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POTENTIAL OF WIND ENERGY AND DESIGN OF SMALL WIND TURBINE SITUATED AT HILLOCK AT NAGPUR

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Abstract

The proposed paper aims to design a small wind turbine upto 50 kW based on the meteorological wind data for the college site which is situated on a hillock at Nagpur, India .The wind turbine design is done by considering the eight year wind data collected from meteorological department Nagpur Airport which is nearby to the proposed site.The design of Wind Turbine and installation is a function of wind quality and wind character. Small wind turbines, are designed to be installed individually, may be at homes, farms, hills as a local source either as a main source at remote place or as a backup to main electricity supply or to offset the use of utility power and reduce electricity bills. To design a wind turbine suitable to local wind conditions is a big technical venture full of art and skills of designing, as the wind never remains stable, is the main objective of our project. An extensive literature survey is done to understand the performance of wind energy conversion system (WECS) for the proposed site. Researches shows that increase in average velocity results into 50% cost reduction .The meteorological data from 2004-2011 is used for predicting the average wind speed and daily, monthly and yearly wind flow directions to maximize the power generation. The Wind Rose PRO *(open source) software is used for the analysis. The wind turbine blades are designed based on different cases. The height of the wind turbine is considered as 120 m above ground level. The proposed approach will be useful for the optimal performance and cost effectiveness in wind power generation.*

Ensure to match

Keywords: *Renewable Energy, Wind Energy, Wind Turbine, Wind-Rose, Design of wind turbine, Wind Energy Conversion System(WECS)*

Introduction:

Wind Energy

Wind is the clean and abudant source of renewable Energy. Earlier, the first windmills were used as a tool in processes that needed force or rotation, like milling grain, pumping water, etc. The technical development of wind turbines has basically happened during the last 20 years.Later the wind power is considered as an alternative means for producing electricity to the well established one(such as coal,etc.).When the technology for creating an efficient wind turbine became available in the late 1970s, concerns about the adverse environmental impacts of non-renewable energy resources (such as fossil fuels) increased.[1]

The domestic wind power industry in India is leading the way in the wind energy sector and has been making steady progress. A strong ecosystem, improved project operation capabilities, and a manufacturing base generating about 12,000 MW annually have all resulted from the wind industry's growth. At 41.93 GW, the nation has the fourth-highest installed wind capacity in the world as of December 31, 2022. An extra 1.85 GW was added to the installed capacity in 2022. The total quantity of units produced by wind power projects between January and November of 2022 was 66.05 billion units.[2]

Globally, India experienced the most substantial surge in electricity demand, registering an impressive growth rate of 8.4%. In the realm of renewable energy, solar photovoltaic (PV) systems took the lead, contributing significantly to the total capacity additions of 348 GW in 2022, accounting for 70%. Wind power followed closely behind, contributing 77 GW (22%), while hydro-power made up 22 GW (6.3%). Notably, the top three nations leading in the incorporation of solar and wind power capacities were China, the United States, and India, reflecting their commitment to advancing renewable energy sources.[4]

Potential of Wind Energy in India

Wind energy is a site-specific and intermittent power source, therefore identifying suitable areas necessitates a thorough Wind Resource Assessment. As of December 31, 2022, the Ministry, in partnership with the National Institute of Wind Energy (NIWE), had erected 993 wind-monitoring stations across the country. Wind potential maps have been released at various heights above ground level, including 50 m, 80 m, 100 m, and 120 m.[2]

At 120 meters above ground level, the current evaluation suggests a significant gross wind power potential of 695.50 GW in India. As seen in the table below, the distribution of this potential is concentrated in eight windy states:

Wind Power Potential in India at 120 meter, above ground Level (agl)

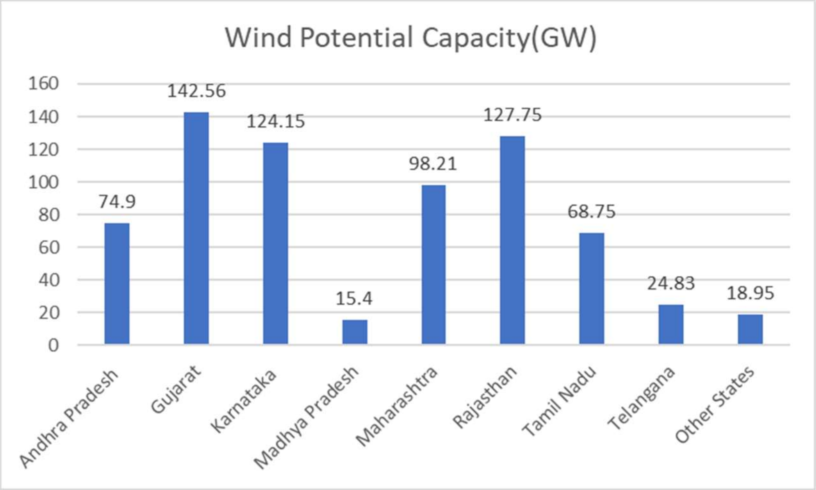

Figure: 1

Installed capacity of Wind Power in India

The installed capacity of grid -interactive wind power in the country as on 31-12-2022 is shown in **Fig-2** below:

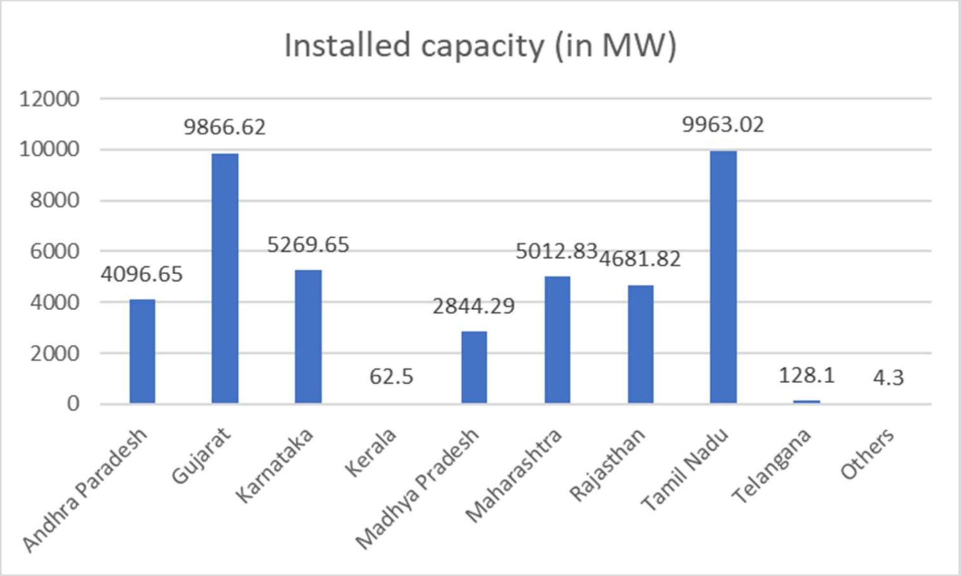

Figure: 2

Renewable energy experiences robust growth across all scenarios, averaging between 4-6% annually.

