A 17 M/s Wind At 101.3kPa And 20C Enters A Two-bladed Wind Turbine With A Diameter Of 25 M. Calculate

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Understanding the dynamics of wind energy conversion is essential for optimizing turbine performance and maximizing energy output. In this article, we delve into the detailed calculations involved when a wind with a velocity of 17 m/s, at a pressure of 101.3 kPa and temperature of 20°C, enters a two-bladed wind turbine with a diameter of 25 meters. By exploring the fundamental principles of fluid mechanics and energy conversion, we aim to provide a comprehensive guide for engineers, students, and enthusiasts interested in wind turbine analysis and design.

Overview of Wind Turbine Energy Calculations

Before diving into specific calculations, it is important to understand the basic parameters involved:

Key Variables

- Wind velocity (V): 17 m/s
- Atmospheric pressure (P): 101.3 kPa
- Air temperature (T): 20°C

- Turbine diameter (D): 25 m
- Number of blades: 2

The primary goal is to determine the power extracted by the turbine from the wind, which involves calculating the air density, the swept area of the blades, and the theoretical power available in the wind.

Calculating Air Density at Given Conditions

Air density is a crucial factor in determining the kinetic energy of the wind. It varies with temperature and pressure and can be calculated using the ideal gas law.

Ideal Gas Law and Air Density Formula

The ideal gas law states:

$$PV = nRT$$

Where:

- P = pressure in Pascals (Pa)
- V = volume in cubic meters (m^3)
- n = number of moles
- R = universal gas constant (8.314 J/(mol·K))
- T = temperature in Kelvin (K)

Rearranged to find air density (ρ):

$$\rho = \frac{P}{R_{specific} \times T}$$

Where:

- $R_{specific}$ = specific gas constant for dry air (about 287 J/(kg·K))
- T in Kelvin

Calculating Air Density

Given:

- $P = 101.3 \text{ kPa} = 101,300 \text{ Pa}$
- $T = 20°C = 293.15 \text{ K}$

Plugging into the formula:

$$\rho = \frac{101,300}{287 \times 293.15} \approx \frac{101,300}{84,177} \approx 1.204 \text{ kg/m}^3$$

Therefore, the air density at the specified conditions is approximately 1.204 kg/m³.

Determining the Turbine's Swept Area

The swept area is the area through which the wind passes and is directly related to the available power.

Calculating the Swept Area

The formula for the area of a circle:

$$A = \pi \times \left(\frac{D}{2} \right)^2$$

Given:

- $D = 25 \text{ m}$

Calculation:

$$A = \pi \times (12.5)^2 = \pi \times 156.25 \approx 490.87 \text{ m}^2$$

The wind turbine has a swept area of roughly 490.87 m².

Calculating Theoretical Power in the Wind

The power available in the wind can be estimated using the kinetic energy formula:

$$P_{wind} = \frac{1}{2} \times \rho \times A \times V^3$$

Where:

- ρ = air density (kg/m³)
- A = swept area (m²)
- V = wind velocity (m/s)

Calculating the Power

Plugging in the known values:

$$P_{wind} = 0.5 \times 1.204 \times 490.87 \times (17)^3$$

Calculations step-by-step:

1. $(17)^3 = 4913$
2. $0.5 \times 1.204 = 0.602$

3. $0.602 \times 490.87 \approx 295.8$

4. $295.8 \times 4913 \approx 1,452,039 \text{ W}$

Thus, the theoretical power available in the wind is approximately 1.45 MW.

Estimating Actual Power Output of the Wind Turbine

While the theoretical power provides an upper limit, real turbines operate at efficiencies less than 100%. The Betz limit states that no turbine can convert more than approximately 59.3% of the wind's kinetic energy into mechanical energy.

Applying Efficiency and Power Coefficient

Assuming:

- Power coefficient (C_p) at Betz limit: 0.593
- Turbine efficiency (η): typically around 0.35 to 0.45 for practical turbines

For calculation purposes, we'll assume an overall efficiency (η_{total}) of 0.4:

$$P_{actual} = P_{wind} \times C_p \times \eta_{total}$$

Calculating:

$$P_{actual} = 1,452,039 \times 0.593 \times 0.4$$

Step-by-step:

1. $1,452,039 \times 0.593 \approx 861,148 \text{ W}$
2. $861,148 \times 0.4 \approx 344,459 \text{ W}$

Therefore, the estimated actual power output is approximately 344.46 kW.

