University of Asia Pacific
Department of Electrical & Electronic Engineering

EEE 401: Energy Conversion and special machines

Module 2: Wind Energy

OBJECTIVE OF THIS MODULE

This module discusses the following:

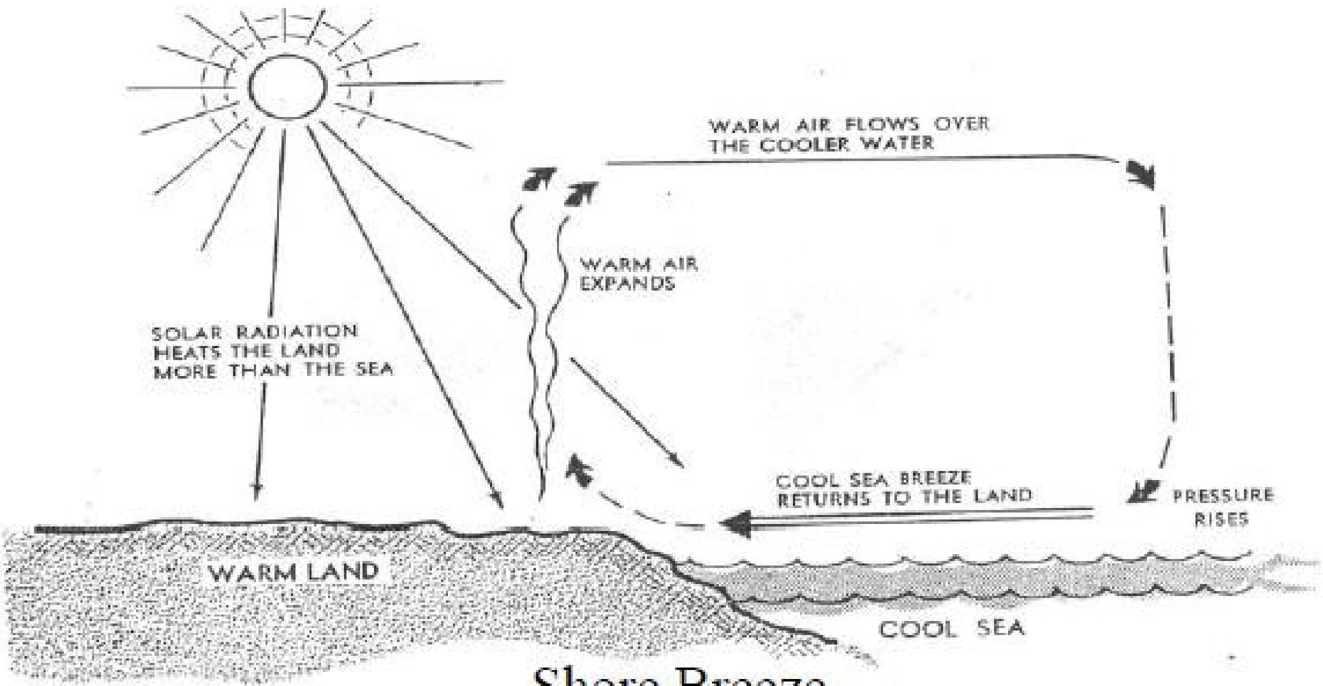
(i) What is wind energy and its potential

(ii) Wind energy resource estimation

(iii) Type of wind turbines and applications

ORIGIN OF WIND POWER

The wind, for example the shoreline breeze, is the result of uneven heating of the earth by the sun.



Shore Breeze

Module 4: Wind Energy

How do you convert wind into electricity???

Wind turbines convert **the kinetic energy** in the wind into **mechanical power.**
This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity.

A wind turbine works the opposite of a fan.
Instead of using electricity to make wind, like a fan, wind turbines use **wind to make electricity**. The wind turns the blades, which spin a shaft, which connects to a generator and makes elec

The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity.
Wind turbines are mounted on a tower to capture the most energy. At 100 feet (30 meters) or more above ground, they can take advantage of faster and less turbulent wind.

Advantages and Disadvantages???

Advantages:

- No pollution.
- Lowest prices renewable resources
- Don't produce atmospheric emissions that cause acid rains and green house effects.