Dominance by 2050

In the Accelerated and Net Zero scenarios, renewable energy emerges as the largest primary energy source by 2050.In the New Momentum scenario, renewable energy is the largest source alongside coal.

Electricity Generation Surge

By 2050, electricity generation sees a significant increase: New Momentum and Accelerated show a fourfold increase compared to 2019.Net Zero exhibits an even more substantial fivefold increase. Solar and wind power contribute significantly to this growth, ranging from 57% to 95%.

Installed Capacities in 2050: Solar and wind installed capacities reach impressive levels in 2050, depending on the scenarios:

Solar capacity ranges from 1.3 to 2.2 TW.

Wind capacity ranges from 0.3 to 1.2 TW.

These projections underscore the pivotal role of renewable energy, particularly solar and wind, in shaping the future energy landscape. The substantial growth reflects a global transition towards cleaner and more sustainable energy sources.[4]

Factors influencing the wind energy economics Cost of wind-generated electricity over the years from 1980 to 2020.The estimates from 2005 to 2020 are projected, following the prevailing trend. We can see that the cost/kWh has fallen from 26 cents in 1980 to nearly 5 cents in 2005 - a reduction of 84 per cent in the last 23 years. The decline in the cost is more prominent during 1980 to 1985, which is attributed mainly to the increase in turbine size. Projections for the future indicate that the cost would further be reduced to 2.6 cents/kWh by 2020. There are many factors that affect the economic viability of a wind energy project. They can broadly be grouped as site-specific factors, machine or system parameters, market factors and policy issues. Let us discuss these factors in brief. 7.1.1 Site specific factors Energy available in wind spectra is proportional to the cube of the wind speed. This implies that when the speed of the wind at a location doubles, the energy increases by eight times. Hence, the strength of the wind spectra.

The wind speed available at the project site is a pivotal determinant of the cost of wind-generated electricity. the impact of the average wind velocity at a site on the cost of unit energy production. Notably, when the average velocity increases from 7 m/s to 9.5 m/s, there is a significant 50% cost reduction, dropping from 5 cents to 2.5 cents per kilowatt-hour (kWh). This exemplifies the direct correlation between wind speed and the economic feasibility of wind energy projects.

For the efficient planning and successful implementation of any wind power project, an understanding on the performance of the Wind Energy Conversion System (WECS), at the proposed site, is essential. The major factors affecting the power produced by a WECS are (a) the strength of the wind spectra prevailing at the site and its availability to the turbine (b) the aerodynamic efficiency of the rotor in converting the power available in the wind to mechanical shaft power and (c) the efficiencies in manipulating, transmitting and transforming this power into the desired form. Hence, assessment of the performance of a WECS is rather a complex process. Wind is a stochastic phenomenon. Velocity and direction of wind at a location considerably vary from season to season and even time to time. Hence, apart from the strength of the wind spectra, its distribution also has significant influence on the performance of the WECS. Further, the characteristic operational speeds of a wind machine should match well with the prevailing wind spectra to ensure the maximum exploitation of the available energy. [1]

[R3]Their will be four times increase in deployment of solar and wind deployment by the year 2030 as compared to 2019 levels. By 2050 the solar and wind capacity will increase 10 folds as compared to year 2019.[3]

Methodology

1. Collection Of Data From Meteorology Department And Wind Data Analysis
2. Study Of Wind Rose
3. Study Of Control Volume Analysis For Wind Turbine
4. Study Of Blade Element Theory For Wind Turbine
5. Study Of Naca Aerofoil
6. Blade Element Calculation
7. Generator And Electrical System

1. Pre Project Study

Collection of Wind Data Records

Meteorological Data Collection (2004-2011)

Wind Speed:

Wind speed, a crucial factor in turbine blade design, was monitored over eight years (2004-2011). Utilizing anemometers and wind vanes, instruments common in the wind energy industry, average daily wind speeds were recorded. Variability in wind speed, both natural and influenced by industrial developments, was observed.

Wind Direction:

The direction from which winds originated was assessed using instruments like windsocks and wind vanes. The prevailing winds' impact on turbine design was considered, with data collected over the eight-year period offering insights into the directional patterns.

Relative Humidity:

The amount of water vapor in air-water mixtures, termed relative humidity, was measured. Using hygrometers, devices designed for humidity measurement, the ratio of water vapor's partial pressure to saturated vapor pressure at prescribed temperatures was determined.

Atmospheric Pressure:

The force exerted by the weight of air above a surface, known as atmospheric pressure, was recorded. Hydrostatic pressure caused by the mass of air above the measurement point was closely approximated. Differences in pressure in low and high-pressure areas were noted.

Temperature (Max and Min):

Maximum and minimum temperatures were tracked, providing insights into the operating temperature range for the monitored period. Extreme climate conditions necessitated specific versions designed for cold and hot weather regions.

Dew Point Temperature:

The dew point, representing the temperature at which water vapor in humid air condenses into liquid water, was determined. Changes in dew point concerning temperature variations and their correlation with relative humidity were analyzed.

Vapour Pressure:

Equilibrium pressure from a liquid or solid at specific temperatures, termed vapor pressure, was assessed. The vapor pressure's independence from the amount of contact with the liquid or solid interface was considered in the analysis.

Wind rose and Wind Data Analysis

A wind rose serves as a concise visual tool utilized by meteorologists to represent the typical distribution of wind speed and direction at a specific location. Its applications span various fields, including wind energy, air quality measurement, environmental impact assessments, oceanography, agricultural engineering, and ambient air monitoring.

In wind data analysis, specialized software such as **Wind Rose PRO** is employed for plotting wind roses. This Windows-based software facilitates the analysis of directional data and the creation of wind roses. It supports the import of data in multiple formats, conducts analyses, and generates diverse chart types. The convenience extends to exporting results in Microsoft Excel format, where charts are automatically generated for enhanced visualization and interpretation of the analyzed wind data.

