

Wind Energy

Class-16

What is wind

- wind energy is a converted form of solar energy.

The sun's radiation heats different parts of the earth at different rates-most notably during the day and night, but also when different surfaces (for example, water and land) absorb or reflect at different rates. This in turn causes portions of the atmosphere to warm differently. Hot air rises, reducing the atmospheric pressure at the earth's surface, and cooler air is drawn in to replace it. The result is wind.

- More Solar Radiation striking the Equator than the poles
- Heating and cooling differences of land and water

Advantages

1. The capital cost is comparable with conventional power plants. For a wind farm, the capital cost ranges between 4.5 crores to 6.85 crores per MW, depending up on the type of turbine, technology, size and location.
2. Construction time is less.
3. Fuel cost is zero.
4. O & M cost is very low.
5. Capacity addition can be in modular form.
6. There is no adverse effect on global environment. The whole system is pollution free and environment friendly.

Why Wind Energy

- The project is environment friendly.
- Good wind potential to harness wind energy.
- A permanent shield against ever increasing power prices. The cost per kwh reduces over a period of time as against rising cost for conventional power projects.
- The cheapest source of electrical energy. (on a levelled cost over 20 years.)
- Least equity participation required, as well as low cost debt is easily available to wind energy projects.
- A project with the fastest payback period.
- A real fast track power project, with the lowest gestation period; and a modular concept.
- Operation and Maintenance (O&M) costs are low.
- No marketing risks, as the product is electrical energy.
- A project with no investment in manpower.

Limitation

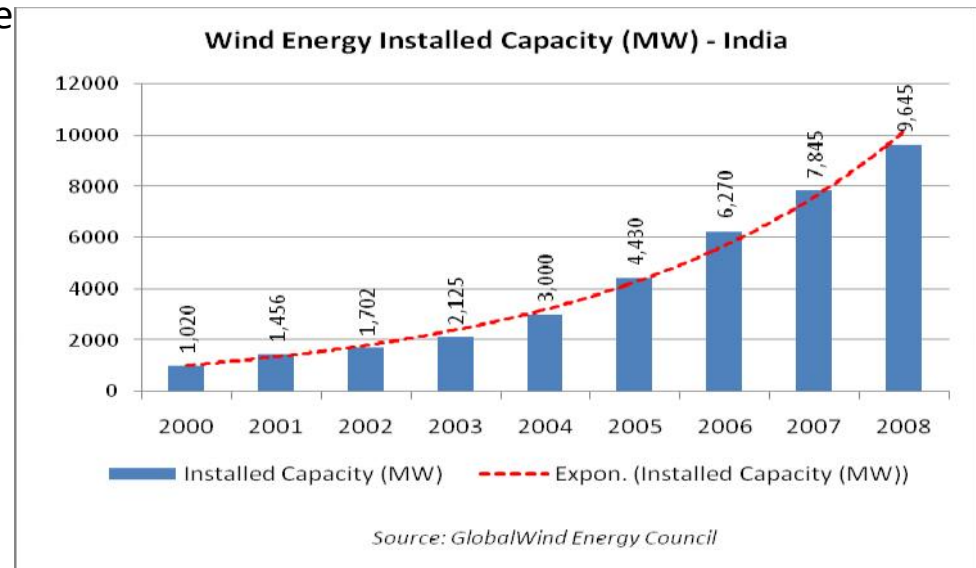
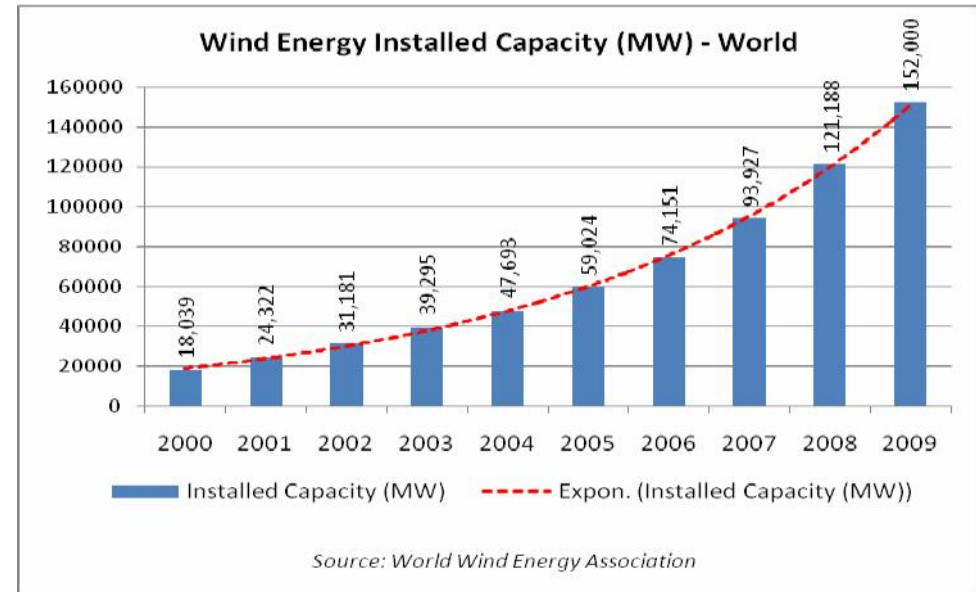
1. Wind machines must be located where strong, dependable winds are available most of the time.
2. Because winds do not blow strongly enough to produce power all the time, energy from wind machines is considered "intermittent," that is, it comes and goes. Therefore, electricity from wind machines must have a back-up supply from another source.
3. As wind power is "intermittent," utility companies can use it for only part of their total energy needs.
4. Wind towers and turbine blades are subject to damage from high winds and lightning. Rotating parts, which are located high off the ground can be difficult and expensive to repair.
5. Electricity produced by wind power sometimes fluctuates in voltage and power factor, which can cause difficulties in linking its power to a utility system.
6. The noise made by rotating wind machine blades can be annoying to nearby neighbours.
7. People have complained about aesthetics of and avian mortality from wind machines.

Wind Energy – Present Scenario

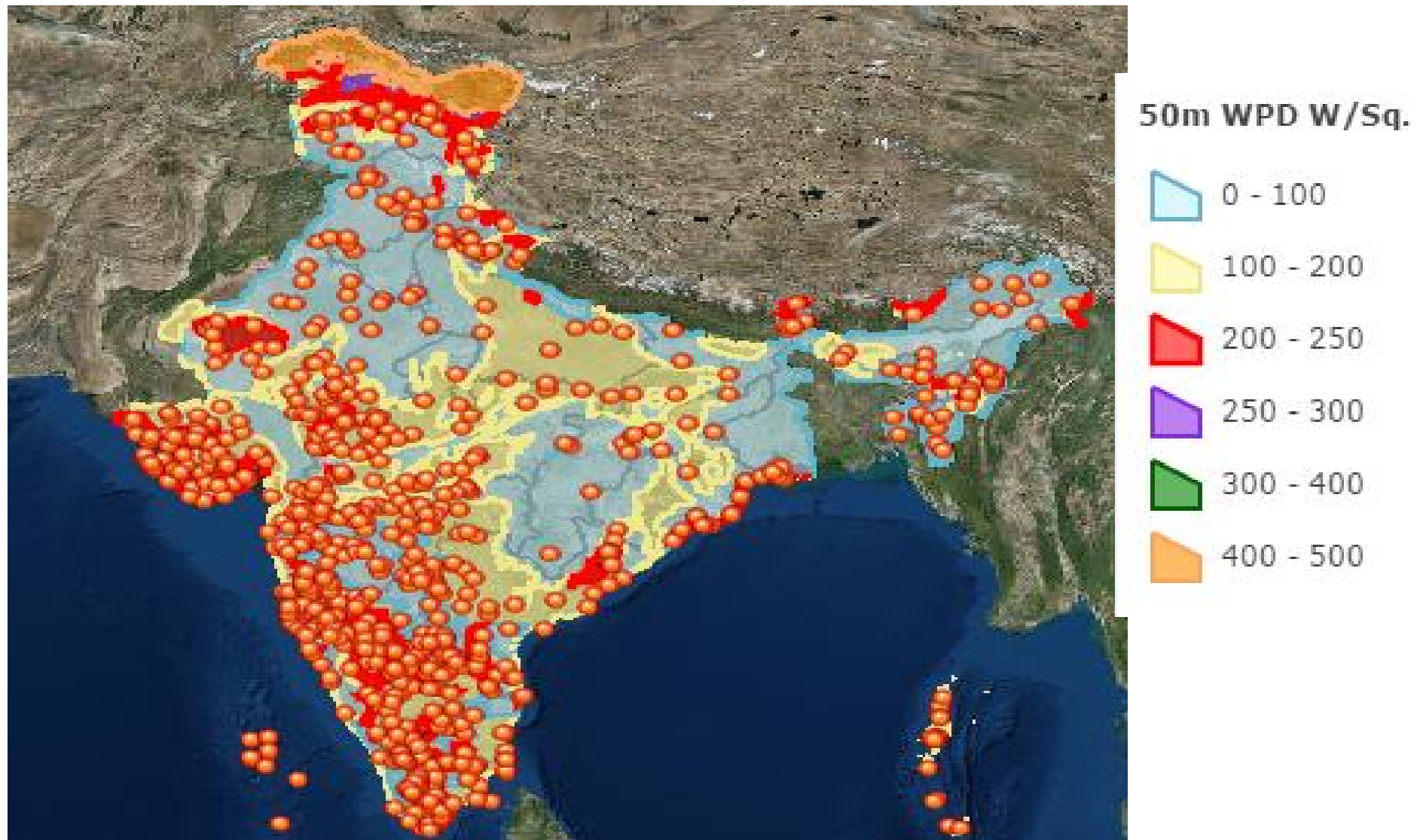
- Wind Power – **Fastest growing** renewable energy source
- Globally, it grew at the average rate of **27 %** pa over the past 10 years.
- While in India it grew at the average rate of **33%** over the past 9 years.
- Presently, India is ranked **5th in the world** in terms of Wind Energy Installed Capacity