Disadvantages:

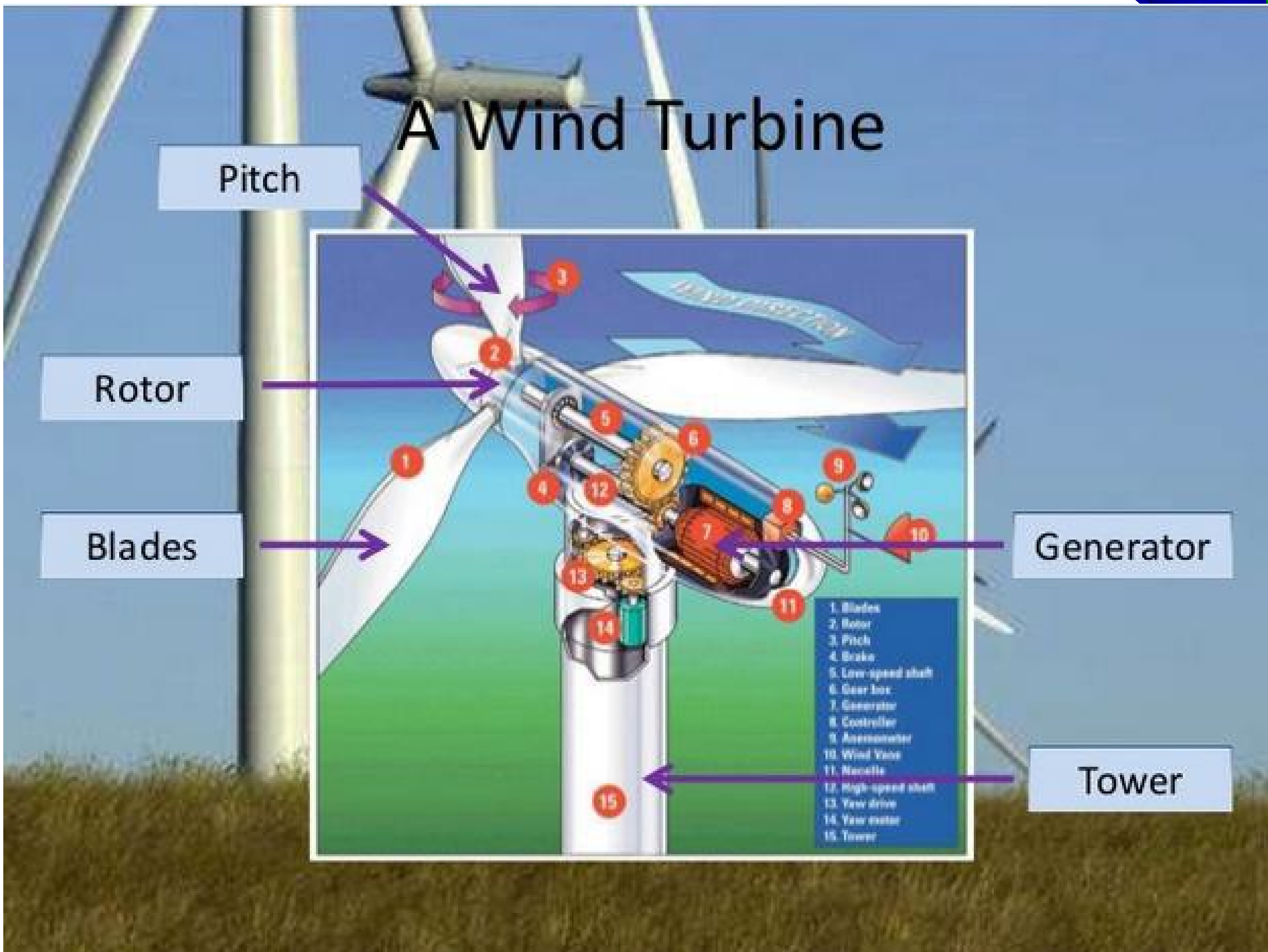
- Depending on how energetic a wind site is, the wind farm may or may not be cost competitive.
- Wind energy cannot be stored (unless batteries are used)
- Good wind sites are often located in remote locations
- Wind resource development may compete with other uses for the land and those alternative uses may be more highly valued than electricity generation.
- sometimes birds have been killed by flying into the rotors

