Renewable Energy
Lecture 15: Wind Energy

Grade: 4th Class

Dr. Eng. Azher M.Abed

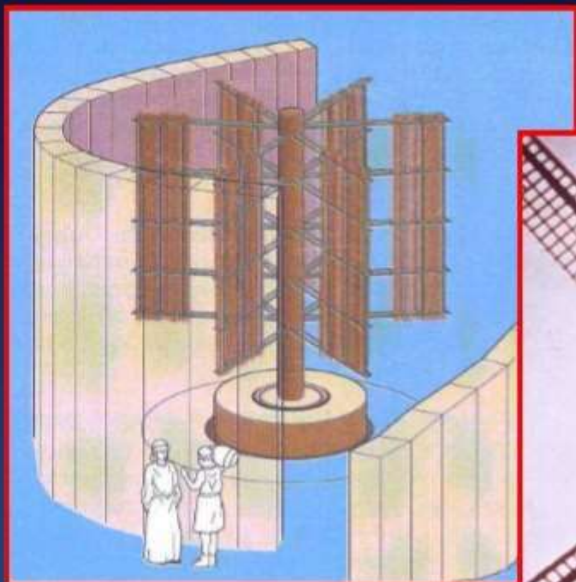
Dr.Haleemah Jaber Mohammed

Exploring Wind Energy

What Makes Wind

What is Wind Power

1400-1800 years go,
in the Middle East



800-900 years ago,
in Europe

140 years ago,
water-pumping
wind mills

70 years ago,
electric power

The ability to harness the power available in the wind and put it to useful work.

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ENERGY AND POWER

ENERGY: The Ability to do work

ENERGY = FORCE * DISTANCE

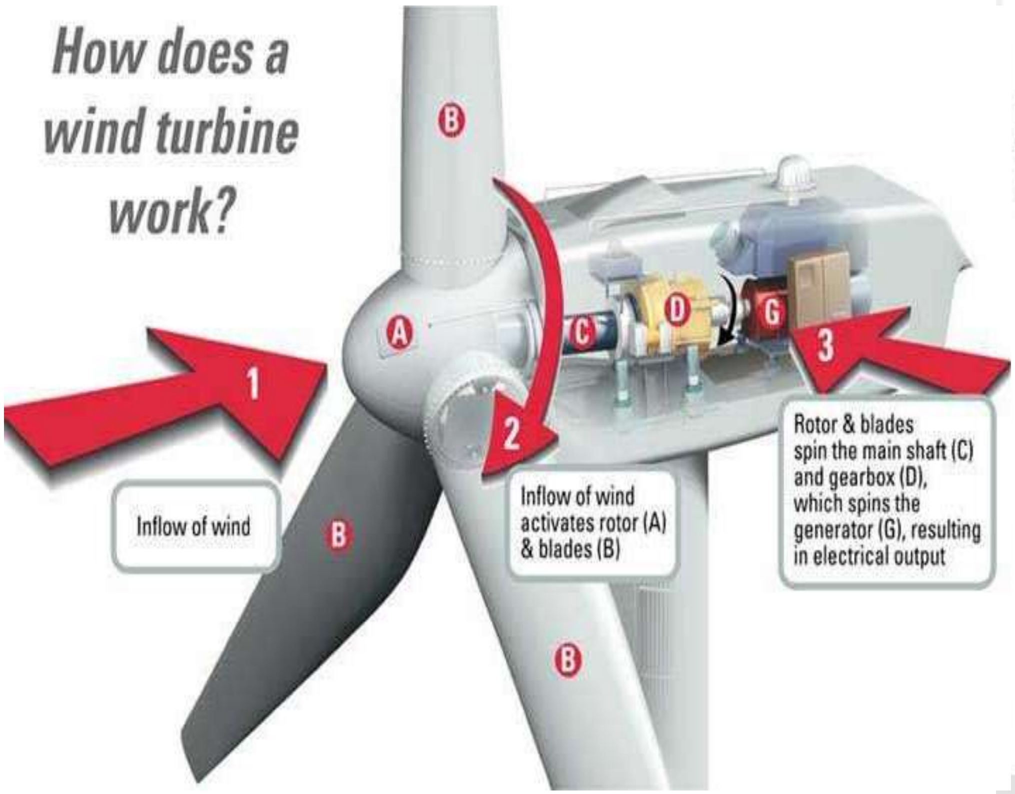
Electrical energy is reported in kWh and may be used to describe a potential, such as in stored energy