- **Drivers of growth**

- Environmental Awareness and Sustainable Development
- Growing Global Energy Demand
- Improving Competitiveness of renewable energy
- Security of Supply Concerns
- New Markets (e.g. India, China etc)
- Carbon Trading
- Fiscal Benefits by Govt. (PTC, feed in tariffs, etc)



Wind Power Density in India



- A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy.
- If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a windmill.
- If the mechanical energy is instead converted to electricity, the machine is called a wind generator, wind turbine, wind power unit (WPU), wind energy converter (WEC), or aerogenerator.

Type of wind farms

- **On shore:** The wind farms which is about three kilometres away from the nearest shore line.
- **Near Shore:** The wind farm lies on land within three kilometres from the nearest shore line or lying in water within ten kilometres from the shore.
- **Off shore:** The wind farms which is more than ten kilometres into the sea from the shore.
- **Airborne:** It is a new concept which is under development. Such wind turbines suspended high in the atmosphere thereby it can obtain fastest and strongest wind available. It is a design concept for a wind turbine that is supported in the air without a tower.

Wind Energy - Technology

A wind turbine obtains its power input by converting the force of the wind into a **torque (turning force)** acting on the rotor blades.

The amount of energy which the wind transfers to the rotor depends on the **density of the air, the rotor area, and the wind speed.**

$$P = 0.5 \times \rho \times A \times V^3$$

P → Power

ρ → Air Density (kg/m³)

A → Blade Area -turbine (m²)

V → Wind velocity (m/s)

What is a wind turbine and how does it work?

- A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use.
- Mechanical energy is most commonly used for pumping water in rural or remote locations- the "farm windmill" but it can also be used for many other purposes (grinding grain, sawing, pushing a sailboat, etc.)
- Wind electric turbines generate electricity for homes and businesses and for sale to utilities.

Type of wind turbine

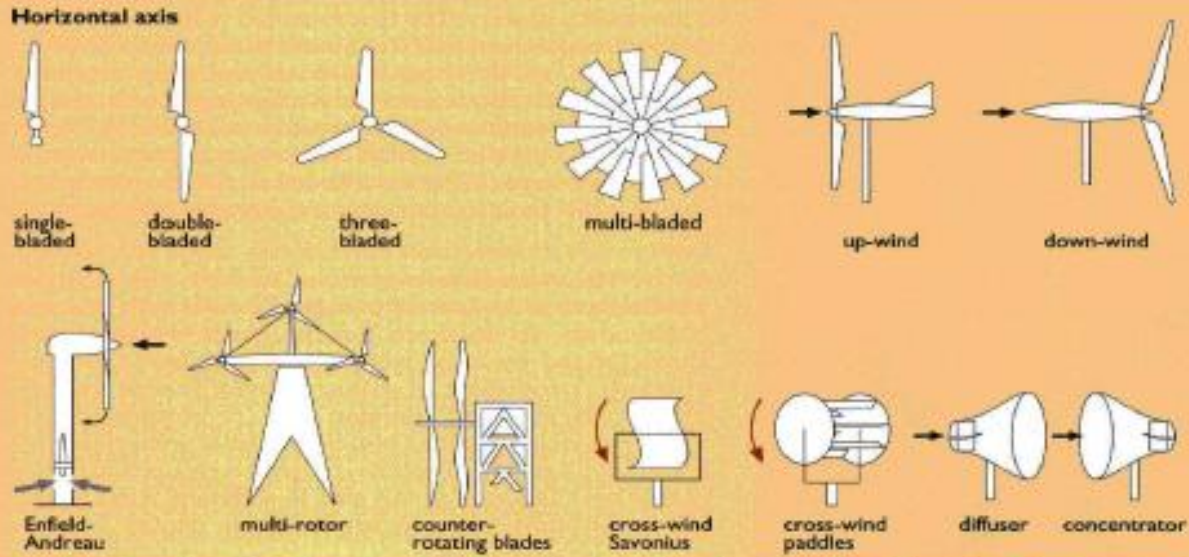
- Horizontal axis wind turbines (HAWT) or Propeller-style
- Vertical-axis, or "egg-beater" style (VAWT)

Aerodynamics of Wind Turbine Blades

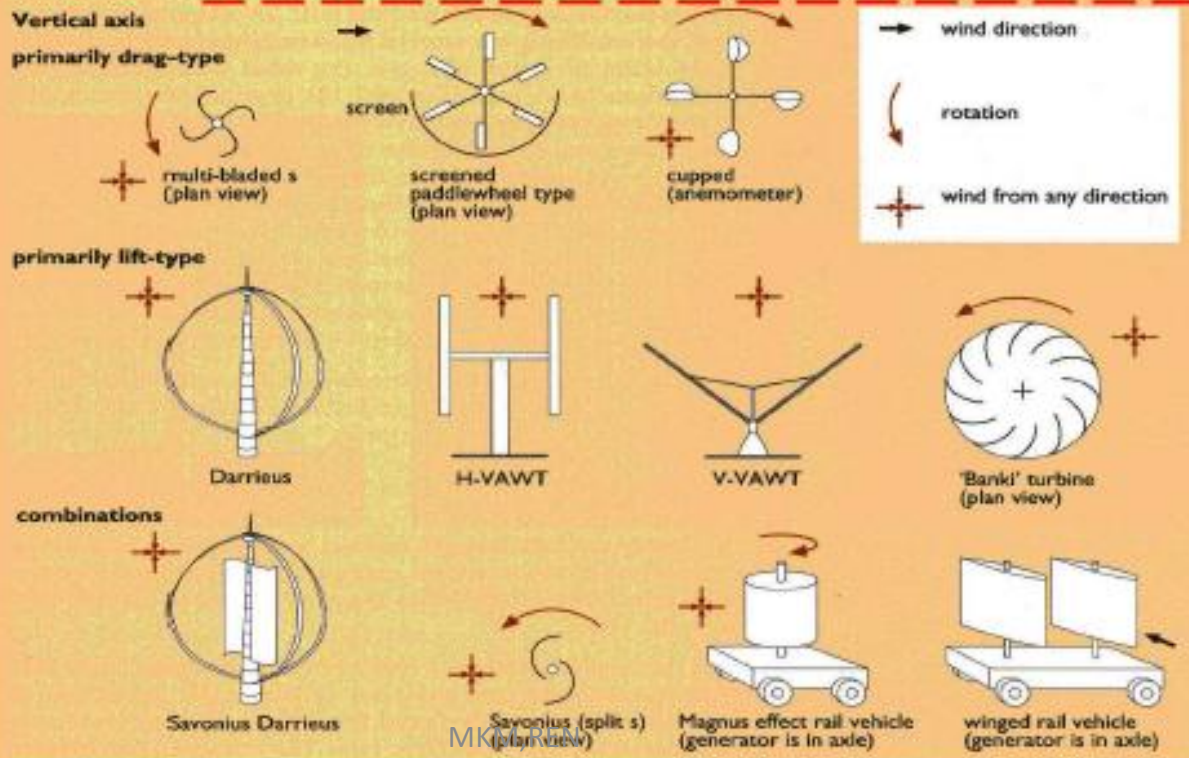
Two Types of Turbine Designs

- Drag Designs: the force component in line with the original flow direction
- Lift Designs : the force component perpendicular to the original flow direction