Wind Turbine Design

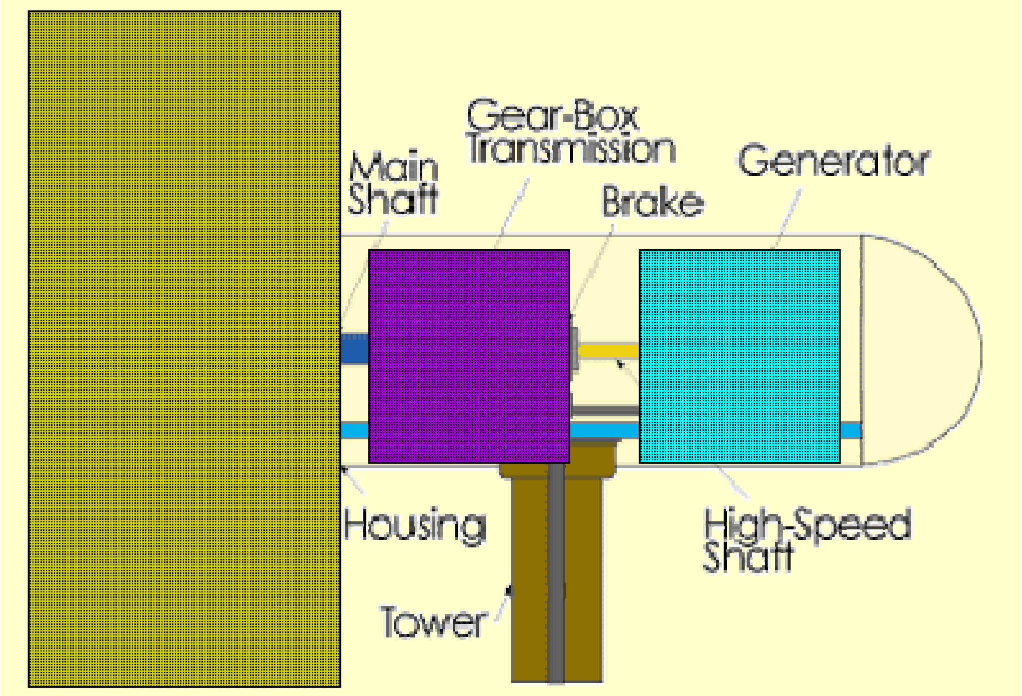
Two types of turbine design are possible – ***Horizontal axis** and **Vertical axis***. In horizontal axis turbine, it is possible to catch more wind and so the power output can be higher than that of vertical axis. But in horizontal axis design, the tower is higher and more blade design parameters have to be defined. In vertical axis turbine, there is no cyclic load on the blade, thus it is easier to design. Maintenance is easier in vertical axis turbine whereas horizontal axis turbine offers better performance.

Vertical axis Turbine (VAT)

Horizontal axis Turbine (HAT)


A Wind Turbine
Pitch
Rotor
Blades
Generator
Tower
1. Blades
2. Rotor
3. Pitch
4. Brake
5. Low-speed shaft
6. Gear box
7. Generator
8. Controller
9. Anemometer
10. Wind Vane
11. Nacelle
12. High-speed shaft
13. Yaw drive
14. Yaw motor
15. Tower