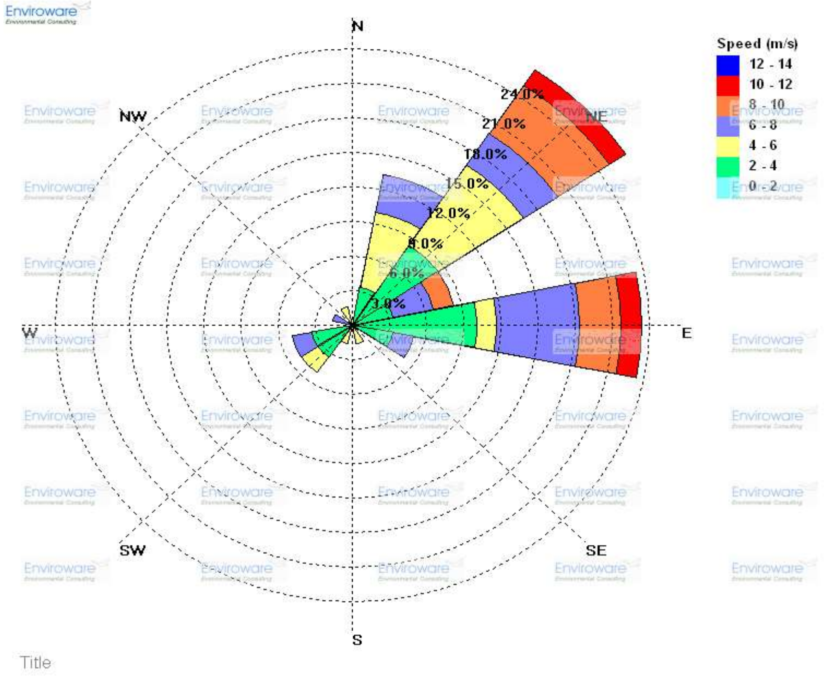

Figure: 3

Wind rose Analysis for Nagpur

The presented wind rose, based on data from the Meteorology Department in Nagpur, illustrates wind characteristics, incorporating both wind speed and wind direction. Wind direction is specified in degrees, where north corresponds to 0° and 360°, east to 90°, south to 180°, and west to 270°.

In this depiction, the wind rose is segmented into eight directions, revealing predominant wind patterns. The visual indicates that the prevailing winds in Nagpur predominantly originate from the northeast and east, with minimal occurrences from the northwest and south-southeast directions.

Additionally, the wind rose provides insights into the distribution of wind speeds across different directions. For instance, it highlights that approximately 31% of the time in Nagpur, winds blow from the northeast and east at speeds ranging between 4 and 8 km/hr. This breakdown allows for a comprehensive understanding of wind behaviors, aiding in various applications such as wind energy assessments and environmental impact studies.

Wind Data Analysis

Fig 4 shows monthly wind speed variations for January 2010. This graph gives us an instant snapshot of wind speed variations over a time period of one month.

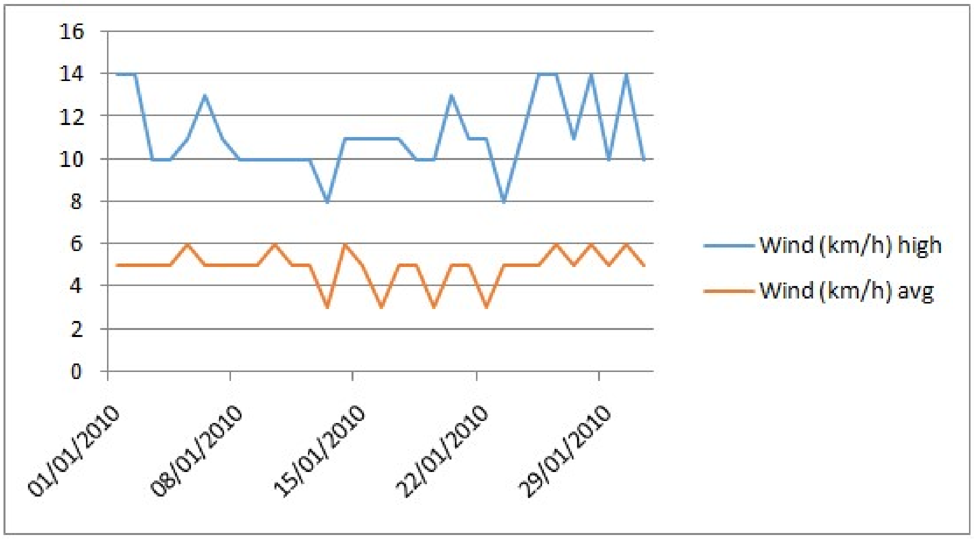

Figure: 4

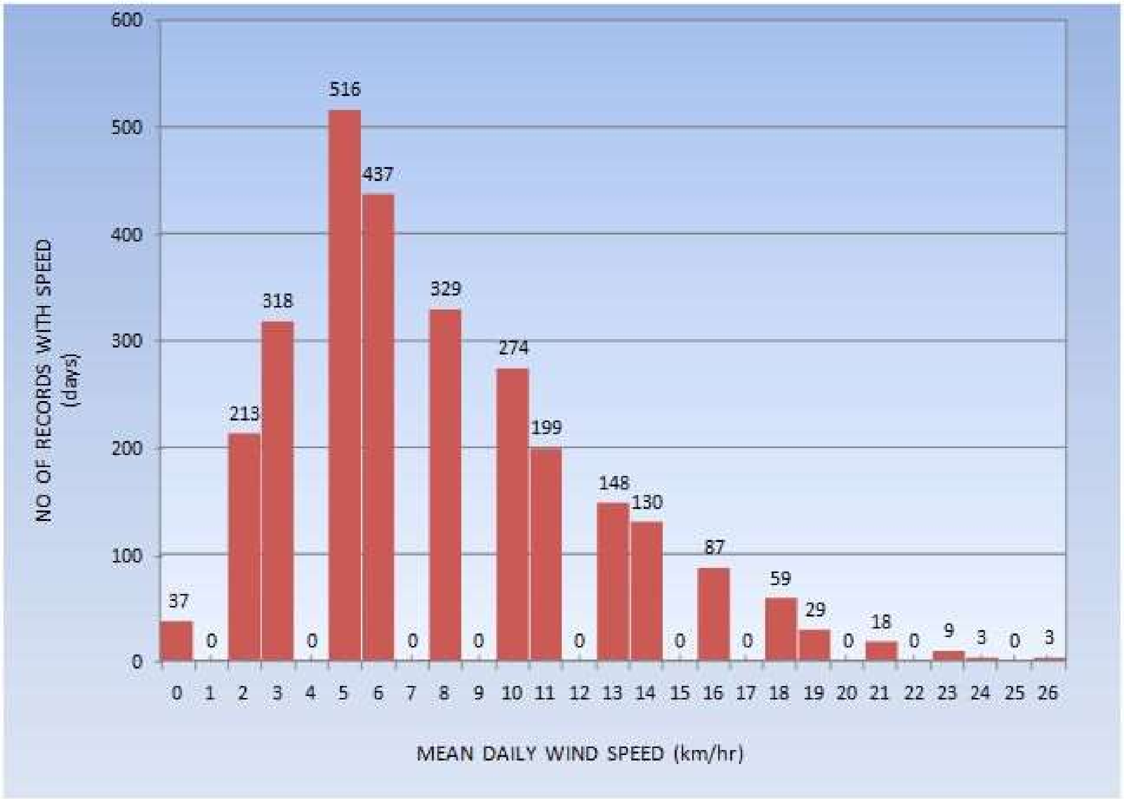

Figure: 5

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Mean Daily Wind Speed Analysis

The histogram in Fig 5 portrays the mean daily wind speed over eight years, with the x-axis representing the mean daily wind speed and the y-axis indicating the number of records for each wind speed category. The dataset encompasses mean daily wind speeds across 2829 days.