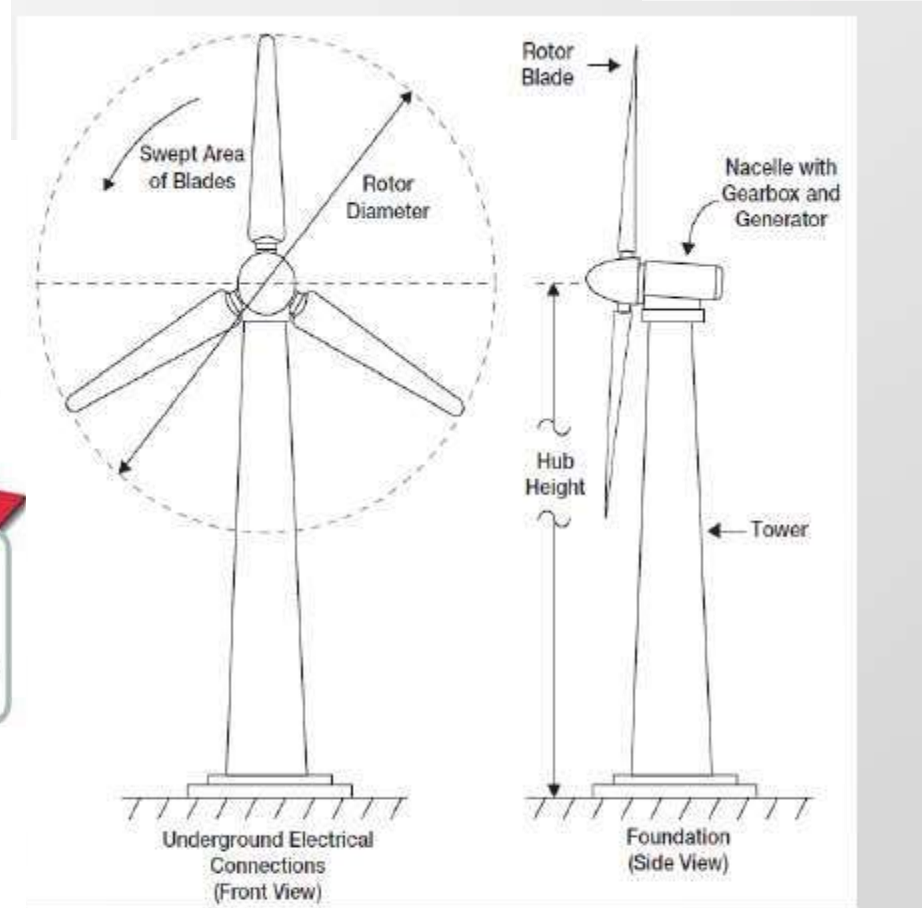
POWER: Force without time

POWER = ENERGY / TIME

Generator Size or an instantaneous load which is measured in kW

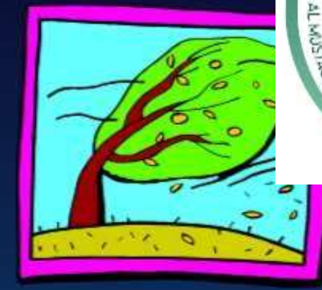
Wind Energy





Wind Energy System Schematic

Power in the Wind



$$P = 0.5\,\rho\,V^3$$

P: power, Watt

ρ: density of air, kg/m^3

V: wind speed, m/s

We call this the **Wind Power Density** (W/m^2)

If we include the area through which the wind flows (m^2), we get the collectable power in Watts.

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Power from the Wind

$$P = 0.5\ \rho\ Cp\ v^3\ A_S$$

Cp = Coefficient of Performance
(an efficiency term)

A_S = The swept area of the wind turbine blades

Multiplied by time give you

Energy…

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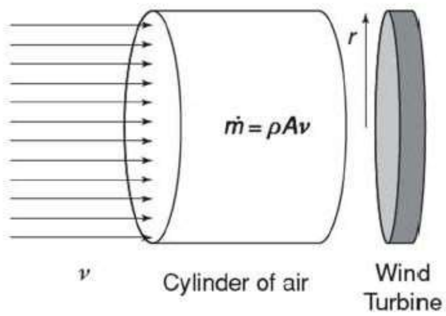
Power Available in the Wind Spectra

Kinetic Energy of Wind

$$E = \frac{1}{2}mv^2$$

where m is mass and v is speed; units of energy are kg m^2/s^2 = Joule.