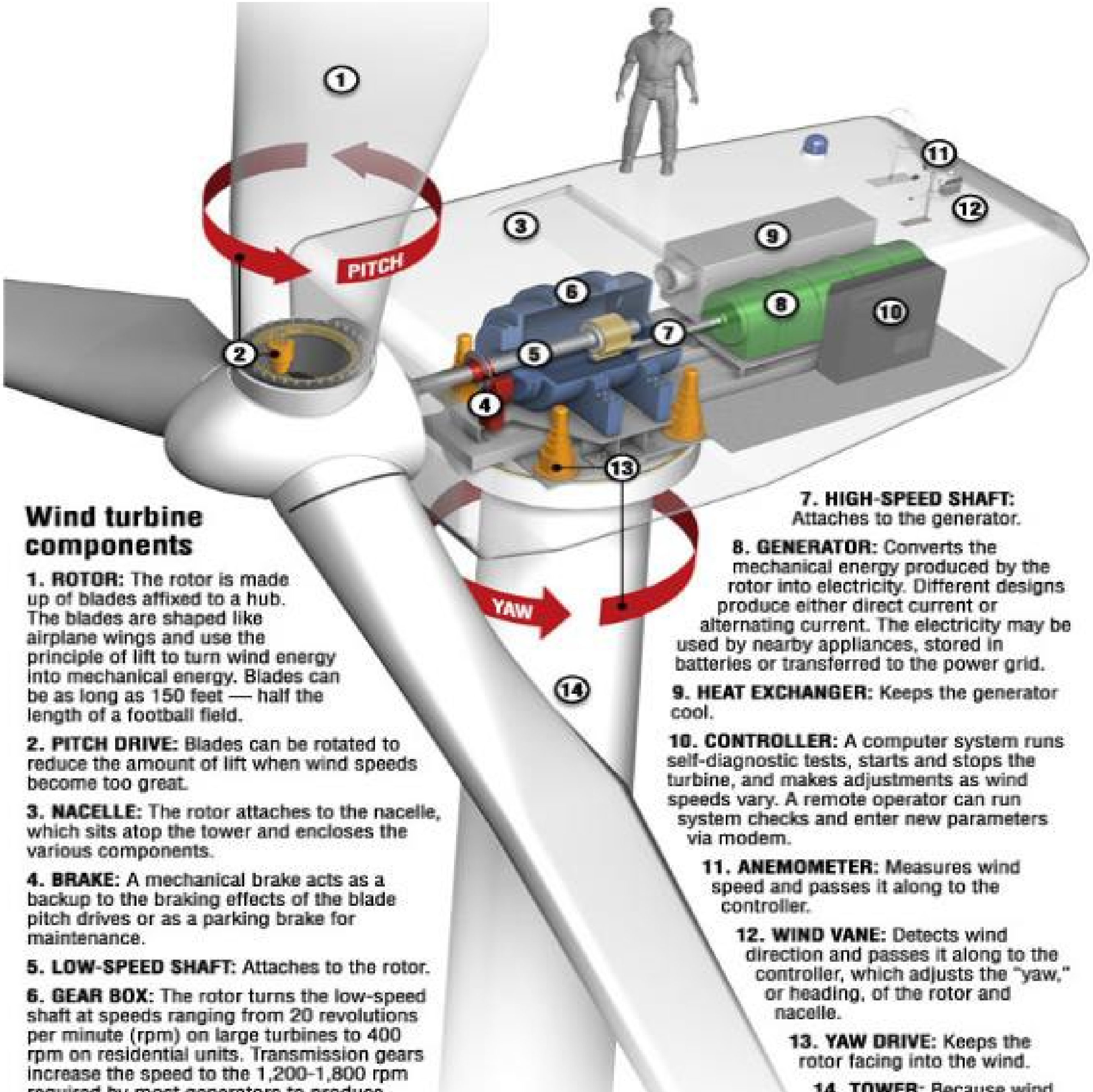
Main components of a Horizontal Axis Wind Turbine



Rotor: Converts the wind power to a rotational mechanical power.

Generator: Converts the rotational mechanical power to electrical power.

Gear box: Wind turbines rotate typically between 20 rpm and 400 rpm. Generators typically rotates at 1,200 to 1,800 rpm. Most wind turbines require a step-up gear-box for efficient generator operation (electricity production).



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PITCH
YAW
Wind turbine components
1. ROTOR: The rotor is made up of blades affixed to a hub. The blades are shaped like airplane wings and use the principle of lift to turn wind energy into mechanical energy. Blades can be as long as 150 feet — half the length of a football field.
2. PITCH DRIVE: Blades can be rotated to reduce the amount of lift when wind speeds become too great.
3. NACELLE: The rotor attaches to the nacelle, which sits atop the tower and encloses the various components.
4. BRAKE: A mechanical brake acts as a backup to the braking effects of the blade pitch drives or as a parking brake for maintenance.
5. LOW-SPEED SHAFT: Attaches to the rotor.
6. GEAR BOX: The rotor turns the low-speed shaft at speeds ranging from 20 revolutions per minute (rpm) on large turbines to 400 rpm on residential units. Transmission gears increase the speed to the 1,200-1,800 rpm required by most generators to produce
7. HIGH-SPEED SHAFT: Attaches to the generator.
8. GENERATOR: Converts the mechanical energy produced by the rotor into electricity. Different designs produce either direct current or alternating current. The electricity may be used by nearby appliances, stored in batteries or transferred to the power grid.
9. HEAT EXCHANGER: Keeps the generator cool.
10. CONTROLLER: A computer system runs self-diagnostic tests, starts and stops the turbine, and makes adjustments as wind speeds vary. A remote operator can run system checks and enter new parameters via modem.
11. ANEMOMETER: Measures wind speed and passes it along to the controller.
12. WIND VANE: Detects wind direction and passes it along to the controller, which adjusts the "yaw," or heading, of the rotor and nacelle.
13. YAW DRIVE: Keeps the rotor facing into the wind.
14. TOWER: Because wind