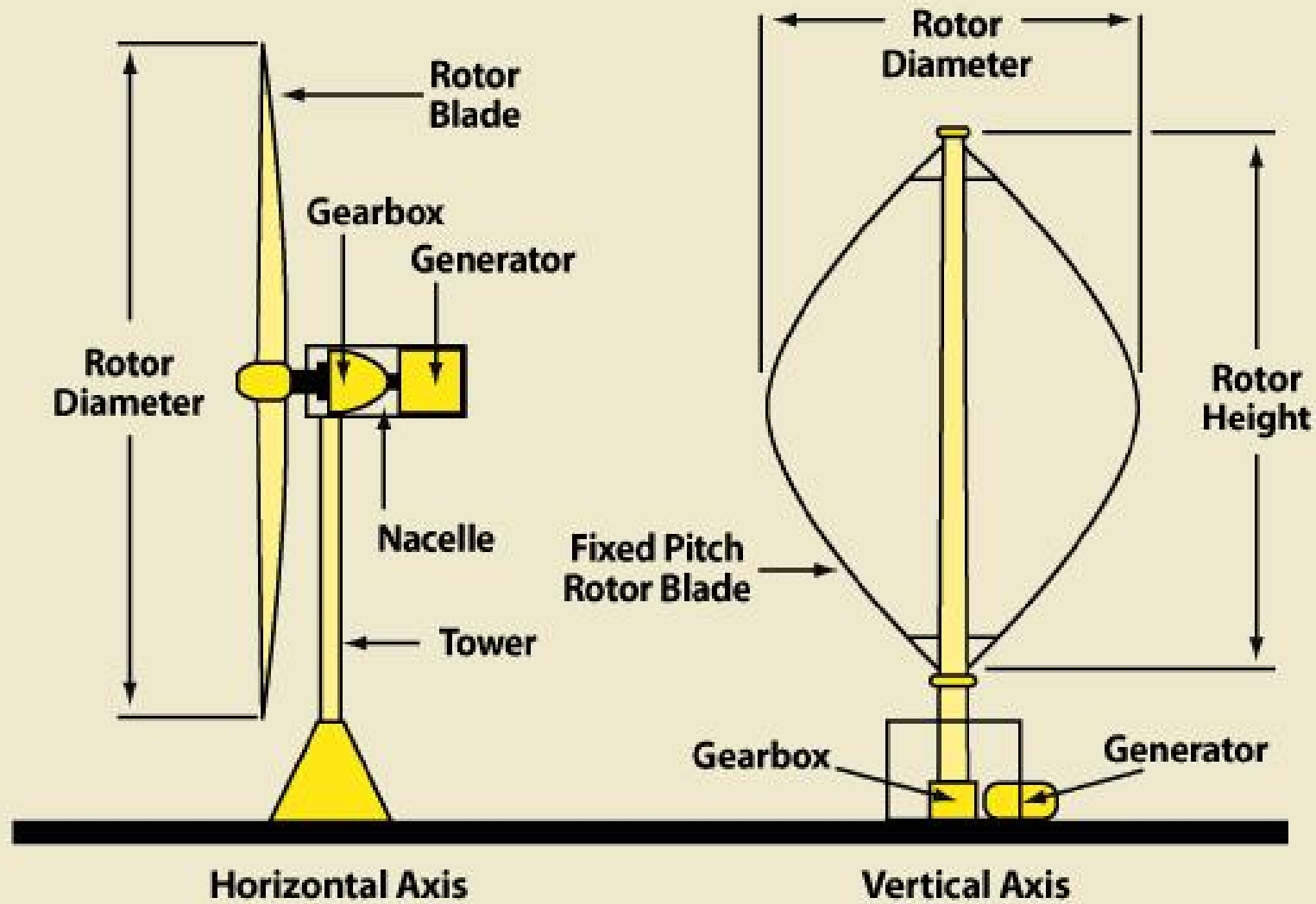
HAWT



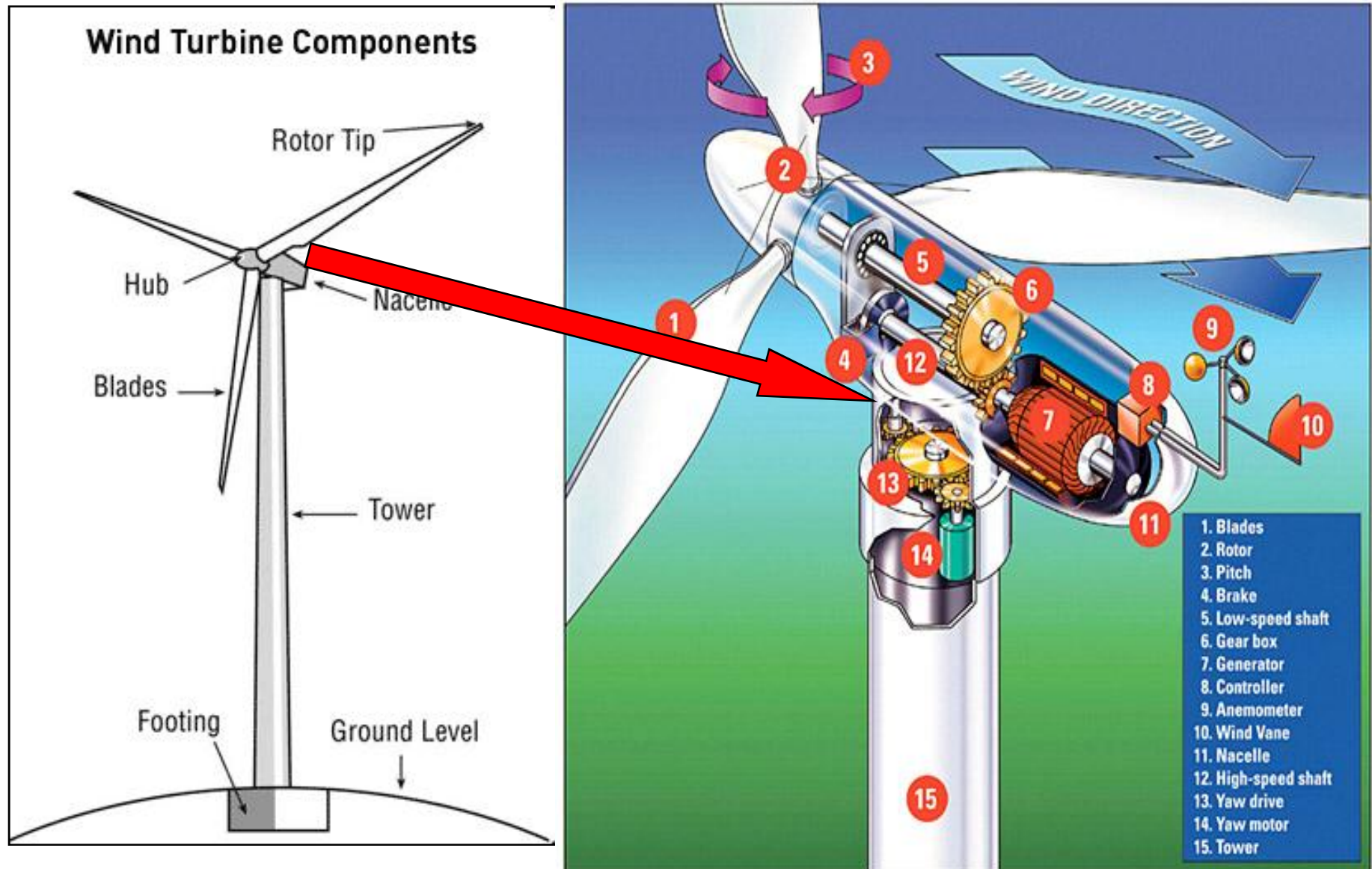
VAWT



Horizontal-Axis and Vertical-Axis Wind Turbines



Major Components of Wind Turbine



Turbine subsystems

- a rotor, or blades, which convert the wind's energy into rotational shaft energy;
- a nacelle (enclosure) containing a drive train, usually including a gearbox* and a generator;
- a tower, to support the rotor and drive train; and
- electronic equipment such as controls, electrical cables, ground support equipment, and interconnection equipment.
- The towers are mostly tubular and made of steel. The blades are made of fiberglass reinforced polyester or wood-epoxy.
- **Yawing: Rotation of the rotor axis about a vertical axis (for horizontal axis WT only)**