Total no of days = 2829 (For 8 years)

Mean wind speed = (no of record *wind speed)/ total no of days
= 21053/2829
= 7.442 km/hr

Mean Wind Speed=7.442km/hr

This analysis, combined with the windrose data, leads to the conclusion that the optimal range for wind speed in the region is between 2-18 km/hr. Understanding the mean wind speed is crucial for various applications, including assessing wind energy potential and optimizing the performance of wind-based systems.

Energy Availability Analysis

In fig.4.the turbine is represented by a circular blade disk whose area $A = \pi R^2$ where R is the blade radius in m.

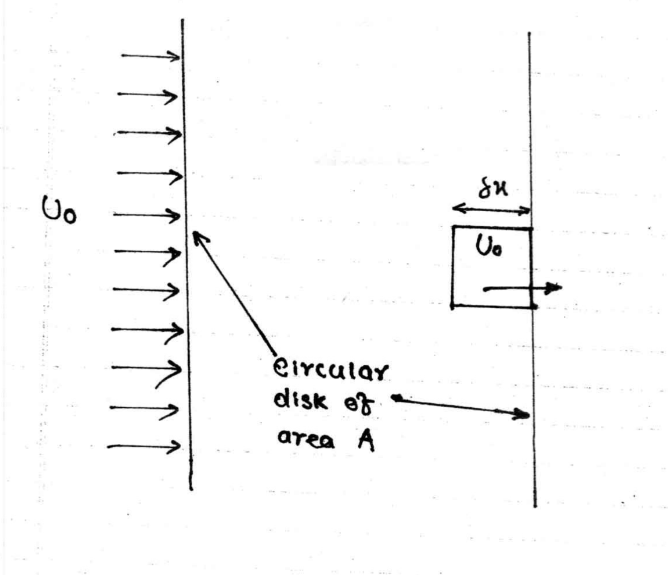


Figure: 6

The right side of Fig.6. shows an elemental value of the airflow. Its exact shape is not critical. The volume is about to cross the imaginary line (when viewed side-on) in the wind that represents the blade disk. The volume of the element is the product of its area, ΔA, and length normal to the disk, δx, so its mass is ρΔAδx and its KE is $\frac{1}{2}\rho \Delta A \delta x U_0^2$. The time taken for this element to cross the blade disk, δt, is given simply by $\delta x = U_0 \delta t$. The contribution of the element to the total amount of KE that passes in δt is symbolised as ΔKE and is given by

$$\delta(\Delta KE) = \frac{1}{2}\rho \Delta A U_0 \delta t U_0^2$$

Summing over all elements of area that make up the disk gives the KE passing the disk as

$$\delta(KE) = \frac{1}{2}\rho A U_0^3 \delta t$$

This equation can be taken formally to the limit as $\delta t \to 0$, to give

$$P = \frac{d(KE)}{dt} = \frac{1}{2}\rho A U_0^3$$

Where P is the power, the time rate change (derivation) of the energy .

assuming radius of blade = 3.5

case1) U_0 = 1.25m/s, A = $7.0685m^2$

p = $\frac{1}{2} \times 1.2 \times 7.0685 \times 1.25^3 = 8.283\ watt$

case2) U_0= 2.067m/s (mean wind speed)9

p = $\frac{1}{2} \times 1.2 \times 7.0685 \times 2.067^3$

= 37.45 watt

Case3) $U_0 = $ 5m/s

P = $\frac{1}{2} \times 1.2 \times 7.0685 \times 5^3$

= 530.1375 watt

Control Volume Analysis for Wind Turbines

The Control Volume (CV) analysis for wind turbines involves the use of a cylinder, as depicted in Fig. 5, where the radius of the CV (Rcv) is significantly larger than the blade tip radius (R). The CV is strategically positioned with its upstream face located far enough upstream, ensuring that the velocity entering the CV is the wind speed (Uo), and the pressure is at ambient or zero gauge pressure. The blades' presence does not influence the flow at the upstream face.

As the turbine extracts energy from the wind, the velocity in the far-wake ( ) is always less than. The radius of the far-wake is denoted by . Consequently, the wake expands, as illustrated by the "bounding streamline," a part of the "bounding stream tube" acting as the boundary between the flow passing through the blades and the external flow. This boundary is distinct and can accommodate a discontinuity in velocity and pressure across the bounding streamline.

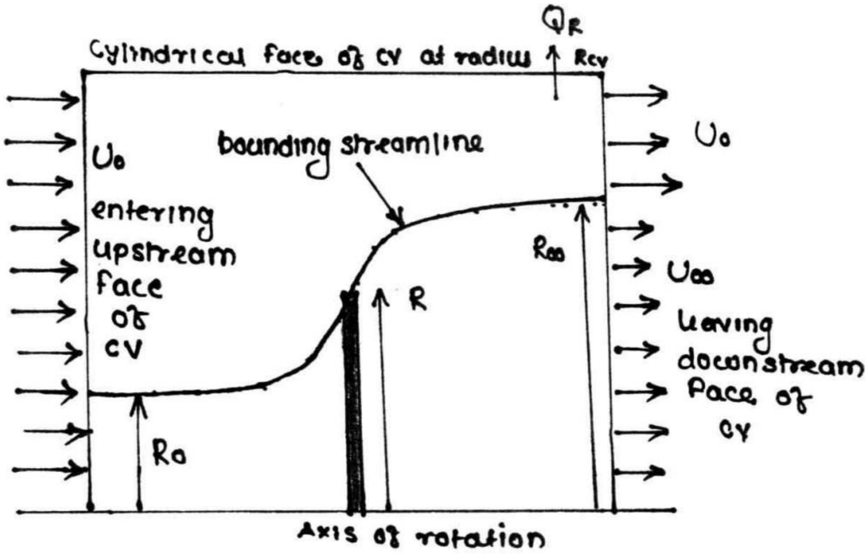


Figure: 7

The Fig. 7 illustrates the expansion of the flow before the blades, with approximately half of the expansion occurring in the upstream flow, measured by the cross-sectional area of the bounding streamtube. This phenomenon explains why the turbine cannot capture all the kinetic energy that would pass through the blade area in the absence of the blades.

The analysis assumes uniform and pressure in the far-wake, with the latter equated to atmospheric pressure. Additionally, any swirl or circumferential velocity generated by the blades is disregarded, despite the fact that the torque on the blades must induce a change in the angular momentum of the air.