WIND POWER LAW

- The **Wind Profile Power Law is a relationship between the wind speeds at one height, and those at another.**

- **The power law is often used in** wind power assessments where wind speeds at the height of a turbine (>~ 50 meters) must be estimated from near surface wind observations (~10 meters), or where wind speed data at various heights must be adjusted to a standard height.

WIND POWER LAW

- The wind profile power law relationship is:

$$u / ur = (z / zr)\alpha$$

where
u is the wind speed (in meters per second) at height z (in meters)
ur is the known wind speed at a reference height zr.
The exponent (α) is an empirically derived coefficient that varies dependent upon the stability of the atmosphere. For neutral stability conditions, α is approximately 1/7th, or 0.143.

- In order to estimate the wind speed at a certain height (x), the relationship would be rearranged to:

$$ux = ur * (zx / zr)\alpha$$

Experimental Coefficient : $\alpha = 1/n$

Ground Surface Condition	n
Grassy Plane	7~10
Seacoast	7~10
Country, Paddy Field	4~6
Urban	2~4

THE WIND POWER

The power in the wind is proportional to:

- the area of windmill being swept by the wind
- the cube of the wind speed
- the air density - which varies with altitude

The power in the wind is:

$$P = 0.5 \times rho \times A \times V3$$

where

P: is power in watts (W)

rho: is the air density in kilograms per cubic metre (kg/m3), (about 1.225 kg/m3 at sea level, less higher up)

A: is the swept rotor area in square metres (m2)

V: is the wind speed in metres per second (m/s).

Power in the Wind (W/m^2)

= 1/2 x air density x swept rotor area x (wind speed)^3

ρ

Density = P/(RxT)

P - pressure (Pa)
R - specific gas constant (287 J/kgK)
T - air temperature (K)

kg/m^3

A

Area = πr^2

m^2

V^3

Instantaneous Speed
(not mean speed)

m/s

Wind Turbine Output

$P = 0.5 \times \rho \times A \times Cp \times V^3 / 1{,}000 (kW)$

Where P : Wind turbine generator output in kW

ρ : Air density (about 1.225kg/m^3 at sea level)

A : Rotor swept area($=\pi/4 \cdot d^2$) in m^2

D : Rotor diameter in m

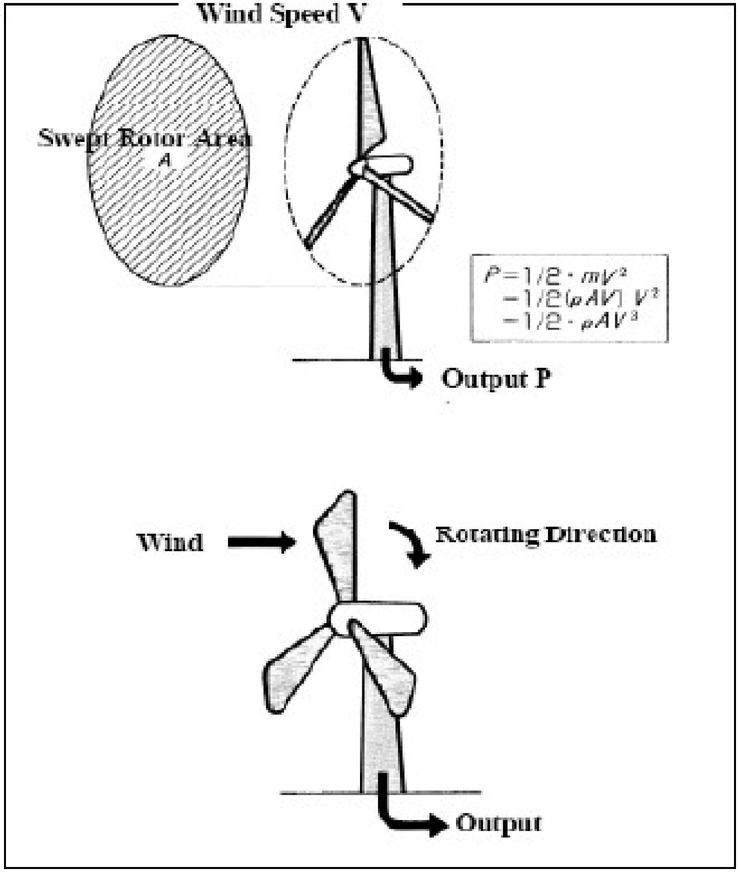
Cp : Power coefficient(=approx.0.35)