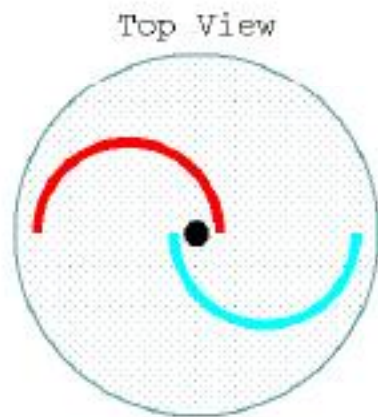
Power & Torque conversions

- $P_T = \frac{1}{2} C_p A \rho u_0^3$
 - C_p = power coefficient
 - A = cross section of wind front contacting turbine
 - ρ = wind density (mass of air per unit area)
 - Depends on air temperature and pressure
 - u_0 = initial wind speed
- $C_p = \lambda C_N$
 - C_p = power coefficient
 - C_N = torque coefficient
 - $\lambda = 4\pi / n$ = tip speed ratio
 - n = number of rotors

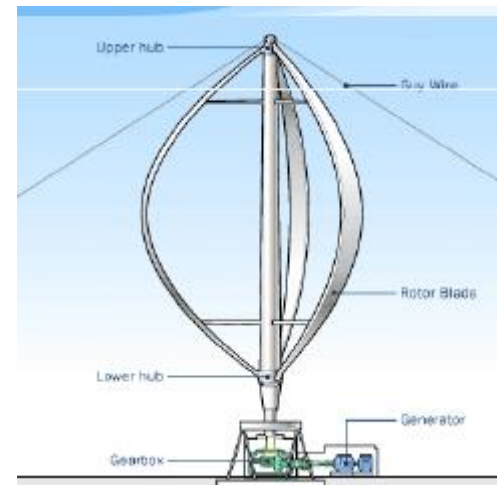
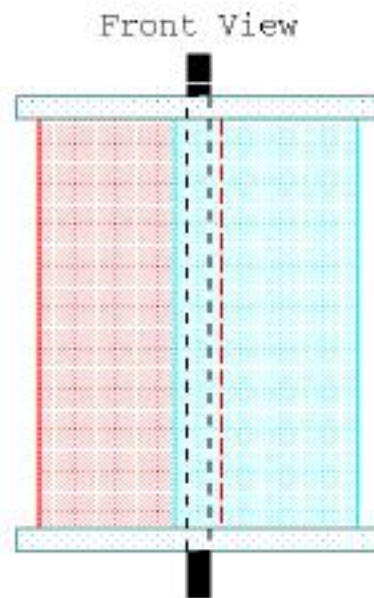
VAWT

a.) The Savonius rotor

b.) The Darrieus rotor.



Savonius Rotor



Darrieus rotor.

VAWT

- Drag is the main force
- Nacelle is placed at the bottom
- Yaw mechanism is not required
- Lower starting torque
- Difficulty in mounting the turbine
- Unwanted fluctuations in the power output because Located closer to ground, which means less wind.
- $1/2$ as efficient as Horizontal axis



HAWT

- Lift is the main force
- Much lower cyclic stresses
- 95% of the existing turbines are HAWTs
- Nacelle is placed at the top of the tower
- Yaw mechanism is required
- 2 bladed
- 3 bladed
- Multi bladed



4/21/2014



MKM,REN

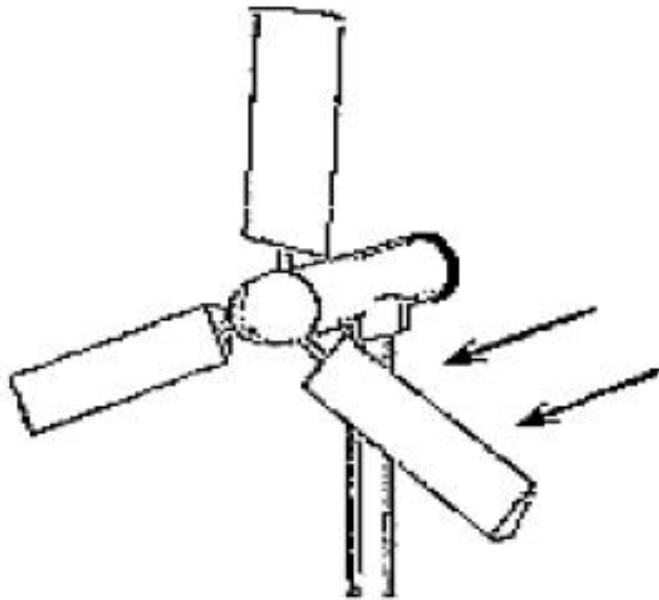


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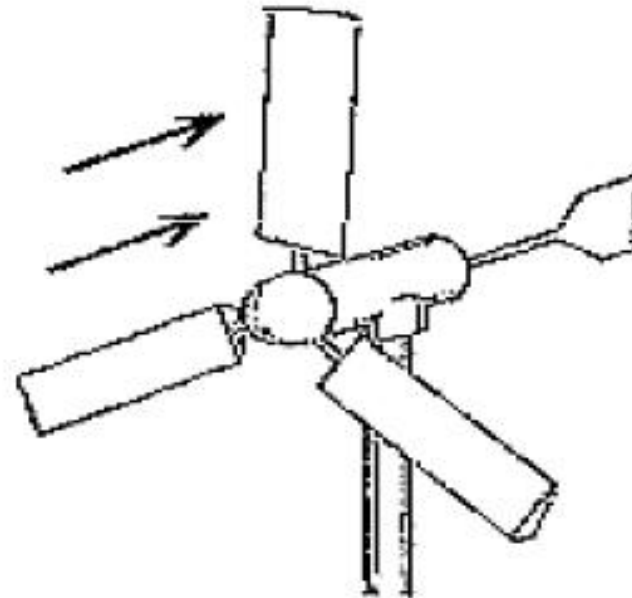
- 2 & 3 bladed machines are used instead of multi/many bladed machines for Electrical Energy because Electric generation requires more steady and higher wind velocities
- Multi blade turbines used
 - Water pumping
 - Corn grinding
- High torque in low wind
- Example
 - $C_{p \text{ MAX}}$ occurs at $\lambda = 4\pi / n$
 - $n = 3 \rightarrow C_{p \text{ MAX}}$ occurs at $\lambda = 4\pi / 3 = 4.19 \text{ m/s}$
 - $n = 6 \rightarrow C_{p \text{ MAX}}$ occurs at $\lambda = 4\pi / 6 = 2.09 \text{ m/s}$
 - $P_{T \text{ max}}$ occurs at $C_{p \text{ MAX}}$
 - Which is reached at lower tip speed with more blades