AEROFOIL GEOMETRY AND DEFINATIONS

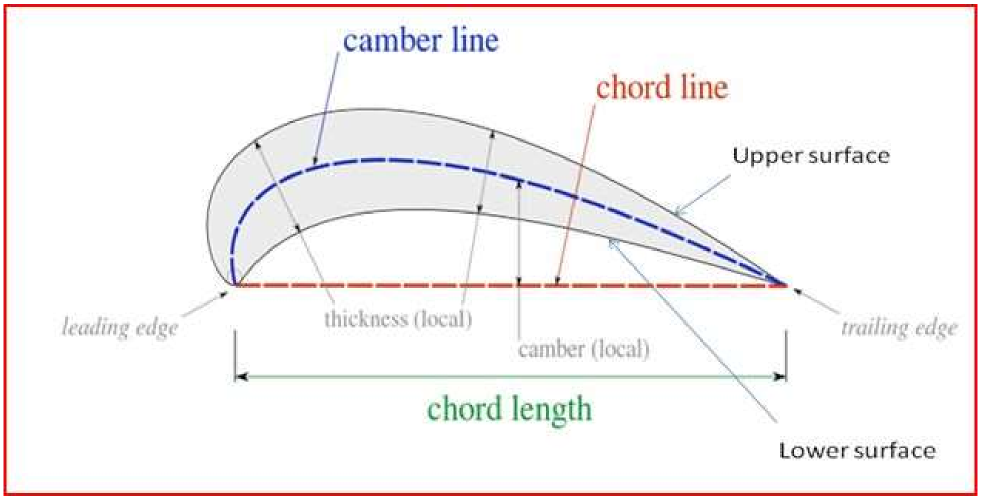


Figure: 8

An aerofoil is a 2-dimensional body in an infinite, uniform flow away from the region influenced by the body. Wind turbine blades consist of aerofoil sections designed to generate lift, the main contributor to torque along the turbine axis during blade rotation. Key terminologies associated with an aerofoil include:

Leading Edge: The foremost point on the aerofoil.

Trailing Edge: The rearmost point on the aerofoil.

Camber Line: The midpoint between the upper and lower surfaces of the aerofoil.

Chord Line: A straight line connecting the leading edge and trailing edge.

Camber: The maximum distance between the chord line and the mean line.

Upper Surface: The suction surface typically associated with higher velocity and lower static pressure.

Lower Surface: The pressure surface with relatively higher static pressure than the suction surface.

Chord Length: The length of the chord line, serving as the characteristic dimension of the airfoil section.

Examples of NACA 4-digit series

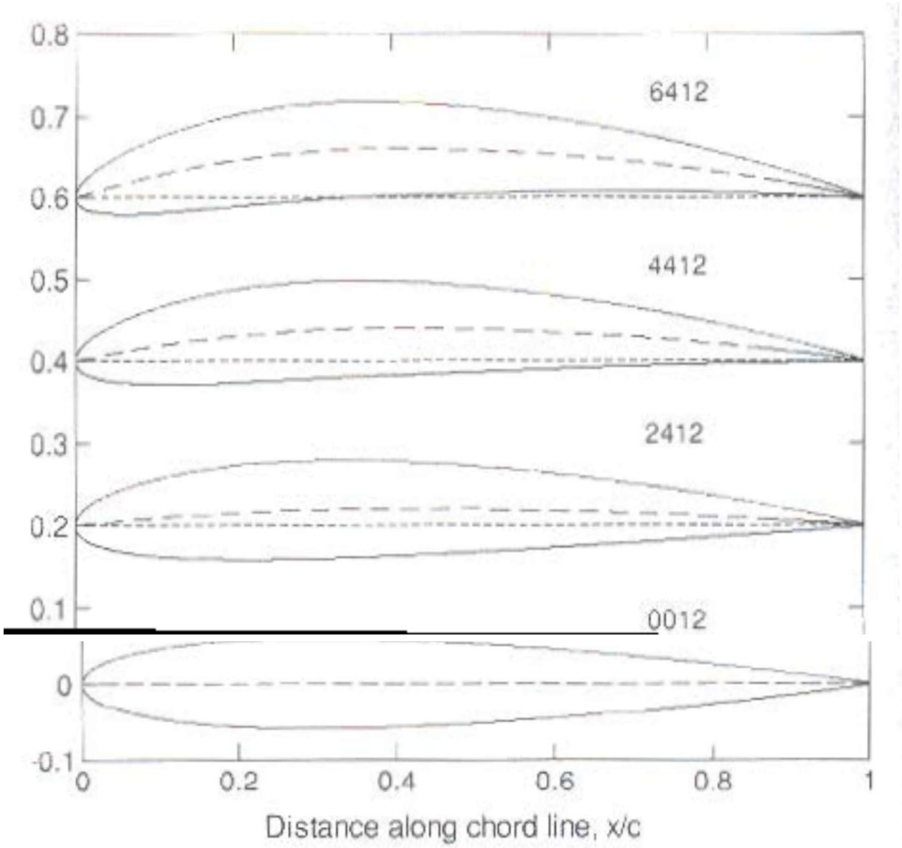


Figure: 7

Figure 7 shows 4 members of the NACA “four digit” series. NACA stands for National Advisory Committee on Aeronautics (U.S.).

- First number indicates camber as a percentage of chord
- Second number indicates camber occurs at X % of chord
- Last two number indicates max thickness t as % of chord

Wind Turbine Blade Element Theory

Some Assumption of Blade Element Theory

To extend the analysis the following assumption were made:

- The flow in each streamtube is independent of that in other streamtubes
- The forces acting on each blade element are the same as those on an aerofoil of the same section, angle of attack, and effective velocity