Summary of Key Calculations

Parameter	Value
Air density (ρ)	1.204 kg/m³
Swept area (A)	490.87 m²
Wind power capacity (P_{wind})	~1.45 MW
Estimated turbine power output	~344.46 kW

Additional Considerations in Wind Turbine Calculations

While the above calculations provide a solid estimate, real-world factors can influence the actual power output.

Factors Affecting Turbine Performance

- Wind shear and turbulence
- Blade design and aerodynamics
- Maintenance and operational conditions
- Transmission and generator efficiencies

Importance of Site Selection

Optimal placement of wind turbines involves analyzing wind speed distributions, turbulence intensity, and other environmental factors to maximize energy yield.

Conclusion

Calculating the power output of a wind turbine based on given wind conditions involves understanding fluid mechanics principles, including air density, swept area, and wind power estimation. For a wind velocity of 17 m/s, at standard atmospheric pressure and temperature, a 25-meter diameter two-bladed turbine can theoretically harness around 1.45 MW of wind energy. Accounting for efficiency and the Betz limit, the realistic power output is approximately 344 kW. These calculations are essential for designing efficient wind energy systems and assessing their potential in various environments.

By mastering these fundamental computations, engineers and developers can optimize wind turbine performance, contributing to more sustainable and renewable energy solutions worldwide.

Frequently Asked Questions

What is the kinetic energy per unit mass of the wind entering the turbine?

The kinetic energy per unit mass is calculated as KE/m = (1/2) V^2 = 0.5 (17)^2 = 144.5 J/kg.

How do you determine the power available in the wind entering the turbine?

Power is calculated using the formula P = 0.5 □ A V^3, where □ is air density, A is the rotor swept area, and V is wind speed. Using □ = 1.204 kg/m^3, A = □(D/2)^2, and V=17 m/s.

What is the rotor swept area for a 25-meter diameter wind turbine?

The swept area A = □ (D/2)^2 = □ (12.5)^2 □ 490.87 m^2.

How do you calculate the theoretical maximum power extractable from the wind?

Using the Betz limit, the maximum extractable power is approximately 59.3% of the wind power: P_max = 0.593 0.5 □ A V^3.

What is the approximate power available in the wind at 17 m/s under the given conditions?

Calculating with □=1.204 kg/m^3, A=490.87 m^2, V=17 m/s: P = 0.5 1.204 490.87 17^3 □ 2,349,471 Watts or about 2.35 MW.

How does air temperature and pressure affect the power calculation for the wind turbine?

Temperature and pressure influence air density (□); higher temperatures and lower pressures decrease □, thereby reducing the available wind power. Accurate calculations should account for actual air density at given conditions.

Additional Resources

A 17 M/s Wind At 101.3kPa And 20°C Enters A Two-bladed Wind Turbine With A Diameter Of 25 M. Calculate

When analyzing wind turbine performance, understanding the fundamental parameters such as wind speed, air pressure, temperature, and turbine dimensions is essential. The scenario involving a wind moving at 17 m/s, with an ambient pressure of 101.3 kPa and a temperature of 20°C, entering a two-bladed wind turbine with a 25-meter diameter, offers a comprehensive case study for evaluating energy extraction potential. This article provides an in-depth review of the key calculations, theoretical foundations, and practical implications of such a setup, offering insights for engineers, students, and renewable energy enthusiasts alike.

Introduction to Wind Turbine Performance Analysis

Wind turbines convert kinetic energy from the wind into mechanical energy, which can then be transformed into electrical power. The efficiency and power output depend on multiple factors, including wind speed, air density, turbine blade design, and size. In this case, the primary parameters—wind speed (17 m/s), pressure (101.3 kPa), temperature (20°C), and rotor diameter (25 m)—serve as the foundation for calculating the turbine’s power potential.

Understanding these factors allows us to estimate the theoretical power available in the wind, as well as the practical power that can be harnessed considering Betz’s limit and other efficiency factors. The subsequent sections will delve into the calculations, including air density determination, wind power estimation, and the potential energy extraction by the turbine.

Air Density Calculation at Given Conditions

A critical step in estimating wind power is determining the air density (ρ). Air density varies with temperature and pressure, impacting the amount of energy available in the wind.