Two types of HAWT

DOWNWIND TURBINE

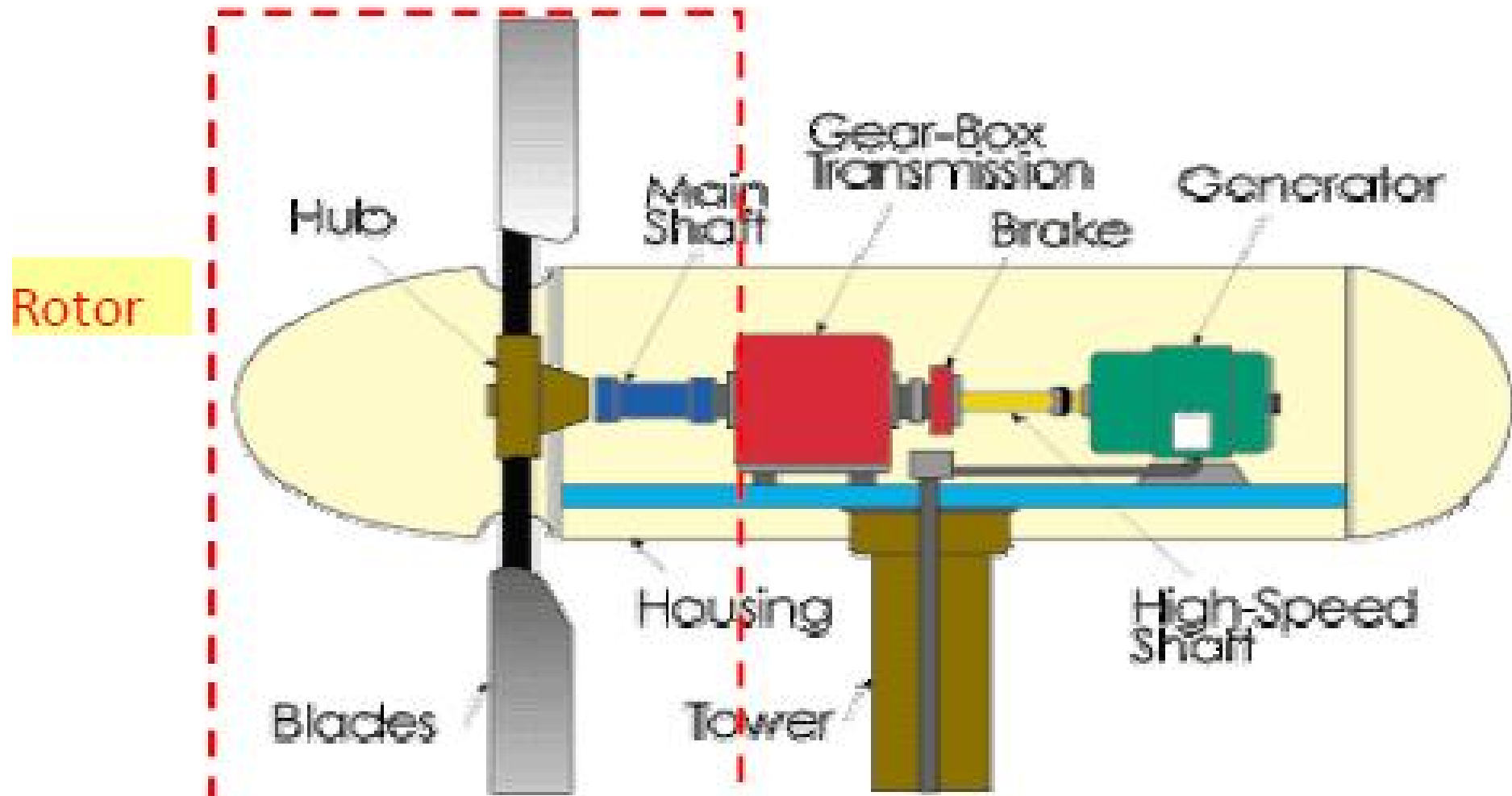


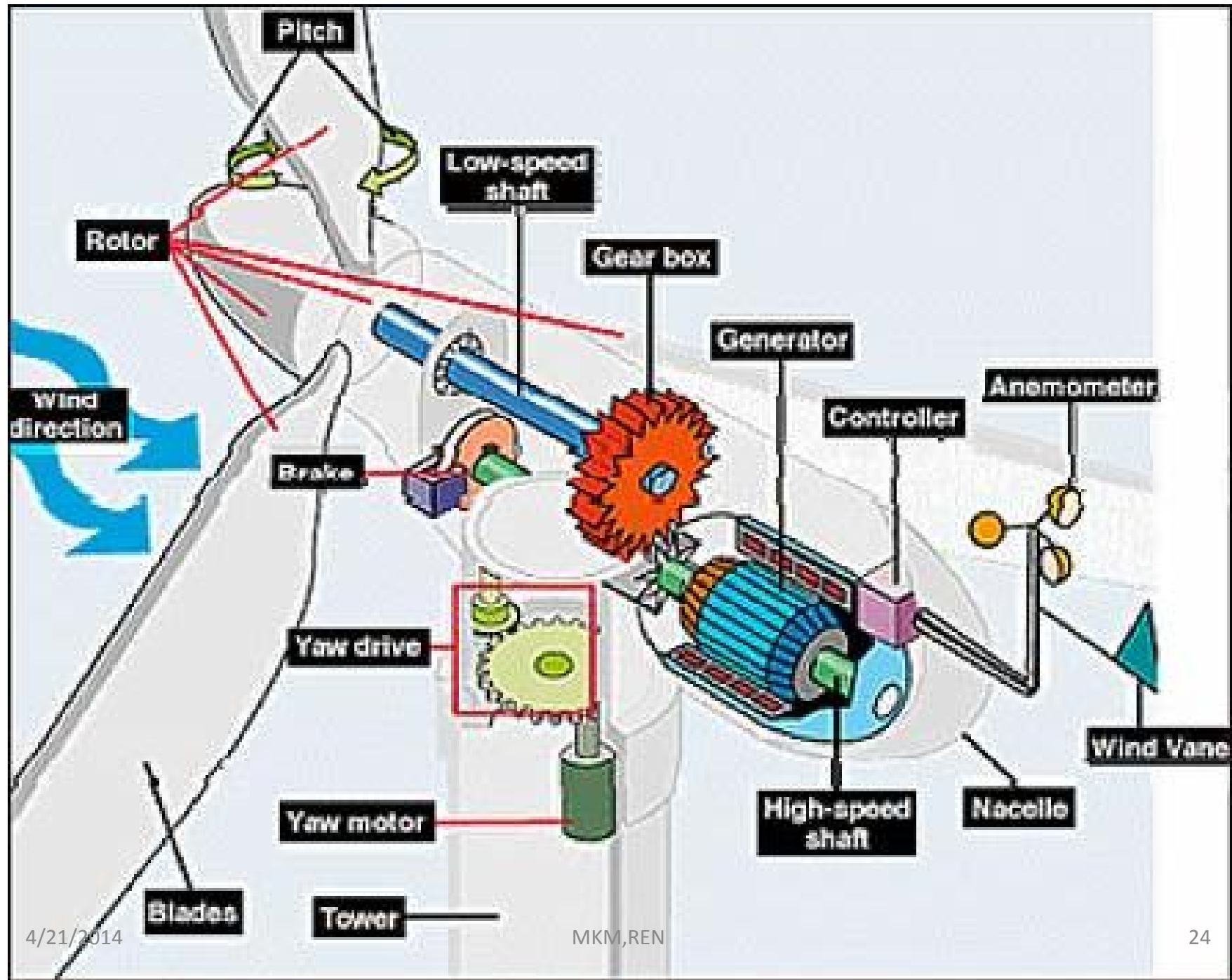
UPWIND TURBINE



- Downwind means that incoming wind hits nacelle before blades automatically yaws with wind as direction changes
- Upwind means blades are on incoming wind side of nacelle, and must have yaw control

