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ESTIMATION OF NUMBER OF TURBINES, POWER RATING, COST, MODELING OF THE WIND TURBINE BLADE & PROSPECTS OF WIND ENERGY IN THE COASTAL REGION OF BANGLADESH

M.M.Tanvir[1*], M.M.Rahman[2*] , M.S.Jui[3] ,S.Rubayan[4],M.M.Uzzaman[5]

[1,3,4] Department of Electrical and Electronic Engineering

[2,5] Department of Electronic and Telecommunication Engineering

Pabna University of Science and Technology , Pabna, Bangladesh

Abstract: This thesis paper describes the design and simulation of a wind turbine blade and possibilities of wind power generation in coastal region of Bangladesh. The main design of the blade of a wind turbine was developed in Q Blade simulation software. By considering the wind speed we have simulated the designed blade and we get optimal power from the blade.

The wind speeds of the coastal regions of Bangladesh have been considered in this paper. The data and calculation for 650 MW of power indicates the prospective source of wind energy is available in coastal regions of Bangladesh. Proper types of wind turbines may be use for the purpose of extracting wind energy from the coastal regions of Bangladesh.

Keywords- Wind turbine Blade; Q blade NACA 4422 Air foil geometry; BEM; Static blade loading; Cost analysis;

I. INTRODUCTION

Wind power is the use of air flow through wind turbines to mechanically power generators for electric power. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land.

Nowadays, modeling is the basic tool for wind power analysis, such as optimization, project, design and control. Wind energy conversion systems are very different in nature from conventional generators, and therefore dynamic studies must be addressed in order to integrate wind power into the power system. According to studies, in the case of power systems with classical sources of energy analysis, the modeling is relatively simple because the models of objects and controllers are well known and even standardized; the data are available. But in the case of wind turbine modeling, researchers meet problems related to the lack of data and lack of control-system structures due to strong competition between wind turbine manufacturers. This leads to the situation in which many researchers model the wind energy conversion systems in relatively simple form, almost neglecting the control systems, which significantly influence the reliability of the analytical results.

II.METHODOLOGY

Wind Turbines work by converting the kinetic energy of wind into electrical energy. The energy available for conversion mainly depends on the wind speed and the swept area of the turbine. The power can be defined as

$$P = \frac{1}{2} \rho A V^3 C_p$$

Here,

P= Power generation (W)

ρ= Density of wind (kg/m3)

A= Swept area (m2)
V= Velocity of wind (m/s)
Cp= Power coefficient

According to Bentz Limit or Bnetz's Law the theoretical maximum power efficiency of any design of WT is 16/27 or 0.59. That is, not more than 59 per cent of the energy carried by the wind can be extracted by a WT . In real world, Bentz Limit with values of 0.35-0.45 is common even in the best designed WT. It varies with wind speed, turbulence and operating characteristic. For our purpose, a Horizontal axis wind turbines (HAWT) has been considered.

III.WORKING PRINCIPAL

Between the two basic types of wind turbine horizontal axis are more common (like a wind mill), while vertical axis wind turbines are less frequently used.

A HAWT has a similar design to a wind mill, it has blades that look like a propeller that spin on the horizontal axis.

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind.

Small turbines are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster 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.

Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds.

Additionally, the blades are placed at a considerable distance in front of the tower and are sometimes tilted up a small amount.

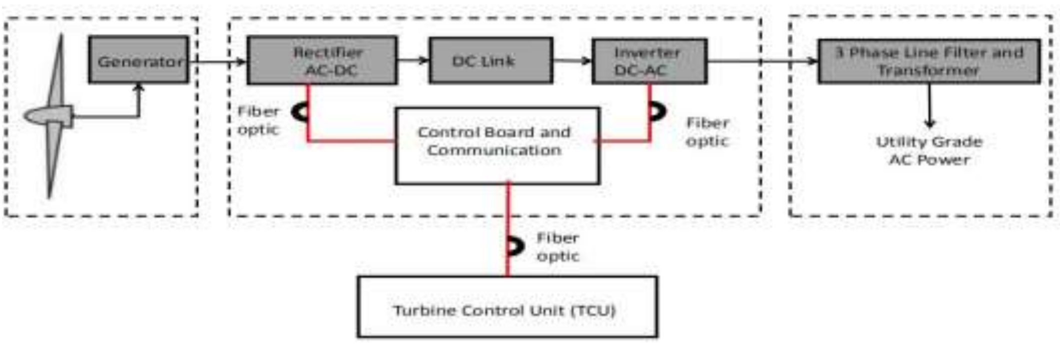

Figure 1: Block Diagram of a wind Turbine. [31]

IV.Calculations

Number of turbine, power rating & rotor size for wind energy generation :
Coefficient of performance, Cp = 0.540385
Density of air = 1.2 kg/m^3 (Sea level)
No. of hours in a year = 8760 hours.
Wind speed at 10 meter height is 10 m/s.
Capacity factor = 30% =0.30
Power density (Power per unit area) of wind turbine hub at 10 meter height is considered.