(=approx.0.35, including turbine,

generator & speed increaser efficiencies)

Max. theoretical(Betz number) : 0.593

V : Wind speed in m/s



Typical Wind Turbine Operation

0 ~ 10 mph --- Wind speed is too low for generating power. Turbine is not operational. *Rotor is locked*.

10 ~ 25 mph --- 10 mph is the minimum operational speed. It is called "*Cut-in speed*". In 10 ~ 25 mph wind, generated power increases with the wind speed.

25 ~ 50 mph --- Typical wind turbines reach the rated power (maximum operating power) at wind speed of 25mph (called *Rated wind speed*). Further increase in wind speed will not result in substantially higher generated power by design. This is accomplished by, for example, pitching the blade angle to reduce the turbine efficiency.

> 50 mph --- Turbine is shut down when wind speed is higher than 50mph (called "Cut-out" speed) to prevent structure failure.

Wind Turbine

Cut-in Speed

Cut-in speed is the minimum wind speed at which the wind turbine will generate usable power. This wind speed is typically between 7 and 15 mph.

Rated Speed

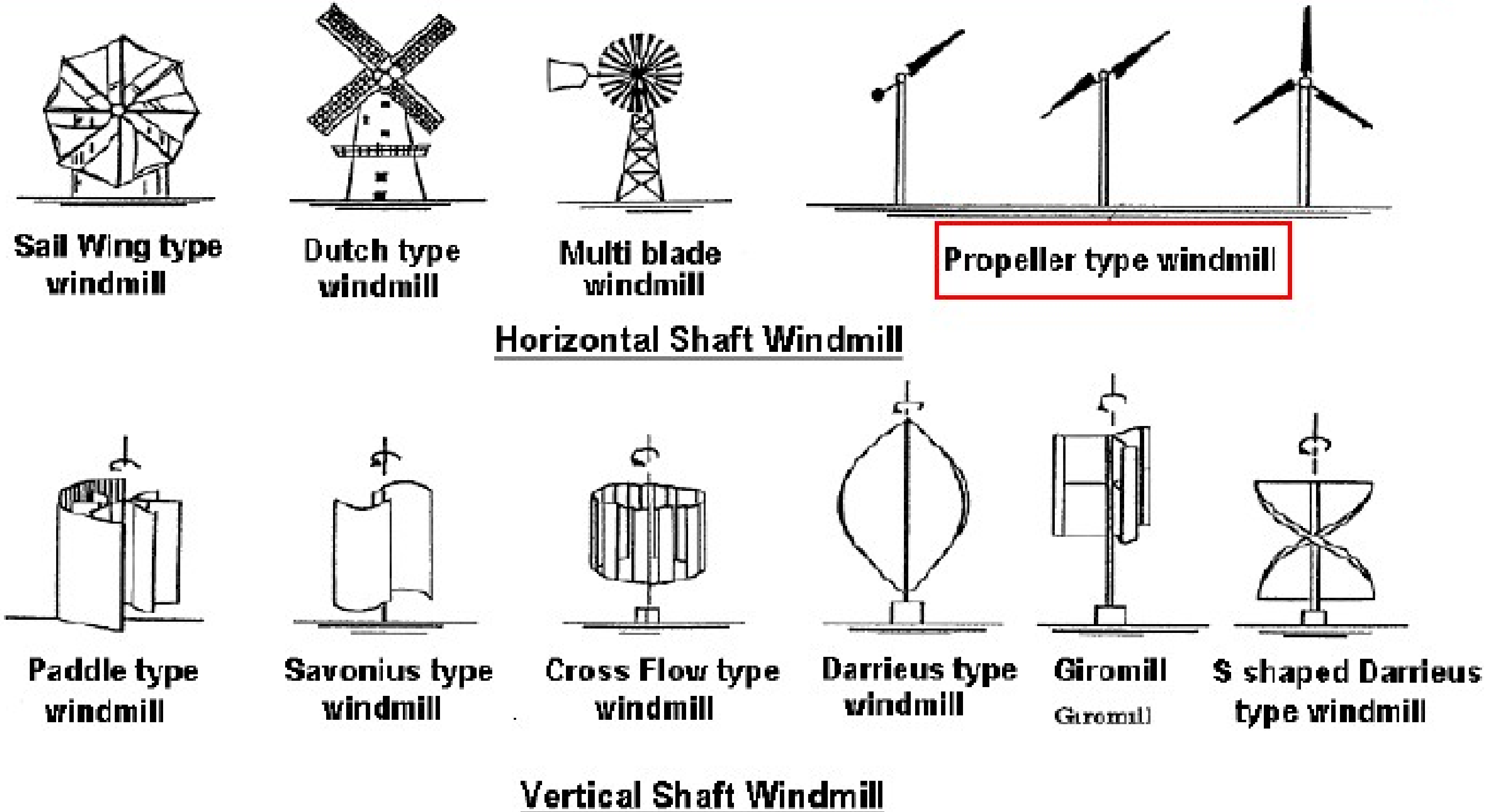
The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10 kilowatts until wind speeds reach 25 mph. Rated speed for most machines is in the range of 25 to 35 mph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases.