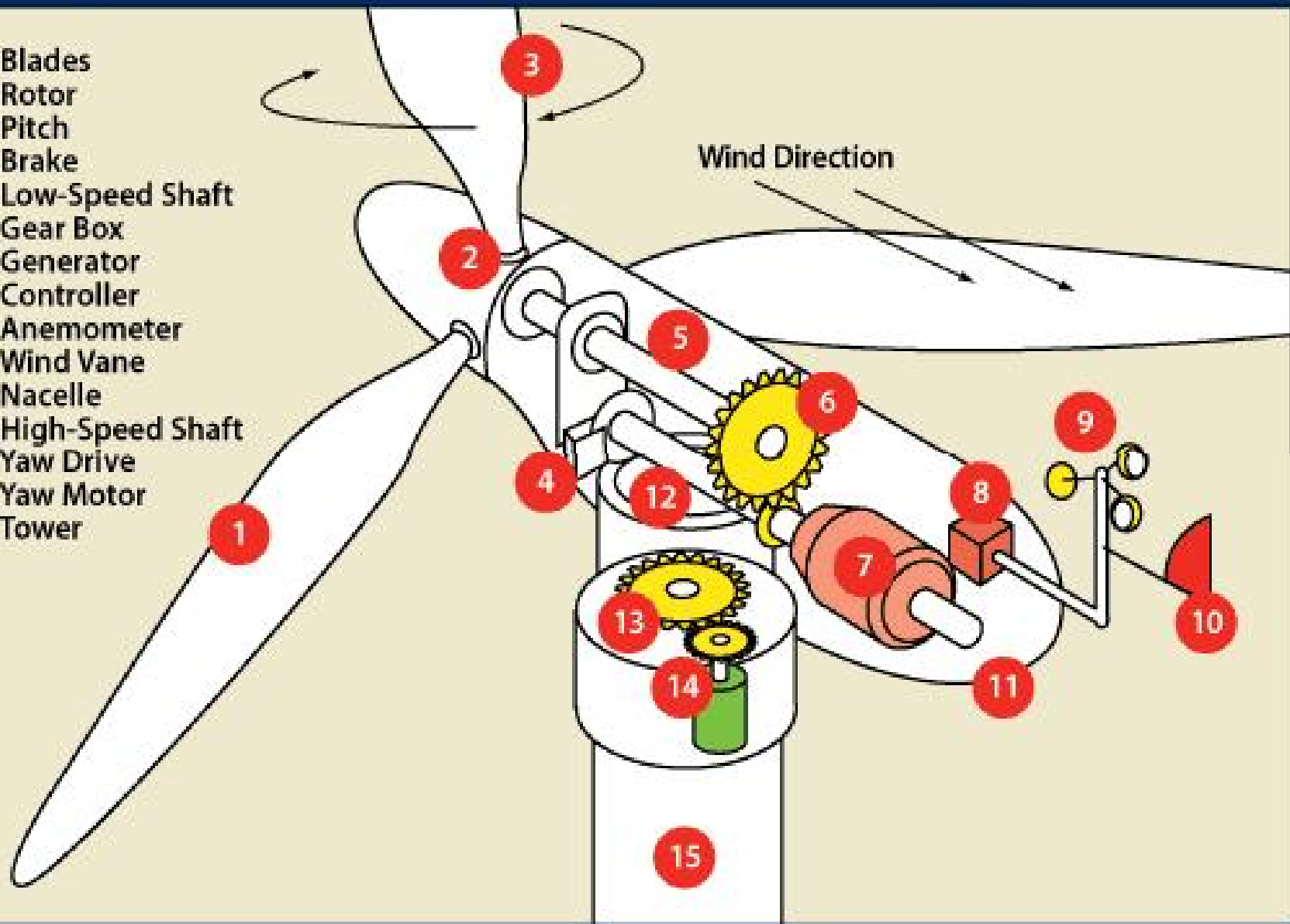
View of HAWT





Components of an Energy-Generating Windmill

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



Major Components

- Rotor
- Blades
- Low speed shaft
- Gear Box
- High speed shaft
- Generator
- Brakes
- Controller

- Conversions from wind → mechanical → electrical + periodicity of wind
 - Efficiency = approx 25-35% (mostly due to its periodicity)
- ❖ A quantitative measure of the wind power available at any location is called Wind Power Density(WPD).
- ❖ Commercial wind farms generally produce a WPD of 400 watts/square meter.

- Location should have average wind speeds of 4-6 m/sec at a distance 10m from ground level
 - Wind velocity is greater and more steady higher of ground level
- Height measured from ground to center of turbine (where blades all meet)
- Must have fail safe shut off for winds greater than 8 m/sec

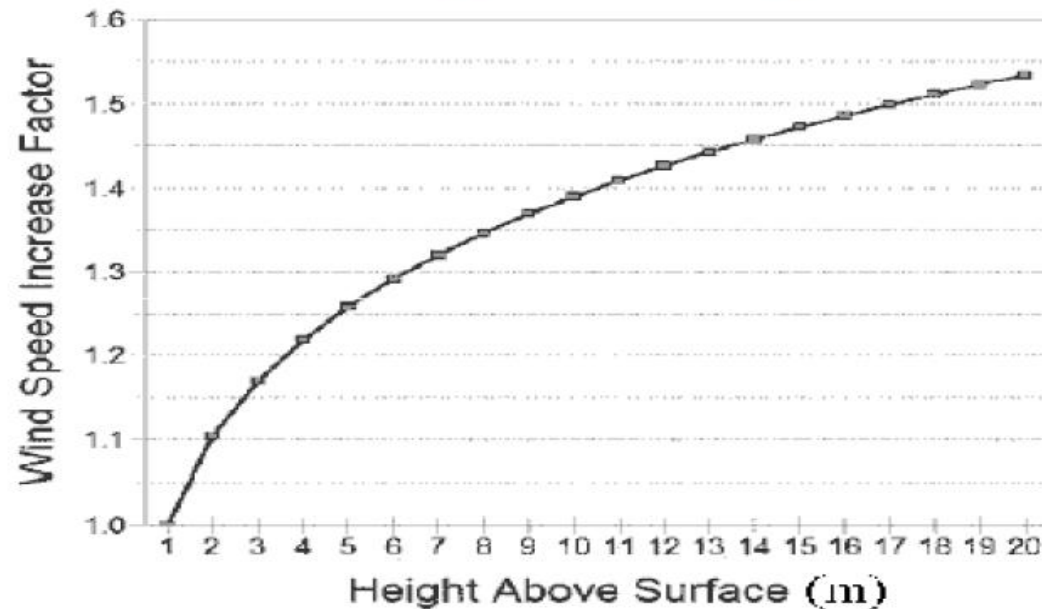
	small	Medium	large
Power (kW)	(<10 kW)	10-250 kW	660 kW - 2+MW
Diameter (m)	6.5 - 15	20 - 50	65 – 130
Height (m)	20 - 30	30 - 50	60 - 80
4/21/2014	<ul style="list-style-type: none"> •Homes •Farms • Remote Application 	MKM,REN Village Power <ul style="list-style-type: none"> • Hybrid Systems • Distributed Power 	Central Station Wind Farms <ul style="list-style-type: none"> • Distributed Power • Community Wind

IMPACT OF TOWER HEIGHT

$$\frac{V}{V_0} = \left(\frac{H}{H_0}\right)^r$$

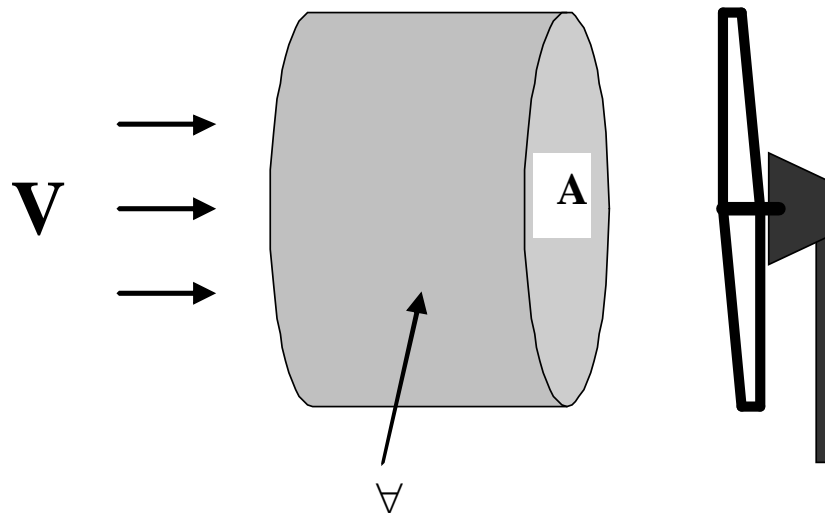
where V is the wind speed at height H , V_0 is the wind speed at height H_0 (often a reference height of 10 m), and r is the friction coefficient.