Power density of wind (ideal) : $P = \frac{1}{2} \rho A V^3$
$= 0.540385 \times 1.2 \times (10)^3$
$= 648.462$ watt / m^2

Considering Losses, Cp = 0.540385

Transmission losses (rotor to generator) = 0.90
Generator losses = 0.90
Overall loss factor = 0.540385 ×0.9 × 0.9 = 0.438
Actual power density = Ideal power density × Overall Loss Factor
= 648.462 × .438
= 284.026 w /m
Annual power density = Actual power density × No. of hours per year.
= 284.026 × 8760
= 2488.068 kWh /m^2
The real annual energy density will be less as the wind of rated speed will not blow for 8760 hours. Thus, the capacity factor need tom be considered.
Real annual power density = Annual energy density × capacity factor.
= 2488.068 × 0.30
= 746.420 kWh /m^2
Area of the rotor:
=108.183 / 746.420
= 0.145 m^2
Radius of the rotor blade covered area, (R)= πR^2 = 326.85m^2
R = 10.2 meter.
Power Rating of Turbine = Actual Power density × Area of rotor
= 2488.068× 326.85
Power Rating of Turbine = 813.225≈ 813 kw
Turbine power rating= 813 kw
Monthly energy consumption = 108.183 /12
= 9.01 kw
Daily energy consumption = 9.01 /30 = 0.3 kw
No. of turbines required = 0.3 /813
=0.78≈ 1
Therefore for producing 108.183 kW electricity annually (with rated average wind speed of 10m/s) for this we need 1 turbine (rated 813 KW) is needed.

V. The Theory Of Wind Turbine

WT work by converting the kinetic energy of wind to electrical energy. The energy available for conversion mainly depends on the wind speed and the swept area of the turbine. The power can be defined as

$$P = \frac{1}{2} \rho A V^3 C_p$$

Our Total coastal zone is 574 km (574000 m). We have taken 50% of the coastal zone (287000 m) for wind turbine and considering 30% more area for operation flexibility, office building and responsible personnel's residence & other facilities. It has been observed that, average wind speed is higher as the height is increased. As a result, extractable power is increased [22]. Average wind speed at 25 m height at Kuakata is approximately 4.463 m/s. Increasing the height to 50 m the average wind speed becomes 6.734 m/s [23]. Obviously, the wind power generation at higher altitude will be more. It supports the relation between tower height and wind power. The maximum height of the turbines known is 140 m and the rotor diameter is 107 m [24]. Estimation of power generation using WT in our near shore wind farm has been done first with Hub height, H = 35 m and Blade diameter, D = 25 m for an average wind speed of 5 m/sec.Then estimation have been done also for H = 60 m, D = 50 m; H = 80 m, D = 60 m and H = 100 m and D = 75 m. Wind speed at these three heights have been taken as 7 m/sec. Here is the weather condition for the costal region of Bangladesh.

Data Table

Month	Muhuri Dam, Feni (m/s) H=50m, RCL=0	Mognamaghat Cox's Bazar (m/s) H=50m, RCL=0	Parky Saikat Patenga, Chittagong (m/s) H=50m, RCL=0	Kuakata Patuakhali (m/s) H=50m, RCL=0
January	5.10	5.30	4.90	5.80
February	5.30	4.80	5.10	5.50
March	7.00	7.30	7.60	7.70
April	7.70	7.90	7.80	8.30
May	8.10	8.20	8.20	7.90
June	7.20	8.00	7.60	6.90
July	7.40	8.40	8.10	7.70
August	6.80	7.70	7.40	7.50
September	6.70	7.10	6.90	6.90
October	6.20	6.80	6.40	6.30
November	5.60	5.90	5.60	5.50
December	4.90	5.40	5.10	4.80
Annual Average Wind Speed (m/s)	6.50	6.90	6.725	6.733

VI. ESTIMATION OF NUMBER OF TURBINES POWER RATING ,COST & ROTOR SIZE FOR WIND ENERGY GENERATION FOR 650 MW POWER GENERATION

The following assumptions were made for calculating the number of turbines, power rating and rotor size for generating 650 MW of power by using wind energy.[32]

Annual energy consumption required = 6,50,000 KWh

Coefficient of performance, Cp = 0.40

Density of air = 1.2 kg/m^3 (Sea level)

No. of hours in a year = 8760 hours.