The mass (m) from which energy is extracted is the mass contained in the volume of air that will flow through the rotor. For a horizontal axis wind turbine (HAWT), the volume of air is cylindrical



The Energy per unit time is calculated as:

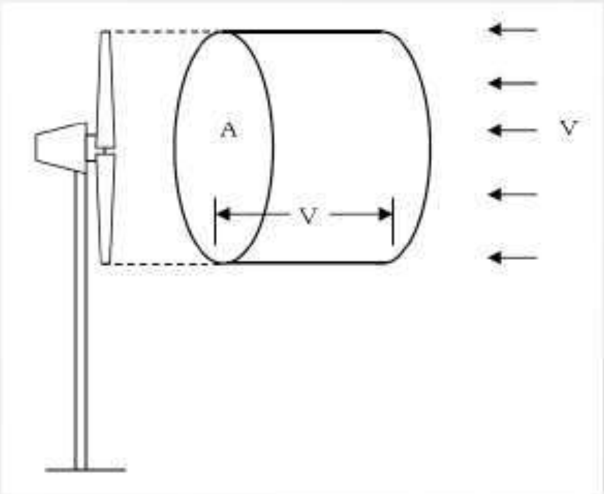
where

ρ	air density and
A	cross-section area.
$\dot{m}$	amount of matter contained in a cylinder of air of length v.
$\dot{E}$	energy per second, which is the same as power P

$$\dot{E} = \frac{1}{2}\dot{m}v^2$$

$$\dot{m} = \rho A v$$

Power Available in the Wind Spectra



An air Parcel Moving towards a Wind Turbine

$$E = \frac{1}{2}\, m\, V^2$$

$$P = \frac{1}{2}\, \rho_a\, v\, V^2$$

ρ_a is the density of air and v is the volume of air parcel available to the rotor.

$$P = \frac{1}{2}\, \rho_a\, A_T\, V^3 \qquad [W]$$

Power Available in the Wind Spectra

Factors like temperature, atmospheric pressure, elevation and air constituents affect the density of air.

Density of air, which is the ratio of the mass of 1 [kilo mole] of air to its volume, is given by:

$$\rho_a = \frac{m}{V_G}$$

density is given by:

$$\rho_a = \frac{m\,p}{R\,T}$$

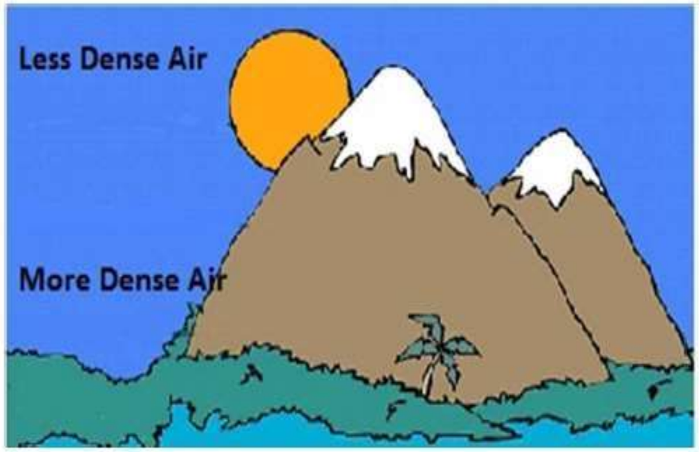
If we know the elevation Z and temperature T at a site, then the air density can be calculated by:

$$\rho_a = \frac{353.049}{T} e^{\left(-0.034\,\frac{Z}{T}\right)}$$

Important Concepts of Wind Energy

Density of Air as a Function of Elevation

Air density is an important parameter that influences power. The proportionality between Power (P) and density (ρ) is linear but equation of Power is not linear..

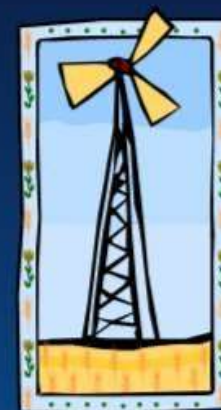


$$P = \rho A v^3 / 2.$$

If ρ, the air density is lower by 10%, then the power will be lower by 10%.