Velocity with Height



POWER IN THE WIND

The kinetic energy of a stream of air: $E = \frac{1}{2}mV^2$



The kinetic energy of the air stream available for the turbine

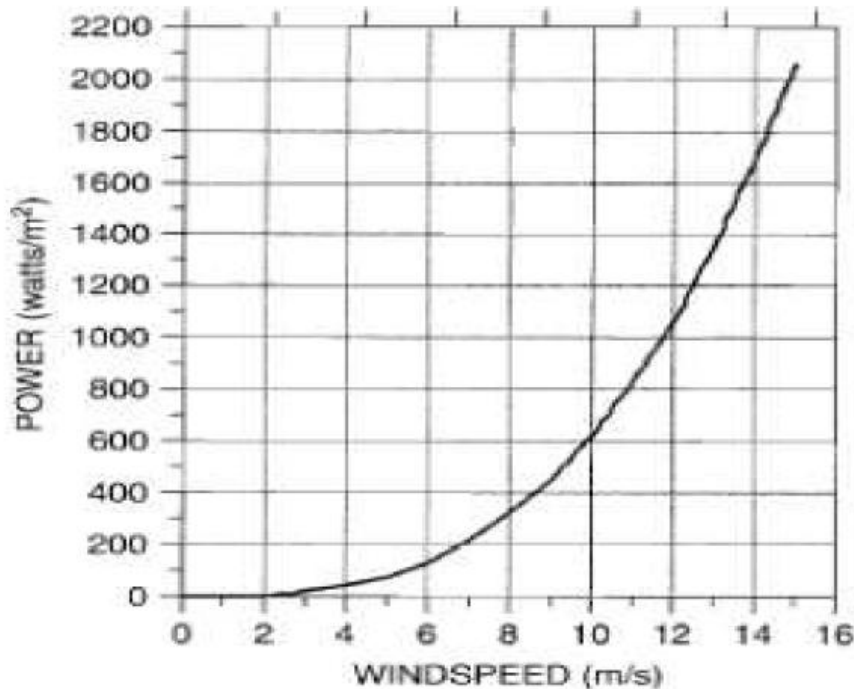
$$E = \frac{1}{2} \Delta V^2$$

Volume of air parcel available to the rotor Δ

The *air parcel interacting with the rotor per unit time* has a cross-sectional area equal to that of the rotor (A_T) and thickness equal to the wind velocity (V).

Power is the *energy per unit* and expressed

$$P = \frac{1}{2} \rho_a A_T V^3$$



Power in the wind, per square meter of cross section, at 15°C and 1 atm.

- **Major Factors:** Air density, area of wind rotor and wind velocity
- The most important factor is ***Wind Speed***
(Power varies cubic power of velocity)
 - **As the velocity doubles, the power is increased by 8 times.**
 - **The rotor area is reduced by a factor of 8.**
- **The selection of site is very critical for the success of a wind power**

Wind Turbine Power and Efficiency

- A wind turbine converts a fraction of the wind energy into mechanical energy
 - A part is transferred to the rotor of the wind turbine (P_T)
 - Rest is carried away by passing air
- The efficiency is the ratio of actual power developed by wind turbine rotor to the available wind power
 - defined as power coefficient and expressed as

$$C_p = \frac{P_T}{\frac{1}{2} \rho a A_T V^3}$$

- The power coefficient or the power picked up by the wind turbine rotor is influenced by many factors:
 - profile of the rotor blade
 - number of blades
 - blade arrangement

Wind Turbine Torque

- The thrust force developed by the rotor is

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

- The rotor torque is

$$\mathbf{T} = \frac{1}{2} C_p A_T V^2 R \quad \longleftarrow \text{Maximum Theoretical Torque}$$

Where R is the radius of the rotor

Rotor Torque

- The torque developed by the rotor shaft is less than the maximum theoretical torque and given in terms of *coefficient of torque*

as

$$C_T = \frac{T_r}{\frac{1}{2} \rho a A_T V^2 T}$$

Rotor Tip Relative Speed

- The rotor power at given wind speed depends on the relative speed between the rotor tip and the wind.
- Higher relative speed between the rotor tip and the wind leads to poor interaction the rotor and the wind.
 - For high speed wind approaching a slower moving rotor, a portion of the wind passes the rotor without transferring energy.
 - For low speed wind approaching a faster moving rotor, the wind deflects from the rotor and energy is lost due to turbulence and vortex shedding.

Relative speed is defined as velocity of rotor tip and wind speed as

$$V_{rw} = \frac{\check{S}R}{V} = \frac{2fNR}{V}$$

N = Rotor rotational speed, rpm
S = Angular velocity

Also, it can be shown that power coefficient and torque coefficient is related by relative speed:

$$\frac{C_P}{C_T} = V_{rw} = \frac{\check{S}R}{V}$$

Betz' Law

- States the theoretical limit for the conversion of wind energy in wind turbine
- According to this law maximum possible wind turbine efficiency is less than 59.3 %
- Derived assuming a thin rotor from a fluid at a speed
Major assumptions:
 - Rotor without any hub
 - Infinite number of blades with no drag
 - axial flow in and out

Some of the terms in Wind Energy

Power Coefficient: The power coefficient of a wind energy converter is given by

$$C_p = \frac{\text{power output from the wind machine}}{\text{power contained in the wind}}$$

specific rated capacity (SRC),

$$SRC = \frac{\text{power rating of the generator}}{\text{rotor swept area}}$$

The SRC varies between 0.2 for small rotors to 0.6 for large ones

$$\text{Capacity factor} = \frac{\text{annual energy output}}{\text{rated power} \times \text{time in an year}}$$

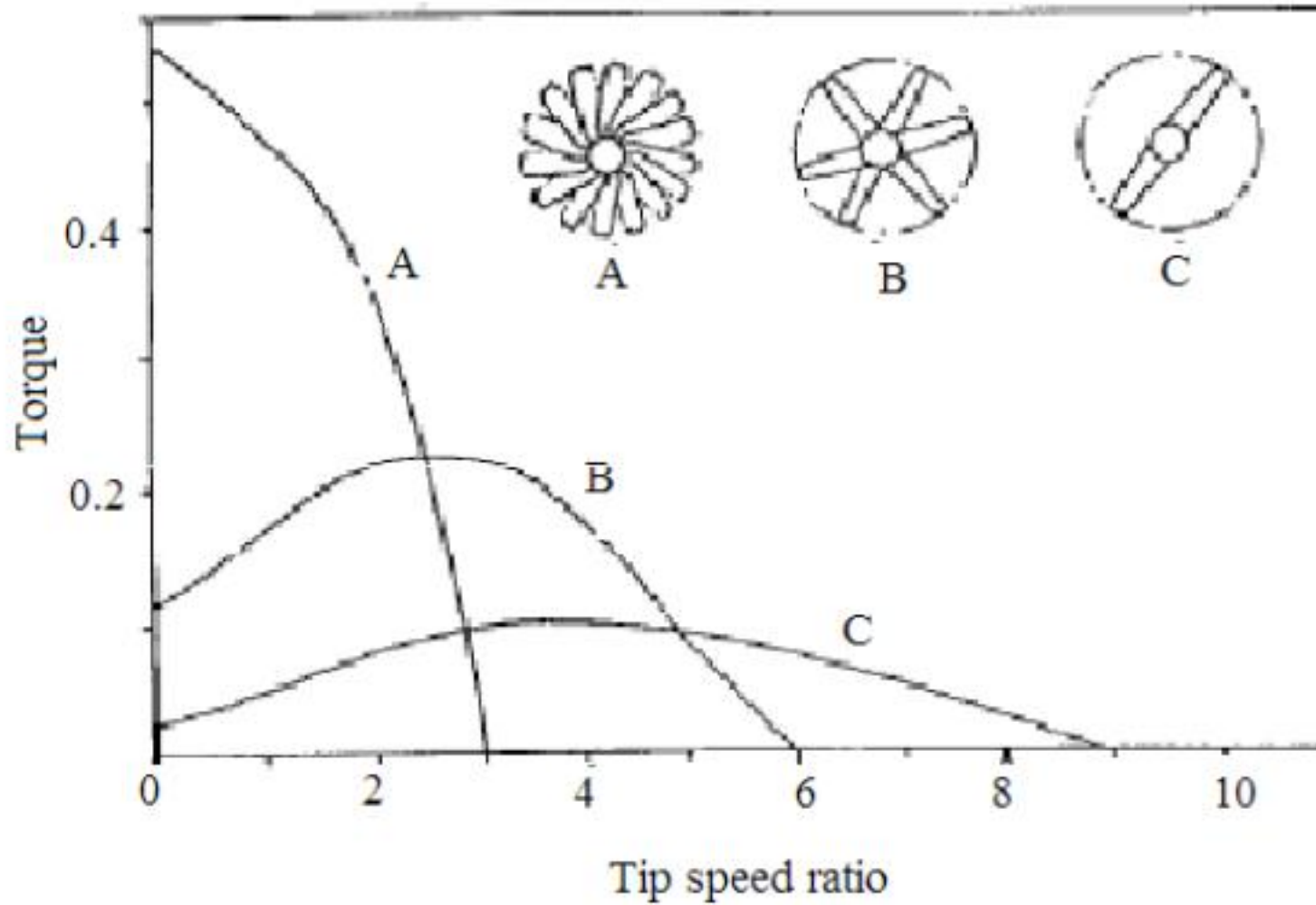
The tip-speed-ratio is the speed at which the outer tip of the blade is moving divided by the wind speed:

$$\text{Tip-Speed-Ratio (TSR)} = \frac{\text{Rotor tip speed}}{\text{Wind speed}} = \frac{\text{rpm} \times \pi D}{60 v}$$

Solidity is usually defined as the percentage of the area of the rotor, which contains material rather than air.