Wind speed at 50 meter height is 6.733 m/s.

Capacity factor = 30% =0.30

Power density (Power per unit area) of wind turbine hub at 50 meter height is considered.

Power density of wind (ideal) , $P = ½ \rho AV^3$

$= 0.5 \times 1.2 \times (6.733)^3$

$= 183.137$ watt / m^2

Considering Losses, Cp = 0.4

Transmission losses (rotor to generator) = 0.90

Generator losses = 0.90

Overall loss factor =0.4 ×0.9 × 0.9 = 0.324

Actual power density = Ideal power density × Overall Loss Factor.

= 183.137 × .324

= 59.336 w /m

Annual power density = Actual power density × No. of hours per year.

= 59.336 × 8760

= 519.787 kWh /m ^{2}

The real annual energy density will be less as the wind of rated speed will not blow for 8760 hours. Thus, the capacity factor need to be considered.

Real annual power density = Annual energy density ×capacity factor.

= 519.787 × 0.30

= 155.936 kWh /m^2

The area of the turbine can be estimated from the real annual energy density.

Area of the rotor = 650000 / 155.936

= 4168.376 m^2

Radius of the rotor blade covered area, (R)= πR^2 = 4168.376

R = 36.425 meter.

Power Rating of Turbine = Actual Power density × Area of rotor

= 59.336 × 4168.376

Power Rating of Turbine = 247.334 ≈ 250 kw

Annual energy requirement = 650000 kWh.

Turbine power rating= 250 kw

Monthly energy consumption = 650000 /12

= 54166.66 kw

Daily energy consumption = 54166.66 /30

=1805.55kw (1.805MW per day)

No. of turbines required = 1805.55/250

=7.22 ≈ 8

Therefore for producing 650 MW electricity annually (with rated average wind speed of 6.733m/s) for this we need 8 numbers of turbine (rated 250 KW) is needed.

VII.COST CALCULATION

The most comprehensive measure of wind energy cost is the per unit cost of energy (CoE). This measure incorporates all elements of cost i.e.,[33] installed capital cost(ICC),cost of operations and maintenance(O&M) over a year

Per Unit CoE = [(ICC+O& M) /Energy production year] £/(kWh/yr

One 250KW rated turbine costs £235,000 (including 50m Tower and Complete unit Installation and Grid connection costs) .Also the annual operation and maintenance needs a cost of £12,640

Per unit CoE = (£235,000 × 8 + £1264) /650,000

= 2.9117 £/(kWh/yr.)

Now, 1£ ≈ 130 Taka (in Bangladesh)

So, Per unit CoE for this design (2.9117 × 130) = 378.521 Tk./(kWh/yr.)

Daily per unit CoE for this design = 1.04 Tk/KWh

7.1 **Cost analysis**

Investment cost (Given in Million Taka)

Table 1 : Cost analysis

EQUIPMENT	BDT Million
EIGHT 250 KW W IND T URBINES	140.4
LAND & SITE D EVELOPMENT	1.9
BUILDING	0.76
BATTERY INVERTER ETC INCLUDING ONE-TIME REPLACEMENT	3.12

Total Investment Cost = BDT 146.18 (Million)

7.2 **Operation & Maintenance Cost:**

Table 2: Operational and Maintenance Cost

Man- power Cost	2.2
Repair & Maintenance Cost	1.6432
Lubricants	1.2

Total Operation & Maintenance Cost = BDT 5.0432 (Million)

7.3 Revenue

Table 3 : Revenue

Gross Generation of Electricity	0.650GW
Electricity Sale	0.617GW

Revenue = (0.2326 × 617 MW) =BDT 143.5457 (Million)

Gross profit per year = Revenue - Total Operation & Maintenance Cost

= BDT 138.5025 (Million)

VIII. BLADE DESIGN FOR OPTIMUM ENERGY CAPTURE

The tip speed ratio is given by: $TSR=\Omega R/V$

Where Ω is the angular velocity of the rotor, R is the distance between the axis of rotation and the tip of the blade, and V is the wind speed. A well designed typical three-bladed rotor would have a tip speed ratio of around 3 to 4.