Cut-out Speed

At very high wind speeds, typically between 50 and 80 mph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Shut down may occur in one of several ways. In some machines an automatic brake is activated by a wind speed sensor.

Typical Wind Turbine

Propeller type windmill having the higher speed ratio will be suitable for power generation.

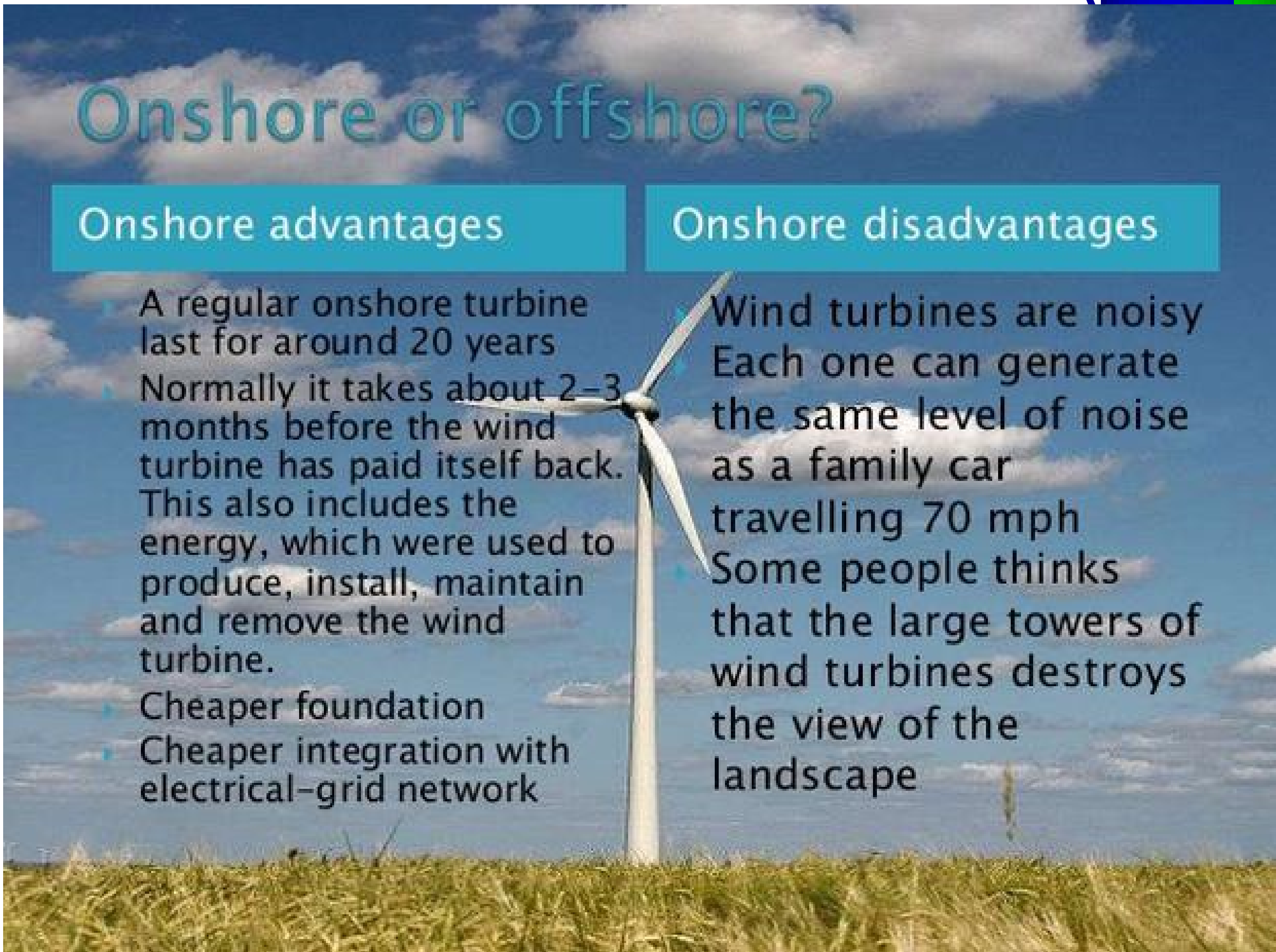


Sizes and Applications

Small (≤10 kW)
- Homes
- Farms
- Remote Application

Intermediate (10-250 kW)
- Village Power
- Hybrid Systems
- Distributed Power

Large (660 kW - 2+MW)
- Central Station Wind Farms
- Distributed Power
- Community Wind


Onshore or offshore?
Onshore advantages
A regular onshore turbine last for around 20 years
Normally it takes about 2-3 months before the wind turbine has paid itself back. This also includes the energy, which were used to produce, install, maintain and remove the wind turbine.
Cheaper foundation
Cheaper integration with electrical-grid network
Onshore disadvantages
Wind turbines are noisy
Each one can generate the same level of noise as a family car travelling 70 mph
Some people thinks that the large towers of wind turbines destroys the view of the landscape


Onshore or offshore?
Offshore advantages
• A offshore wind turbine is stronger than a onshore turbine. It lasts around 25-30 years, and produces about 50 % more energy than a onshore turbine.
• When a strong wind blows, it produces around 3-5 MW per hour.
• Higher and more constant wind speed
Offshore disadvantages