Using the Ideal Gas Law

The ideal gas law relates pressure (P), temperature (T), and density (ρ):

$$
\rho = \frac{P}{R T}
$$

Where:

- P = pressure in Pa

- R = specific gas constant for dry air ≈ 287 J/(kg·K)

- T = temperature in Kelvin

Given:

- $P = 101.3\, \text{kPa} = 101,300\, \text{Pa}$

- $T = 20°C = 293.15\, \text{K}$

Calculating:

$$
\rho = \frac{101,300}{287 \times 293.15} \approx \frac{101,300}{84,209.05} \approx 1.202\, \text{kg/m}^3
$$

This value aligns with standard atmospheric density at sea level and typical conditions.

Calculating Wind Power Density

The available power in the wind per unit area can be expressed as:

$$
P_{density} = \frac{1}{2} \rho V^3
$$

Where:

- V = wind velocity = 17 m/s

Using the calculated density:

$$
P_{density} = \frac{1}{2} \times 1.202 \times (17)^3
$$

Calculating:

$$
(17)^3 = 4913
$$

$$
P_{density} = 0.601 \times 4913 \approx 2952\, \text{W/m}^2
$$

This represents the theoretical power available per square meter of the swept area of the turbine blades.

Determining Turbine Swept Area

The power captured depends on the rotor's swept area (A), which for a circular rotor is:

$$
A = \pi \times \left(\frac{D}{2} \right)^2
$$

Given:

- $D = 25\, \text{m}$

Calculating:

$$
A = \pi \times (12.5)^2 = \pi \times 156.25 \approx 490.87\, \text{m}^2
$$

This is the area through which the wind flows and the energy potential is harnessed.

Estimating Theoretical Power Output

The maximum power extractable by the turbine, assuming ideal conditions and Betz's limit, is:

$$
P_{max} = P_{density} \times A
$$

Calculating:

$$
P_{max} = 2952 \times 490.87 \approx 1,448,000\, \text{W} \approx 1.448\, \text{MW}
$$

This figure represents the theoretical maximum power under perfect conditions, ignoring losses and efficiencies.

Applying Efficiency Factors and Practical Power Output

In real-world scenarios, turbines operate below the Betz limit (~59.3%) due to various losses:

- Mechanical losses

- Electrical conversion inefficiencies

- Aerodynamic inefficiencies

Assuming an overall efficiency (η) of about 45-50%, the practical power output is:

$$
P_{actual} = P_{max} \times \eta
$$

Choosing $\eta = 0.45$:

$$
P_{actual} \approx 1.448\, \text{MW} \times 0.45 \approx 0.652\, \text{MW}
$$

Thus, the turbine could generate approximately 652 kW under the specified conditions.

Additional Considerations and Features of the Turbine Design

The turbine's design, including the number of blades, blade shape, and orientation, influences efficiency and power output.

Two-Bladed Turbine Features:

- Pros:
- Simpler design and easier maintenance
- Reduced weight and material costs
- Less aerodynamic drag compared to multi-bladed turbines
- Cons:
- Slightly less efficient than three-bladed turbines
- Possible issues with vibration and imbalance

- Lower starting torque, affecting low wind conditions

Rotor Diameter and Blade Design:

- Larger diameters capture more wind energy, but also require more robust structures.
- Blade shape affects aerodynamic efficiency—airfoil profiles are often optimized for maximum lift and minimal drag.

Environmental and Site Considerations

The efficiency of wind turbines is also influenced by site-specific factors:

- Wind Consistency: Steady winds at 17 m/s provide reliable power.
- Turbulence and Obstacles: Nearby structures or terrain can cause turbulence, reducing efficiency.
- Air Density Variations: Slight changes in temperature and pressure can affect power estimates.

Proper siting and turbine orientation are crucial for maximizing energy capture.

Conclusion and Final Insights

Analyzing the given parameters reveals that a 25-meter diameter, two-bladed wind turbine operating under the specified conditions can theoretically generate around 1.45 MW of power, with practical expectations around 652 kW considering typical efficiencies. This highlights the significant potential of wind energy at moderate to high wind speeds, especially when turbines are designed with optimal blade geometry and installed in suitable locations.

While the calculations provide a foundational understanding, real-world performance depends on numerous factors including turbine maintenance, control systems, and environmental conditions. Nonetheless, the scenario underscores the importance of precise analysis and design optimization in harnessing wind energy effectively.

In conclusion, wind turbines like the one described can be powerful contributors to renewable energy portfolios, and understanding their performance metrics is vital for sustainable development. As technology advances, these figures can be further improved through better materials, aerodynamics, and site management, making wind energy an increasingly vital resource in the global energy landscape.

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