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8.5 Airfoil Geometry

	Name	Thickness (%)	at (%)	Camber (%)	at (%)	Points	TE Flap (deg)	TE XHinge	TE YHinge
1	Spline foil	11.53	35.10	1.36	40.60	300	0.00	0.00	0.00
2	Circular Foil	100.00	50.00	-0.00	99.90	101	0.00	0.00	0.00
3	NACA 2416	16.00	29.10	2.00	39.50	99	0.00	0.00	0.00
4	NACA 4416	16.00	29.10	4.00	39.50	99	0.00	0.00	0.00
5	NACA 4420	20.00	29.10	4.00	39.50	99	0.00	0.00	0.00
6	NACA 4422	22.00	29.10	4.00	39.50	99	0.00	0.00	0.00
7	NACA 4424	24.00	29.10	4.00	39.50	99	0.00	0.00	0.00

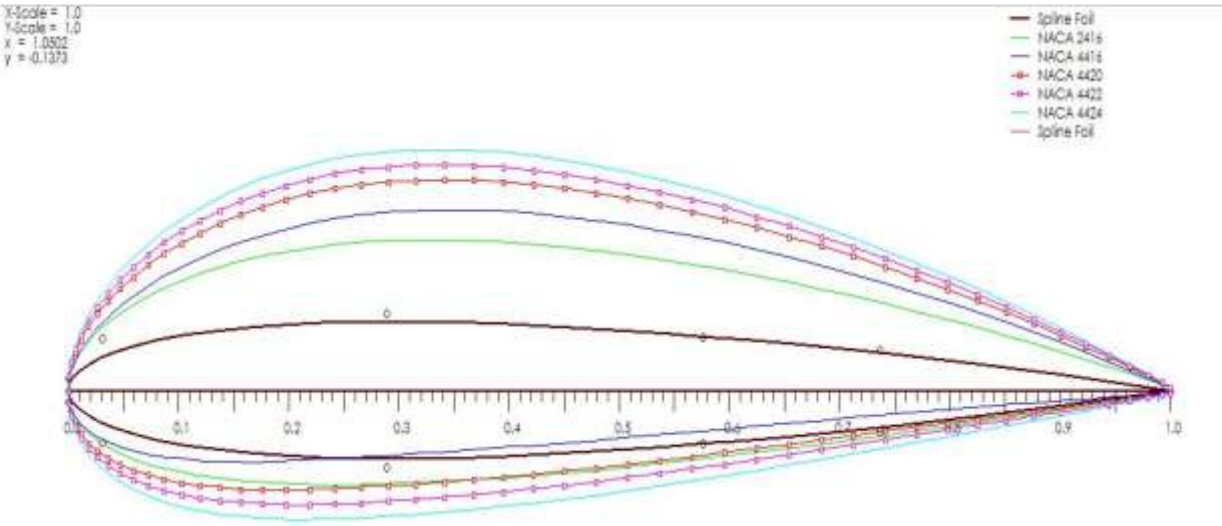

Figure 2: NACA airfoil design modules

8.5 XFOIL Direct Analysis

Once the aerodynamic lift- drag and moment coercions cl, cd and cm are known the resulting forces for lift L, drag D and pitching moment M can then be calculated by

$$c_l(\alpha) = \frac{L}{\frac{\rho}{2}U_\infty^2 c}$$
$$c_d(\alpha) = \frac{D}{\frac{\rho}{2}U_\infty^2 c}$$
$$c_m(\alpha) = \frac{M}{\frac{\rho}{2}U_\infty^2 c^2}$$

Here our outputs are:

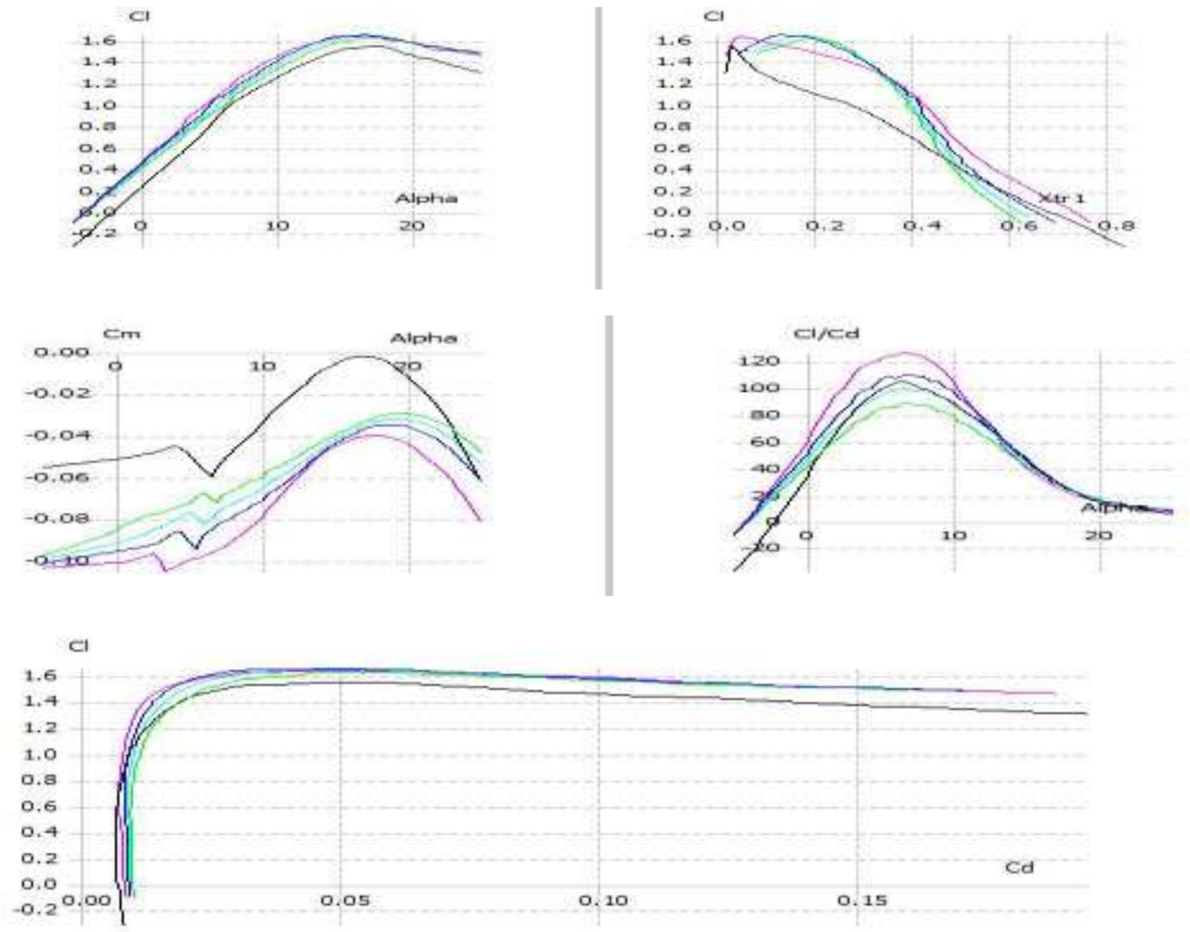

Figure 3 : XFOIL Direct Analysis of the blade element

8.6 Polar extrapolation

As mentioned above the total new angle φ is given as (assuming a blade pitch angle of $\theta p = 0$):

$\varphi = \theta p + \beta + \alpha = \beta + \alpha$

To keep the angle of attack α constant, the twist β must increase when the total new angle φ increases.

Here our output:

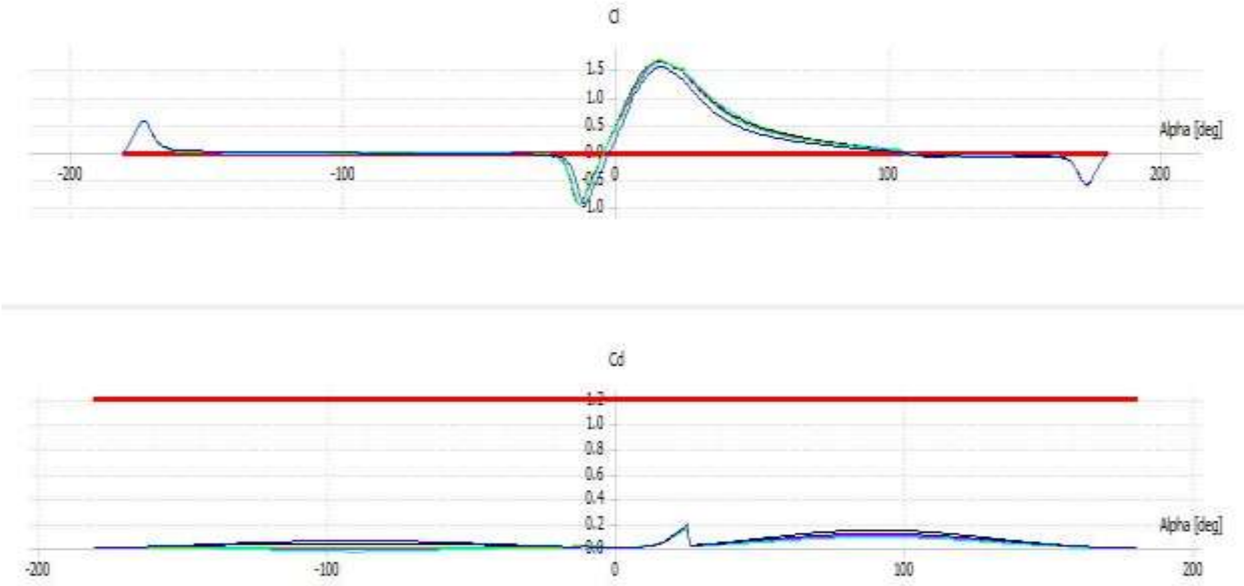

Figure 4 : Polar extrapolation of the blade

8.7 Blade Design

Here we have designed a blade which parameters are given below:

Blade Data

New Blade

3 blades and 0.20 m hub radius ☑ Blade Root Coordinates

	Pos (m)	Chord (m)	Twist	Foil	Polar
1	0	0.4	24.74	Circular Foil	CD = 1.2 360 Polar
2	0.651	0.4	24.74	NACA 2416	T1_Re1.000_M0.00_N9.0 360 M
3	1.25	1.4	24.74	NACA 4416	T1_Re1.000_M0.00_N9.0 360 M
4	2.5	1	9	NACA 4420	T1_Re1.000_M0.00_N9.0 360 M
5	5	0.7	5	NACA 4422	T1_Re1.000_M0.00_N9.0 360 M
6	7.5	0.5	2	NACA 4424	T1_Re1.000_M0.00_N9.0 360 M
7	10	0.414574	0.5	NACA 4424	T1_Re1.000_M0.00_N9.0 360 M

Table 5: Blade design measurements using NACA 4422 airfoil

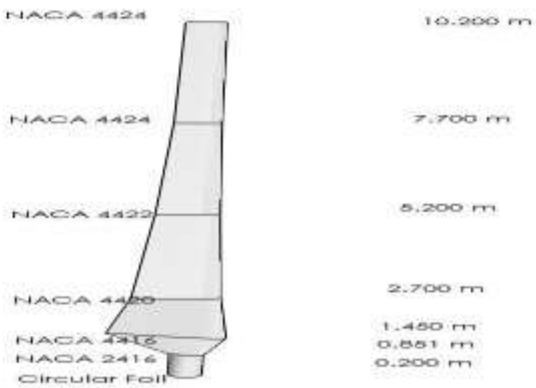

Figure 5: A blade on design module of NACA 4422 airfoil

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8.8 Rotor / Turbine Blade Element Momentum (BEM) Simulation

The Rotor / Turbine Simulation modules perform a Blade Element Momentum Method simulation of a rotor or a turbine. A rotor simulation only contains dimensionless variables such as tip speed ratio or power coefficient. After a turbine object is defined from a rotor within the turbine simulation module a non-dimensionless simulation can be performed (power, wind speed, etc.).