• More expensive to built
• More difficult to maintain and access

Wind energy is a kind of solar energy. Wind energy describes the process by which wind is used to produce electricity. The wind turbines convert the kinetic energy present in the wind to mechanical power.

Wind energy is a renewable source of energy that determines the total power in the wind. The wind turbines which convert kinetic energy to mechanical power, wherein the mechanical power is converted into electricity which acts as a useful source.

The wind energy formula is given by,

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

Where,

P = power,

ρ = air density,

A = swept area of blades given by $A = \pi r^2$

where r is the radius of the blades.

V = velocity of the wind.

Example 1

Determine the power in the wind if the wind speed is 20 m/s and blade length is 50 m.

Solution:

Given:

Wind speed v = 20 m/s,

Blade length l = 50 m,

Air density ρ = 1.23 kg/m.

The area is given by, $A = \pi r^2$

A = π × 2500

= 7850 m

The wind power formula is given as,

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

$$P = \frac{1}{2}(1.23)(7850)20^3$$

P = 38622 W

Example 2

A wind turbine travels with the speed is 10 m/s and has a blade length of 20 m. Determine wind power.

Solution:

Given:

Wind speed v =10 m/s,

Blade length l = 20 m,

air density ρ = 1.23 kg/m3,

area ,$A = \pi r^2$

= π × 400

= 1256 m^2

The wind power formula is given as,

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

= 0.5 × 1.23 × 1256 × 1000

P = 772440 W.