts is given below:
- Aero foil Length (Chord) = 15 cm
- Length of Blade = 20.32 cm (8inch)
- Diameter of Hub = 15.24cm (6inch)
- Radius of Rotor = 27.94 cm

![Figure 1. Design of NACA-2415 model](image1)

![Figure 2. Experimental Setup](image2)
Swept Area = 0.2452 m²  
Angle of Blade = 25° with flight direction  
RPM obtained = 580 rpm

4. Results and Discussion

The primary output was 6 watts but power in the turbine was 51 watts so the wind turbine efficiency is 11%. But on particular experiment at MIT’s Media Laboratory with cheap alternative energy sources and a recent study has found that wind energy is more efficient than solar energy. If a wind with 36 km per hour (7 ms⁻¹) velocity with a swept area of 3 square meter by turbine with complete efficiency of 30%, about 300 watts can be obtained. But 5 February in 1998 Eric Eggleston suggested a power equation. A survey was made on a pharmaceuticals industry in (Tongi) Gazipur, Dhaka, Bangladesh to measure the exhaust air velocity of cooling tower. It was found that the air velocity of cooling tower varies in between (7.8-12.9 ms⁻¹). It’s shown above that for a wind with 36 km per hour (7 ms⁻¹) velocity with a swept area of 3 square meter by turbine with entire efficiency of 30%, about 300 watts can be obtained. So, it’s practically feasible to generate about 1.10kw electricity from this plant including the cooling tower of generator.

4.1. Calculation of power for cooling tower

| Wind Speed(ms⁻¹) | Power(watt) | rpm |
|-----------------|-------------|-----|
| 5.1             | 3           | 420 |
| 5.5             | 3.3         | 435 |
| 5.8             | 3.6         | 450 |
| 6.2             | 3.95        | 472 |
| 6.5             | 4.2         | 490 |
| 6.9             | 4.6         | 515 |
| 7.3             | 5           | 537 |
| 7.7             | 5.5         | 561 |

Voltage (V) of Generator = 20 Volt  
Current (I) require for 500 rpm = 0.3 amp  

\[
\text{Power} = V \times I
\]
\[= 200 \times 0.3\]
\[= 60 \text{ watts}\]

But 5 February in 1998 Eric Eggleston suggested an equation:  
The wind turbine rotor swept the power in the area:  
\[
P = 0.5 \rho AV^3
\]
\[= 0.5 \times 1.225 \times 0.2452 \times 7^3\]
\[= 51.51 \text{ watts}\]

\[
\text{Efficiency} = \frac{6}{51.51} = 11\%
\]

Extracting all the power from the wind was impossible as the rotor must maintain some flow. As a result some terms are included to get a practical equation for a wind turbine.
Power of wind turbine,

\[ P = 0.5 \rho A C_p V^3 N_g N_b \]  \hspace{1cm} (2)

Here:
- \( P \) = Power of wind turbine (watts)
- \( \rho \) = Air density (which is 1.225 kgm\(^{-3}\) at sea level)
- \( A \) = Swept area of rotor, exposed to the wind (m\(^2\))
- \( C_p \) = Coefficient of performance is 0.35 (for good design)
- \( V \) = Wind speed (meters/sec)
- \( N_g \) = Generator efficiency (80% or more for a permanent magnet generator)
- \( N_b \) = Efficiency of Gearbox\Bearing (depends, if good it could be as high as 95%)

From equation (2) we have

\[ P = 0.5 \times 1.225 \times 0.2452 \times 0.35 \times 7^3 \times 0.80 \times 0.95 \]

\[ \text{Or, } P = 13.70 \text{ watts} \]

For 4 setup total output of generator’s cooling tower will be

\[ P = 4 \times 13.70 = 54.8 \text{ watt} \]

Using the experimental data of air velocity from table 2, the theoretical graph of RPM Vs air velocity is plotted.

\[ \text{Figure 3. Graph of RPM vs Air Velocity} \]

From the above performance test graph, it’s noticed that RPM of blade increases with respect to air velocity.

Using the experimental data from table 2 of air velocity, the theoretical graph of power vs air velocity is plotted.
From the above performance graph, it’s seen that power increases with respect to the air velocity.

Using the experimental data of RPM from table 2, the theoretical graph of power Vs RPM has been plotted:

From the performance graph, it is seen that power increases with respect to RPM.

4.2. Calculation of payback period

We have,

\[
1 \text{ kwhr} = \text{Power} \times \text{Time}
\]

\[
1 \times 1000 \times 3600 = 1.1 \times 1000 \times \text{Time}
\]

Or, \( \text{Time} = 54.54 \) minutes

It takes 54.54 minutes to generate 1 unit electricity.

So, the amount electricity would be generated in a day = 8.80 units

The amount electricity would be generated in one month = 30 x 8.80 = 264 units

The amount electricity would be generated in one year = 264 x 12 = 3168 units

On average in Bangladesh per unit electricity cost is about BDT 6.50/unit.
Annual cost of 3168 units electricity would be = \(3168 \times 6.50 = \text{BDT} 20592\) (Approximately)
So, payback period = \(\frac{\text{investment required}}{\text{net annual cash inflow}} = \frac{42400}{20592} = 2.05\) years

4.3. Cost Estimation

| Sector                          | Cost   |
|---------------------------------|--------|
| Blade with Hub                  | BDT 800 |
| If Magnet Generator is used or Grid-Connected Generator is used | BDT 1200 |
| Bearing (4 Pieces)              | BDT 250 |
| Gear Arrangement                | BDT 200 |
| Others                          | BDT 200 |
| Total Cost (For One Setup)      | BDT 2650 |
| Total Cost (For Sixteen Setup)  | BDT 42400 |

From the above table we have got,
The cost of sixteen setup BDT 42400
Payback period = 2.84 years
Longevity of those arrangements = 5 years (Approximately)
From the above cost estimation, it is cleared that the project is practically feasible and economical.

5. Conclusion

Wind energy is very much available and it is used in many sectors for energy production. But using in a cooling tower is something unusual, as far authors’ concern. As there is exhaust gas which is harmful for the environment and considered as waste product, this addition of a blade can make this gas to be used again. In short, the concept may be helpful to reuse the energy that is wasted in a cooling tower. Concerning the feasibility, this setup will be beneficial in terms of economical perspective. The payback period is 2.84 years, which is almost 3 years. In terms of producing enough power this concept fulfills the condition regarding renewable energy. The efficiency is about 11% and the produced power is 54.8 watt per setup. This power can be used in many other sectors. If this setup can be upgraded in order to increase the efficiency then it may help to produce enough power for running additional equipment.

Acknowledgments

At first, all the praise to almighty God, who has given authors the knowledge and capability of thinking for successful completion of this research. Authors would like to acknowledge with proper honor to Prof. Dr. Md. Nurul Islam, Head of the Department of Mechanical Engineering, Rajshahi university of engineering & technology for his important contribution, suggestions and advices for completing this research. Authors extend a special note to the University research authority for providing the required equipment & provide funding for completing the research. Authors also would like to give thanks to Technical officer, assistant technical officer other stuffs of the Wood Shop, Machine Shop and Welding Shop of the university for extending their helping hand towards this research.

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