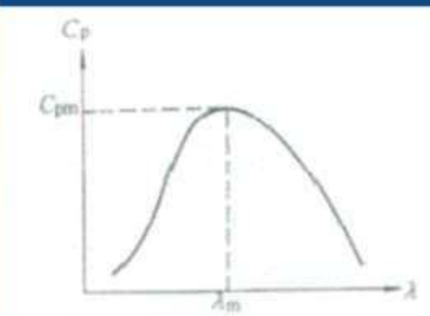
Critical Aspects of Wind Energy

$$P = 0.5\ \rho\ Cp\ v^3\ A_s$$



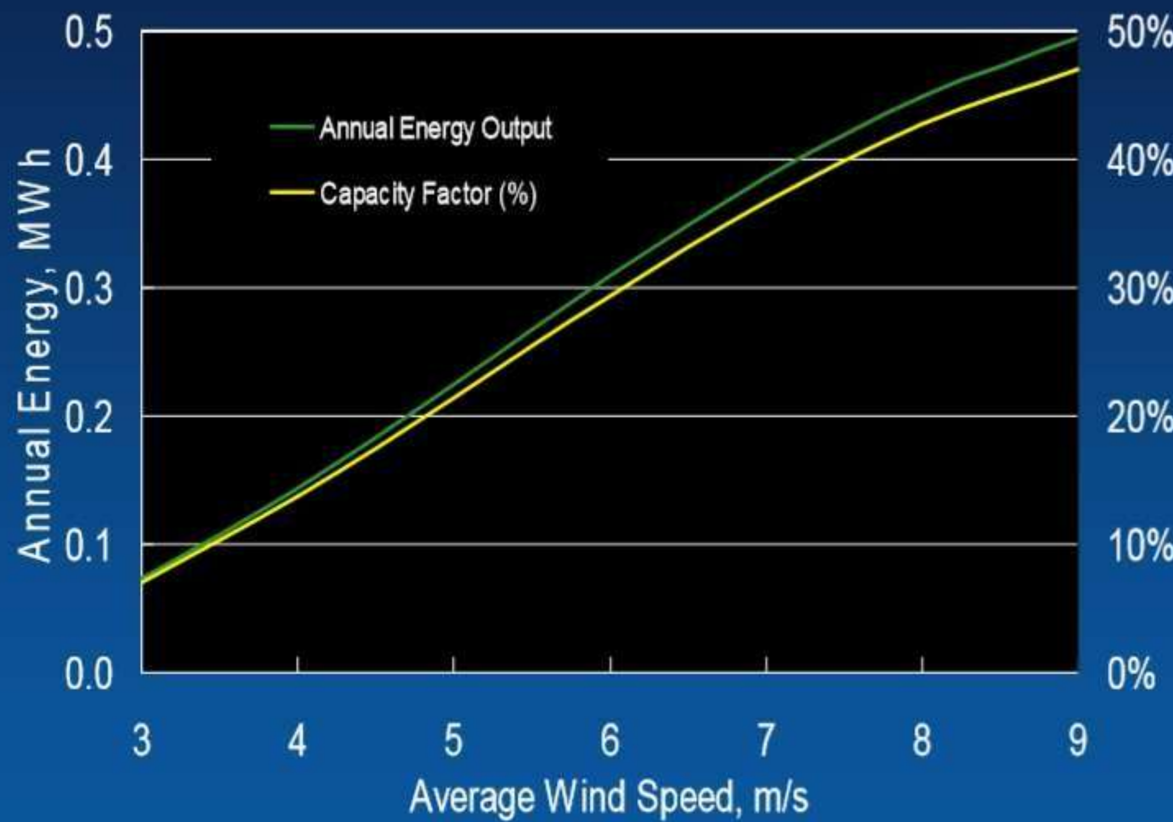
- V^3: Doubling of the wind speed results in an 8 fold increase in power
- ρ: High density air results in more power (altitude and temperature)
- A_s: A slight increase in blade length, increases the area greatly

Cp: Different types of wind turbines have different maximum theoretical efficiencies (Betz limit $\approx$0.593) but usually between .4 and .5