AEROFOIL SELECTION AND BLADE DESIGN

NACA 0012 SECTION SHAPE

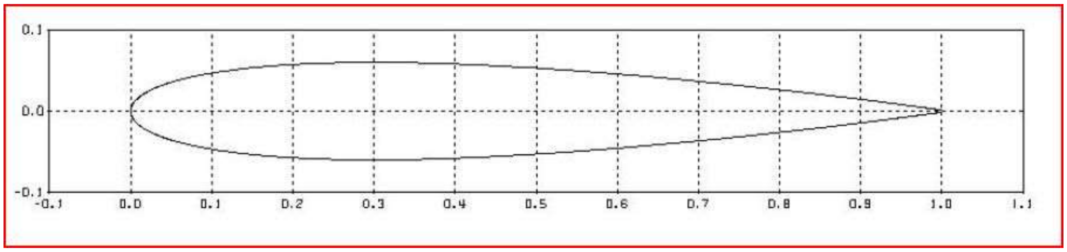
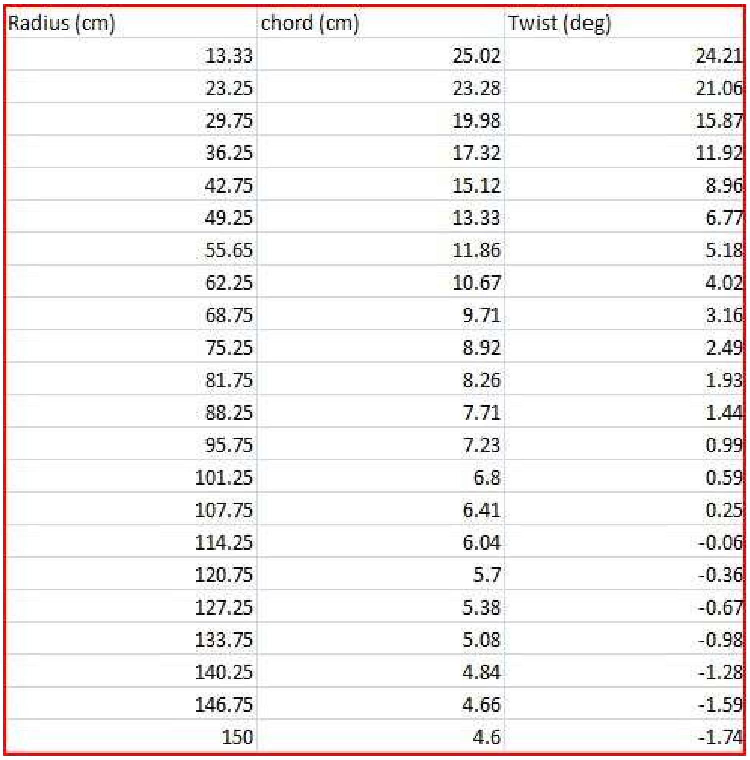


Figure 9

Blade Design

Then complete turbine blade is divided into 22 elements and decided the twist chord distribution along the blade length as follows in Fig 10-



Radius (cm)	chord (cm)	Twist (deg)
13.33	25.02	24.21
23.25	23.28	21.06
29.75	19.98	15.87
36.25	17.32	11.92
42.75	15.12	8.96
49.25	13.33	6.77
55.65	11.86	5.18
62.25	10.67	4.02
68.75	9.71	3.16
75.25	8.92	2.49
81.75	8.26	1.93
88.25	7.71	1.44
95.75	7.23	0.99
101.25	6.8	0.59
107.75	6.41	0.25
114.25	6.04	-0.06
120.75	5.7	-0.36
127.25	5.38	-0.67
133.75	5.08	-0.98
140.25	4.84	-1.28
146.75	4.66	-1.59
150	4.6	-1.74

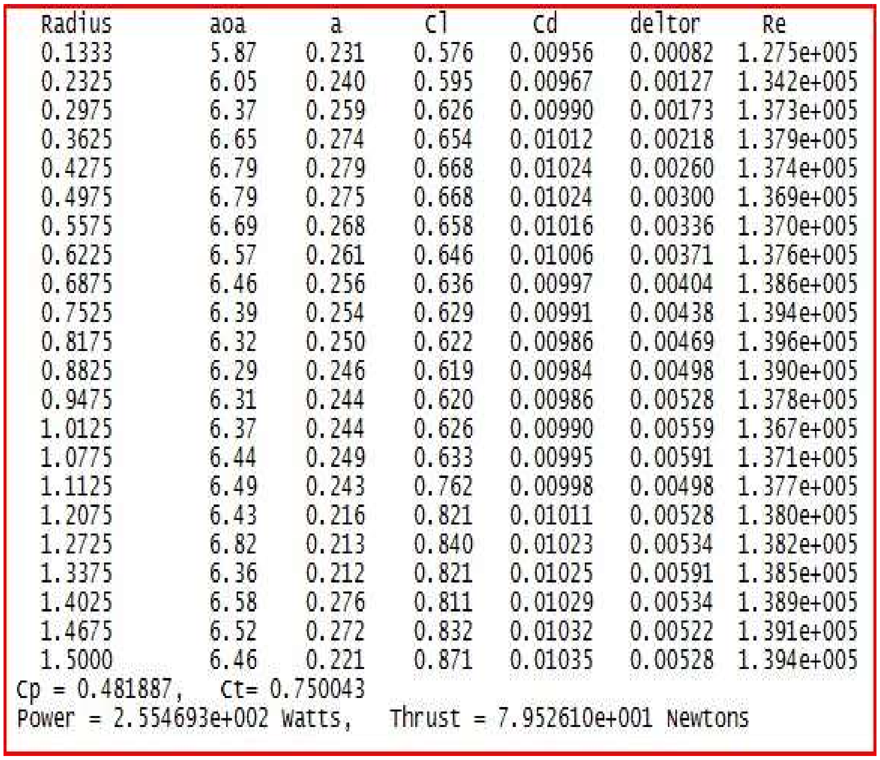
Figure: 10

Tip Speed Ratio

The tip speed ratio is the ratio of circumferential velocity of the blade tip to the wind speed. It is very critical as it sets the angle of attack of the blade section or elements. Very simply the tip speed ratio controls the blade aerodynamics.

- Now our aim was to choose the best tip speed ratio to extract maximum power from available energy
- Tip speed ratio ranges from 7 to 10 for a turbine operating at maximum coefficient of power which is universally accepted for the design of small wind turbine
- Thus for power calculations we considered 4 cases-
  1) tip speed ratio = 7 wind velocity = 5m/s
  2) tip speed ratio = 8 wind velocity = 5m/s
  3) tip speed ratio =9 wind velocity = 5m/s
  4) tip speed ratio = 10 wind velocity = 5m/s