From Blade Element Momentum (BEM) Simulation we have found that NASA 4412 blade has better efficiency than other test. Here the BEM simulation of our designed blade:

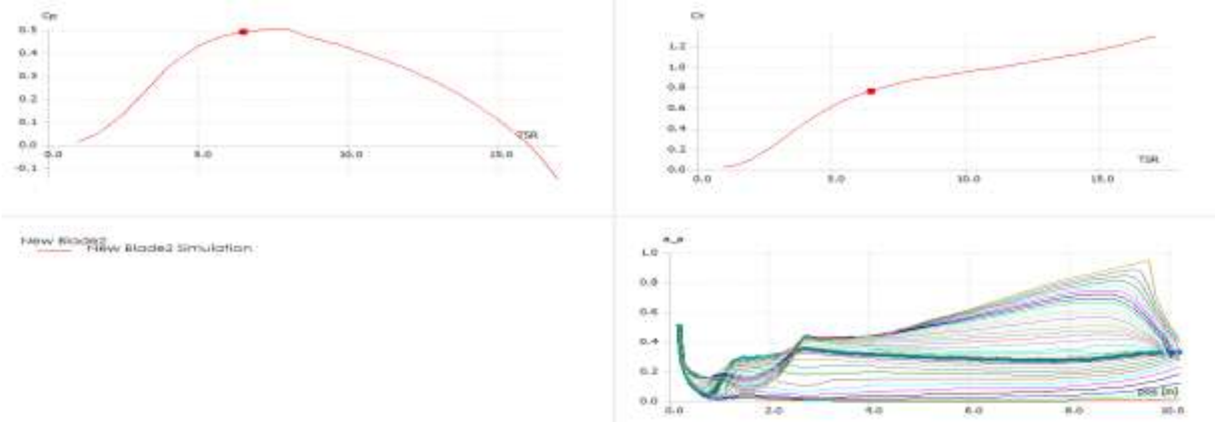

Figure 6: Rotor Blade Element Momentum (BEM) Simulation of the blade

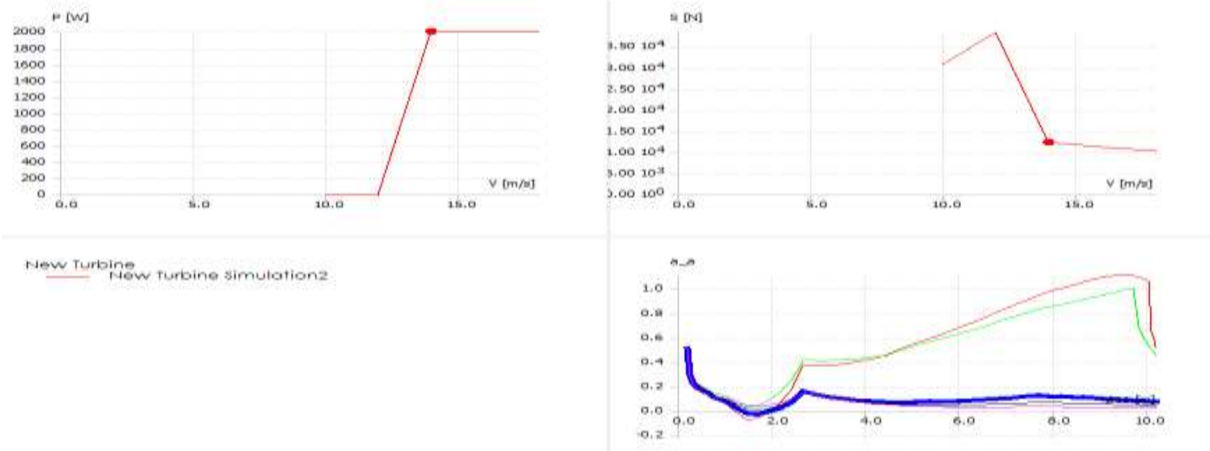

Figure 7: Turbine Blade Element Momentum (BEM) Simulation of the blade

8.9 Static blade loading:

Static blade loading shows the air pressure on rotor blade.

Here we have designed a blade which Static blade loading is given below:

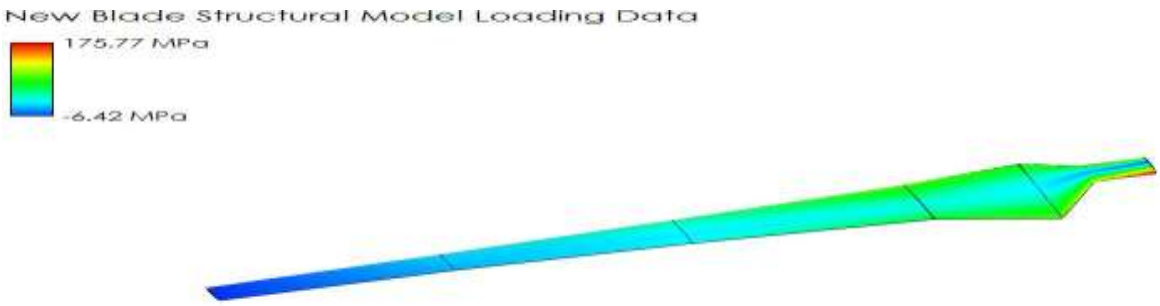

Figure 8: Static blade loading

8.10 Output Generated

The output throughout the simulation is acquired average of **108.183 kW**

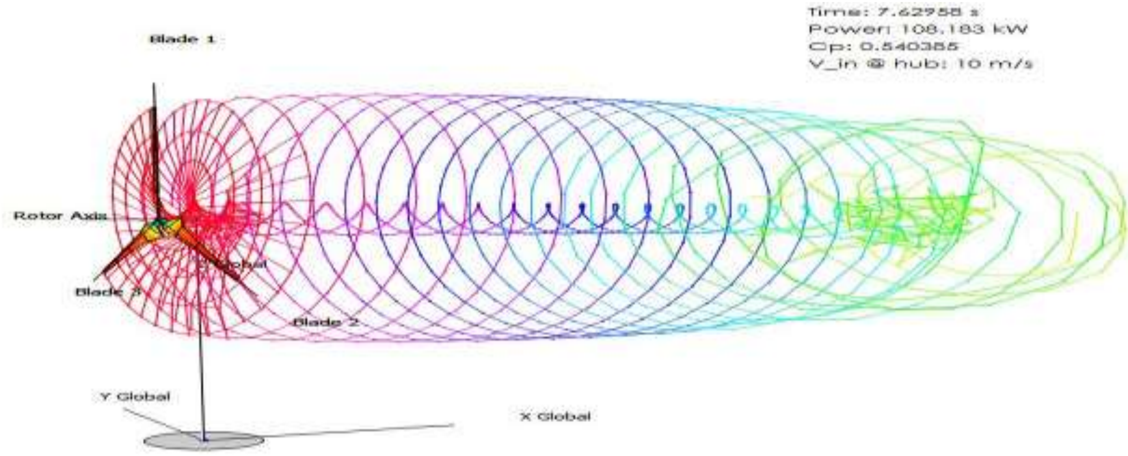

Figure 9: Simulation of generated output

IX. DESIGN REVIEW

There are so many designs are made for the optimal power capture. In the other papers, they used several types of NACA airfoils. Which are NACA 4412, NACA 0018, NACA 2412 and others. At the question of power developed a research was held on NACA 4422 with the consideration of wind speed of Bangladesh in the coastal area like Patenga sea beach, Chittagong Bangladesh. They have experimented that NACA 4412 airfoil with a 0.9m long blade can deliver 1 kW power. Here we have researched with NACA 0012, NACA 2412, NACA 2416 and NACA 4418. With the simulation software, we have experimented that with NACA 4420 airfoil and a set of 10.00m long three blades it can deliver 108.183 kW of power average at maximum 10m/s wind speed.

X.CONCLUSION

Wind energy is one of the growing sources of Bangladesh. Wind power is conversion of wind energy. Into electricity using wind turbines. Wind turbines work done by wind flow i.e. wind speed. We collect wind speed data from different costal region. Then we simulation this data in Q-blade design software. The output throughout the simulation is achieved 108.183 kW. We want to make second prototype which will be delivered at least 1 MW or more at any given time.

In this thesis, we have tried to design a small wind turbine and possibilities of wind power generation in Bangladesh. Including the entitled Q-blade software, we design the wind turbine blade in such a way which may apply to the wind velocity of our costal area to produce the maximum electricity. We are able to design in such wind turbine that can theoretically produce average 108.1kW power.

By the by, we want to give an advance wind turbine design to generate high efficient wind power which can make a valuable contribution to an electrical system.

As it is the 21st century, life is directly depending on electricity. But the energy crisis is becoming a huge threat for economic development of Bangladesh. Still only 39% of the populations have access to electricity. In the coastal area and the isolated Island where grid connection is not feasible, alternate electric source like wind power system can be very cost effective. On the other hand, other renewable energy system like PV system is at least 4 to 5 times more expensive than wind power system. Therefore, the above calculation indicates that it is possible to generate electricity by using wind energy at a very reasonable rate. The per unit cost will be cheaper if the generation is more than 650 MW. So, government and the private sectors should emphasis on wind power system as a solution of power crisis in Bangladesh.

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