Impact on Increasing Wind Speed

A small increase in wind speed can increase the power greatly



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Wind Characteristics and Resources

Understanding the wind resource at your location is critical to understanding the potential for using wind energy

- Wind Speed
  - Wind Profile
  - Wind classes
  - Collection and reporting
- Wind Direction
- Wind speed change with height

Wind Turbine Power and Torque

$$C_p = \frac{P_T}{P_W} = \frac{2P_T}{\rho_a A_T V^3}$$

P_T is the power developed by the turbine.

$$F = \frac{1}{2} \rho_a A_T V^2$$

$$T = \frac{1}{2} \rho_a A_T V^2 R$$

R is the radius of the rotor.

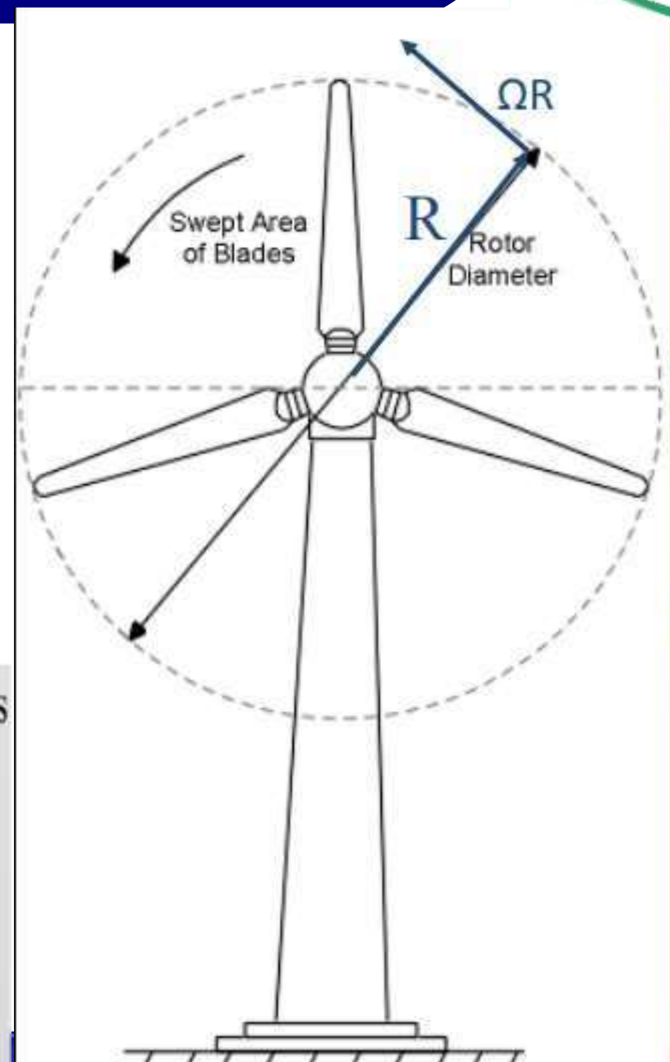
The torque coefficient is given by:

$$C_T = \frac{2T_T}{\rho_a A_T V^2 R}$$

T_T is the actual torque developed by the rotor.

Tip -Speed Ratio

Tip -speed ratio is the ratio of the speed of the rotating blade tip to the speed of the free stream wind. There is an optimum angle of attack which creates the highest lift to drag ratio. Because angle of attack is dependent on wind speed, there is an optimum tip -speed ratio



The ratio between the velocity of the rotor tip and the wind velocity is termed as the tip speed ratio (λ). Thus,

$$\lambda = \frac{R\,\Omega}{V} = \frac{2\pi\,N\,R}{V}$$

Ω is the angular velocity and N is the rotational speed of the rotor

Wind Turbine Power and Torque

The relationship between the power coefficient and the tip speed ratio.

$$C_P = \frac{2\, P_T}{\rho_a\, A_T\, V^3} = \frac{2 T_T\, \Omega}{\rho_a\, A_T\, V^3}$$