Case 3:- TSR = 9, speed = 5m/s is considered and it is as shown in F**ig-11**



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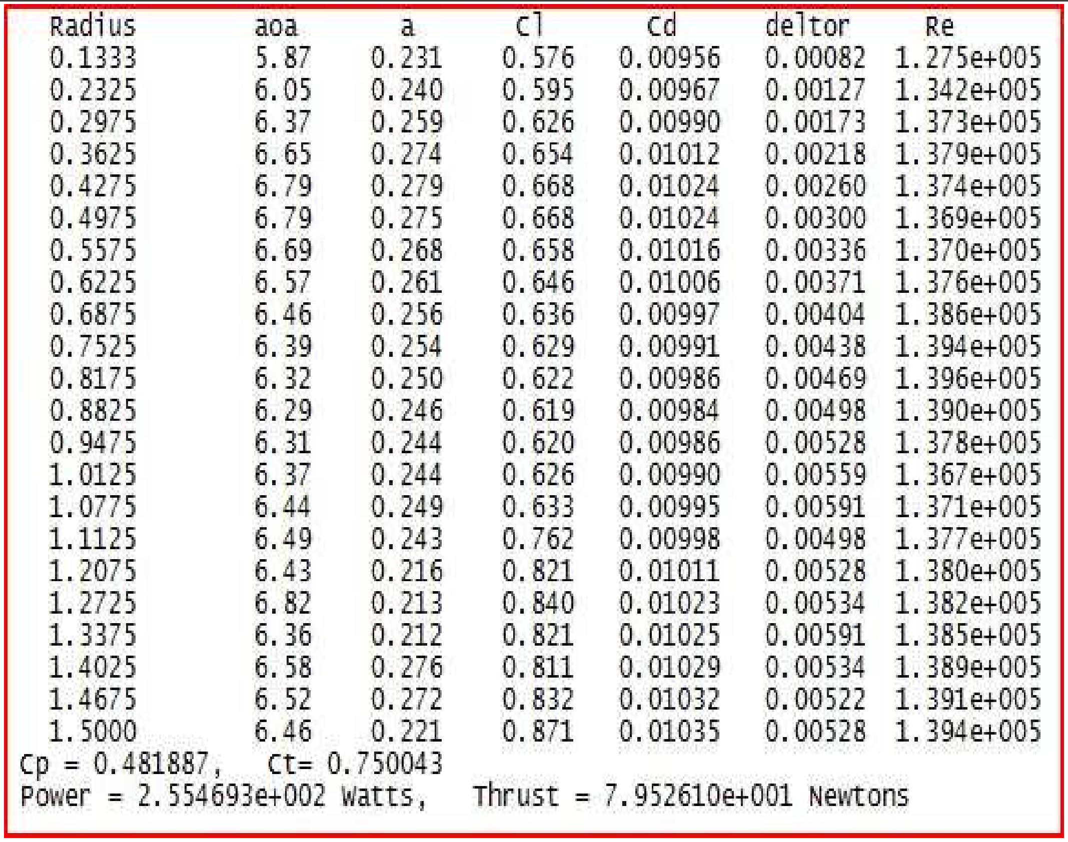
  Radius        aoa     a       Cl      Cd       deltor   Re
  0.1333        5.87    0.231   0.576   0.00956  0.00082  1.275e+005
  0.2325        6.05    0.240   0.595   0.00967  0.00127  1.342e+005
  0.2975        6.37    0.259   0.626   0.00990  0.00173  1.373e+005
  0.3625        6.65    0.274   0.654   0.01012  0.00218  1.379e+005
  0.4275        6.79    0.279   0.668   0.01024  0.00260  1.374e+005
  0.4975        6.79    0.275   0.668   0.01024  0.00300  1.369e+005
  0.5575        6.69    0.268   0.658   0.01016  0.00336  1.370e+005
  0.6225        6.57    0.261   0.646   0.01006  0.00371  1.376e+005
  0.6875        6.46    0.256   0.636   0.00997  0.00404  1.386e+005
  0.7525        6.39    0.254   0.629   0.00991  0.00438  1.394e+005
  0.8175        6.32    0.250   0.622   0.00986  0.00469  1.396e+005
  0.8825        6.29    0.246   0.619   0.00984  0.00498  1.390e+005
  0.9475        6.31    0.244   0.620   0.00986  0.00528  1.378e+005
  1.0125        6.37    0.244   0.626   0.00990  0.00559  1.367e+005
  1.0775        6.44    0.249   0.633   0.00995  0.00591  1.371e+005
  1.1125        6.49    0.243   0.762   0.00998  0.00498  1.377e+005
  1.2075        6.43    0.216   0.821   0.01011  0.00528  1.380e+005
  1.2725        6.82    0.213   0.840   0.01023  0.00534  1.382e+005
  1.3375        6.36    0.212   0.821   0.01025  0.00591  1.385e+005
  1.4025        6.58    0.276   0.811   0.01029  0.00534  1.389e+005
  1.4675        6.52    0.272   0.832   0.01032  0.00522  1.391e+005
  1.5000        6.46    0.221   0.871   0.01035  0.00528  1.394e+005
Cp = 0.481887,   Ct= 0.750043
Power = 2.554693e+002 Watts,   Thrust = 7.952610e+001 Newtons
```

Figure: 11

Number of Blades

Following the determination of the tip speed ratio, the subsequent crucial parameter was the selection of the number of blades.

- CASE 1 – number of blades = 2, TSR = 9, speed=5m/s
- CASE 2- number of blades=3, TSR=9, wind speed=5m/s. Case 2 is considered for the given project shown in Fig-11 .



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  Radius       aoa     a      Cl      Cd       deltor     Re
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  0.3625       6.65   0.274  0.654  0.01012  0.00218  1.379e+005
  0.4275       6.79   0.279  0.668  0.01024  0.00260  1.374e+005
  0.4975       6.79   0.275  0.668  0.01024  0.00300  1.369e+005
  0.5575       6.69   0.268  0.658  0.01016  0.00336  1.370e+005
  0.6225       6.57   0.261  0.646  0.01006  0.00371  1.376e+005
  0.6875       6.46   0.256  0.636  0.00997  0.00404  1.386e+005
  0.7525       6.39   0.254  0.629  0.00991  0.00438  1.394e+005
  0.8175       6.32   0.250  0.622  0.00986  0.00469  1.396e+005
  0.8825       6.29   0.246  0.619  0.00984  0.00498  1.390e+005
  0.9475       6.31   0.244  0.620  0.00986  0.00528  1.378e+005
  1.0125       6.37   0.244  0.626  0.00990  0.00559  1.367e+005
  1.0775       6.44   0.249  0.633  0.00995  0.00591  1.371e+005
  1.1125       6.49   0.243  0.762  0.00998  0.00498  1.377e+005
  1.2075       6.43   0.216  0.821  0.01011  0.00528  1.380e+005
  1.2725       6.82   0.213  0.840  0.01023  0.00534  1.382e+005
  1.3375       6.36   0.212  0.821  0.01025  0.00591  1.385e+005
  1.4025       6.58   0.276  0.811  0.01029  0.00534  1.389e+005
  1.4675       6.52   0.272  0.832  0.01032  0.00522  1.391e+005
  1.5000       6.46   0.221  0.871  0.01035  0.00528  1.394e+005
Cp = 0.481887,   Ct= 0.750043
Power = 2.554693e+002 Watts,   Thrust = 7.952610e+001 Newtons
```

Figure: 12

Design Parameters

- Tip speed ratio for our turbine is 9
- Angular velocity = 30 rad/sec
- Number of blades = 3
- Coefficient of power = 0.481887
- Coefficient of thrust = 0.75
- Power = 255.469 W

Thrust =79.526 N

Sample Blade Element Calculation

Symbols

1) viscosity of air = 1.5 x 10^{-5} (m^3/sec)
2) λ -tip speed ratio
3) a - axial interference factor assuming a=0.3
4) λ_r-local tip – speed ratio
5) σ_1-blade element solidity
6) Φ -blade in flow angle
7) Re-Reynolds number
8) U_T-total velocity at blade element
9) Cd_0min drag coefficient

10) c-a factor for element thrust
11) del r -radius width of blade element
12) C_L-coefficient of lift
13) aoa -angle of attack
14) chord -chord of blade element
15) tol-convergance tolerance for BE analysis
16) deltathr -trust on blade element
17) deltator -torque on blade element
18) Numb- number of blades
19) U_0-wind speed m/sec

Formula used

1) $\lambda_r = r\Omega/U_0$
2) σ = 0.5 x 3 x chord(i) / π (radi)
3) Φ = $tan^{-1}\ (1 - a/\lambda_r(1 + a'))$
   find cosΦ, sinΦ
4) aoa = $(\Phi\ \times 180/\pi)$ – twist i
5) $U_t = \sqrt{(1-a)^2} + \ [(1+d)\lambda_r]^2$
6) $R_e = U_t \times U_0 \times chordi\ \times rtip/$ viscosity
7) for calculation of C_L and C_d
   If aoa> 12.0 aoa = 12.0
   If aoa< -12.0 aoa = -12.0
8) C_L = aoa x [0.1025 + 0.00485 x log_{10} $(R_e/10^6)$]
9) to find C_d
C_{d0} = 0.0044 + 0.018 $R_e^{-0.15}$
   Delcd = $(C_L/1.2)^2$ x 0.009
   $C_d = Cd_0 +\ delcd$
10) $C\_a = C_L\ cos\Phi +\ C_d\ sin\Phi$
11) $C\_adash =\ C_L\ cos\Phi\ -\ C_d\ sin\Phi$
12)Faca = $U_t^2\ \times\ \sigma\ \times\ C\_a$
13) if faca < 1
   New a = 1- $\sqrt{1 - faca}/2$
   If faca> 1
   New a = 1 + $\sqrt{faca - 1}/2$
14) diffa =| a- new a|
15) a = a + newa / 2
16) adash = a x C_adash / $C_a\ \times\ \lambda_r$
17) delthr = numb x U_T^2 x chord (i) x delr / π
18) deltor = delthr x rad(i) x C_adash

Consider V= 1.25 m/s

For element no 1 sample calculation :-

1) del r = 13.33 – 0 = 13.33 x 10^{-2} = 13.33 cm

2) λ_r = 13.13 x 10^{-2} x 9/1-5 = 0.7878

3) σ_1 = 0.5 x 3 x 25.02 x 10^{-2} / π x 13.33 x 10^{-2} = 0.896

4) diffa = 4.878

5) Φ = tan^{-1} (1- 0.3 0 / 0.787(1+ 0)) = 41.65

6) aoa = (Φ x 180/π) – 24.21 x 180/π

= (68.9 x 180 /) – 24.21 x 180 / π

= 44.690

= 2560.54 rad. thus aoa = 12°

7) $U_t = \sqrt{(1-0.3)^2 + [(1+a')\lambda_r]^2}$

$= \sqrt{(1-0.3)^2 + [(1+0).787]^2}$

= 1.053

8) R_e = $U_t \times U_0$x chordi x rtip / viscosity

= 1.053 x 1.25 x 25.02 x 13.33 x 10^{-4} / 1.5 x 10^{-5} = 2926.608

9) as aoa = 44.69° $>$ 12° consider aoa = 12°

$C_L = aoa\ x\ [0.1025 + 0.00485\ x\ log_{10}(2926.608 / 10^6)]$

= 12 x [0.1025 + 0.00485 x log_{10}(2926.608/10^6)]

= 1.2301

10) find ‘cd’

cd_0 = 0.0044 + 0.018 x $R_e^{-0.15}$

=0.0044 + 0.018 x ($(2926.608 / 10^6)^{-0.15}$

= 4.452 x 10^{-3}

deltacd = $(c_1/1.2)^2$ x 0.009

= $(1.23/1.2)^2$ x 0.009

= 9.455 x 10^{-3}

cd = cd_0 + delcd

= 4.452 x 10^{-3} + 9.455 x 10^{-3}

= 0.013907

11) c- adash = 1.2301sinΦ –cdcosΦ

= 1.2301sin(41.65) – 0.0139cos(41.65)

= 1.142

12) c-a = C_L x cosΦ + cdsinΦ

= 1.15 x cos(41.65) + 0.0139sin(41.65)

= 0.4269

13)faca = Ut^2 x σ_1 x c-a

= $(1.053)^2$ x 0.896 x 0.426

= 0.423

14) new a = 1- $\sqrt{1-0.423}$ / 2 if faca < 1 = 0.120

15) diff a = | a – newa|

= $|\ddot{a}^{0.3}$ – 0.120|

= 0.88

16) a = a + new a / 2 = 0.3 + 0.120 / 2 = 0.21

17) a dash = a x c-adash / c-a x λ_r

= 0.21 x 1.142 / 0.426 x 0.787

= 0.7153

18) delthr = 3 x Ut^2 x chord(i) x delr / π

= 3 x $(1.053)^2$x 25.02 x 13.33 x 10^{-2} / π

= 3.523

19) deltor = 3.523 x 13.33x 10^{-2} x 1.067

= 0.501

GENERATOR AND ELECTRICAL SYSTEM

Initially reliant on DC generators, contemporary small turbines favor three-phase AC permanent magnet generators (PMGs), often choosing induction generators as a secondary option. Some PMGs repurpose materials from domestic appliances like washing machines, with China playing a key role in their production due to its rare earth magnetic reserves. This shift responds to consumer demand for AC-powered products and benefits from advancements in power electronics. Most modern generators are now three-phased, optimizing power-to-weight ratios.

For grid-connected small turbines, the common approach involves rectifying variable generator power and inverting it to produce stable AC power, facilitated by modern inverters. This process often incorporates maximum power point tracking (MPPT), aligning generator output with blade characteristics to maximize power extraction from varying wind speeds—a standard for turbines beyond the micro category.

Innovations extend to simpler control systems for micro-turbines, especially those charging batteries. Another recent development integrates controllers and inverters for streamlined grid connection.

Generators for Small Turbines

While DC generators are worth a brief mention for their easy controllability via field current and cost-effectiveness for small applications, their drawbacks need consideration. DC generators, found in devices like portable electric drills or vacuum cleaner motors, have brushes and a commutator that wear out rapidly. Unlike well-designed permanent magnet generators (PMGs), DC generators have more losses due to the need for field current to establish the magnetic field, rendering them generally less efficient.

Figure: 13

Conclusion

Thus the wind turbine blade is designed by considering the wind speed and wind direction collected from year 2004-2011 for proposed site.

The design approach employed in crafting a wind turbine proves instrumental in achieving a seamless integration with the wind profile at the project site. This alignment is crucial for minimizing generation costs, highlighting the significance of a harmonious match between the wind profile and the turbine's requirements. It goes beyond merely considering wind speed magnitude; instead, it emphasizes the critical need for compatibility between the specific wind profile characteristics at the site and the technology employed. This holistic approach ensures not only optimal performance but also cost-effectiveness in wind energy generation.

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