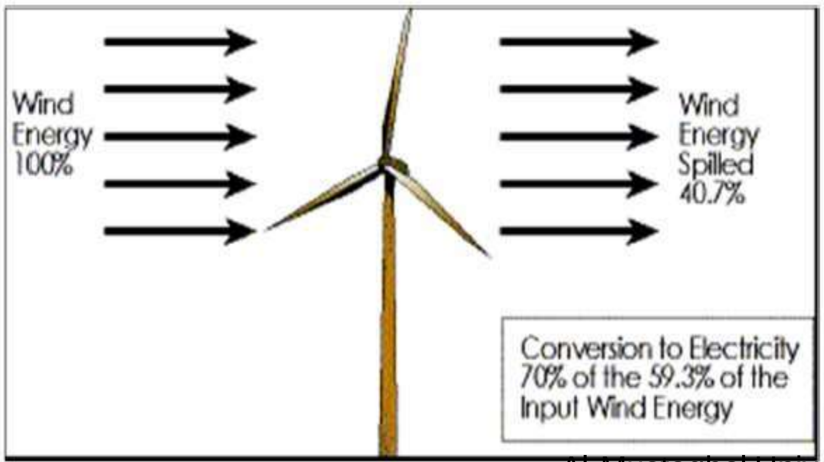
$$\frac{C_P}{C_T} = \frac{R\, \Omega}{V} = \lambda$$

Betz Limit

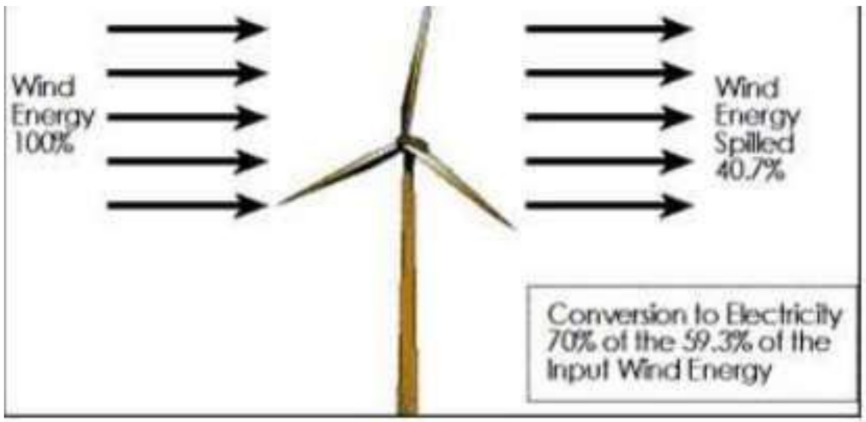
Important Concepts of Wind Energy

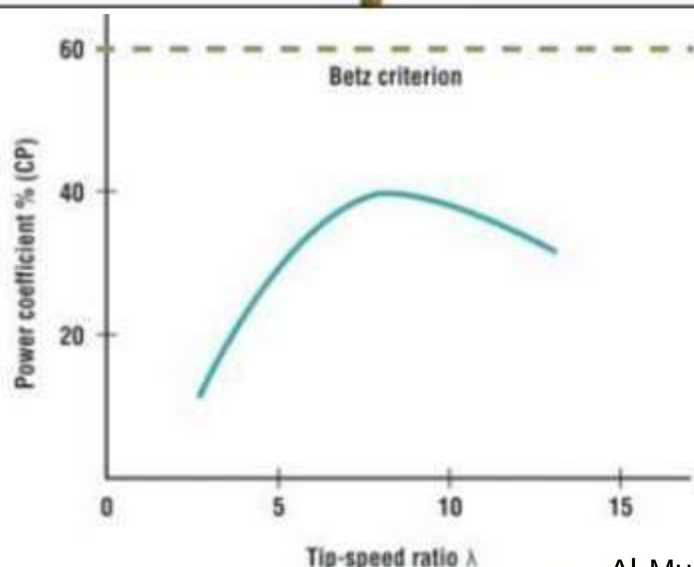
Betz Limit

In 1919, Albert Betz a German physicist postulated a theory about the efficiency of rotor based turbines.



Betz Limit





All wind power cannot be captured by rotor or air would be completely still behind rotor and not allow more wind to pass through. Theoretical limit of rotor efficiency is 59% Most modern wind turbines are in the 35 – 45% range

Betz Limit

Betz Limit

Using simple concepts of conservation of mass, momentum, and energy, he postulated that a wind turbine with a disc-like rotor **cannot capture more than 59.3% of energy** contained in a mass of air that will pass through the rotor.

$$\frac{16}{27}$$

Do You Have Any Questions?