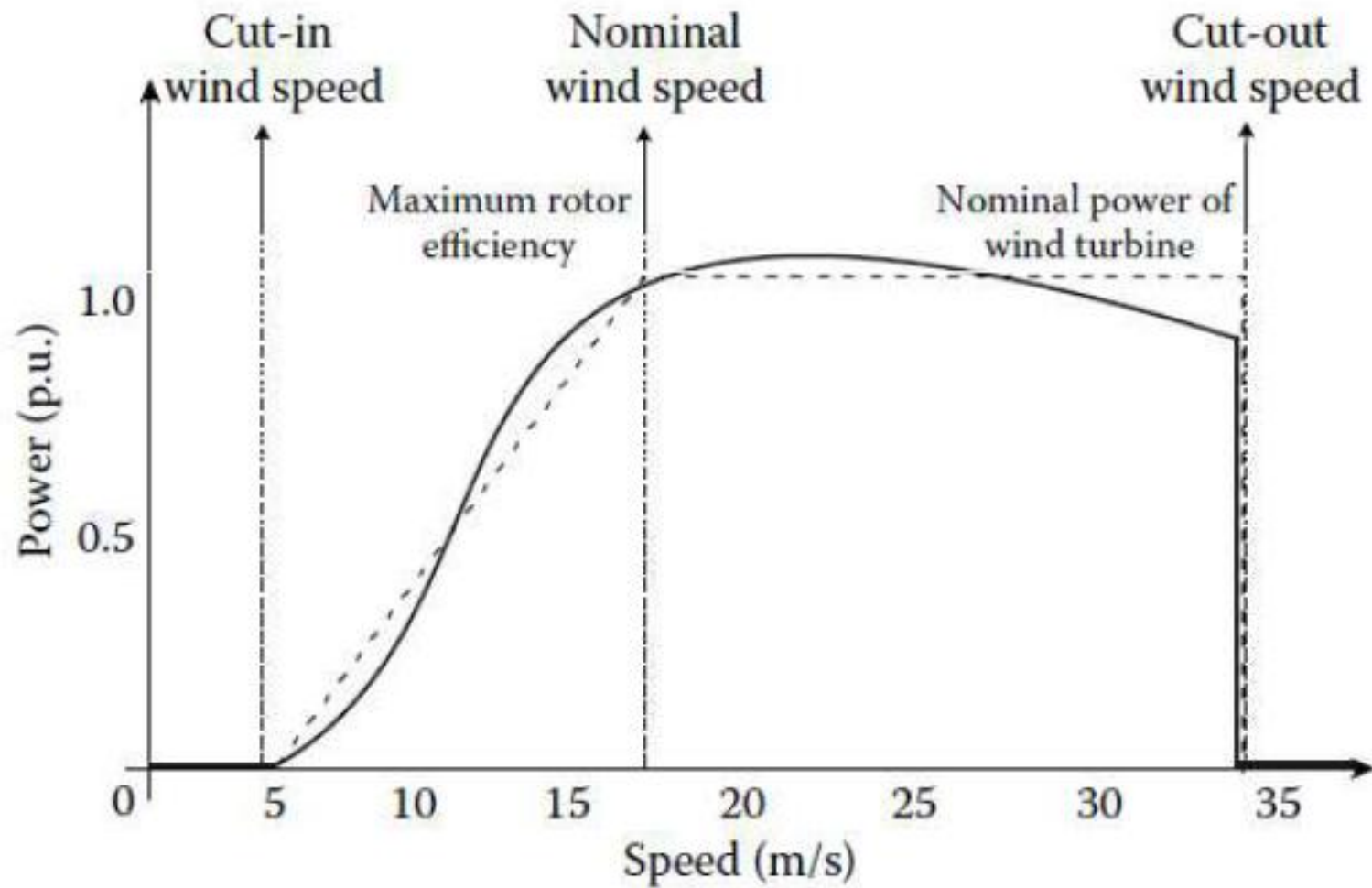
- Low-solidity machines run at higher speed and tend to be used for electricity generation.
- High-solidity machines carry a lot of material and have coarse blade angles. They generate much higher starting torque (torque is the twisting or rotary force produced by the rotor) than low solidity machines but are inherently less efficient than low-solidity machines.
- High solidity machines will have a low tip-speed ratio and vice versa.

Solidity and Tip speed ratio



- **Start-up wind speed** - the wind speed that will turn an unloaded rotor
- **Cut-in wind speed (V_{in})** : Lowest mean wind speed at hub-height at which the WT starts to produce power
- **Cut-out wind speed (V_{out})**: Highest mean wind speed at hub-height at which the WT is designed to produce power
- **Rated wind speed** – the wind speed at which the machine is designed to run (this is at optimum tip-speed ratio)
- **Furling wind speed** – the wind speed at which the machine will be turned out of the wind to prevent damage

Power Curve: The power curve is a diagram that shows the specific output power of a turbine at various wind speeds, which is important in turbine design. Power curves are made by a series of measurements for one turbine with different wind speeds. In order to obtain accurate power curves, the wind should be non turbulent.



common rotor types and their characteristics

Type	Speed	Torque	C_p	Solidity (%)	Use
Horizontal Axis					
Multi blade	Low	High	0.25 - 0.4	50 - 80	Mechanical Power
Three-bladed aerofoil	High	Low	up to 0.45	Less than 5	Electricity Production
Vertical Axis					
Panemone	Low	Medium	less than 0.1	50	Mechanical Power
Darrieus	Moderate	Very low	0.25 - 0.35	10 - 20	Electricity Production

How Much Wind is Enough?

A wind energy system needs an average annual wind speed of at least 4 metres per second (m/s) to be able to operate with any degree of efficiency.

Average Wind Speed

Wind Regime

Up to 4 m/s (about 15 km/h)

No good

5 m/s (18 km/h)

Poor

6 m/s (22 km/h)

Moderate

7 m/s (25 km/h)

Good

8 m/s (29 km/h)

Excellent

Leading Manufacturers of Wind Turbine

1. Vestas (Denmark) - 35,000 MW
2. Enercon (Germany) - 19,000 MW
3. Gamesa (Spain) – 16,000 MW
4. General Electric (USA, Germany) – 15,000 MW
5. Siemens (Denmark, Germany) – 8,800 MW
6. Suzlon (India) – 6,000 MW
7. Nordex (Germany) – 5,400 MW
8. Acciona (spain) – 4,300 MW
9. Repower (Germany) – 3,000 MW
10. Goldwind (china) – 2,889

Estimated Wind Power Potential

Sl. No.	State	Gross Potential (MW)
1	Andhra Pradesh	8275
2	Gujarat	9675
3	Karnataka	6620
4	Kerala	875
5	Madhy Pradesh	5500
6	Maharashtra	3650
7	Orissa	1700
8	Rajasthan	5400
9	Tamil Nadu	3050
10	West Bengal	450
	Total	45195

Indian government supports wind energy sector

Government of India supports wind energy sector in many ways. Some of them are financial provisions for wind energy generators. Following list provide information on current fiscal and Tax incentives for the wind energy project developers. (Source: Global Wind Energy Council)

- 80% accelerated depreciation for investors if the project is commissioned before 30 September of the same financial year; or 40% if the project is commissioned before 31 March of the same financial year.
- [Generation Based Incentive \(GBI\) scheme](#) for grid interactive wind power projects -a GBI of Rs 0.50 per kWh as introduced in 2009
 - Concession on import duty on specified wind turbine component
 - 10 year income tax holiday for wind power generation project
 - 100% exemption from excise duty on certain wind turbine component
 - Wheeling, banking and third party sales, buy–back facility by state
 - Guaranteed market through a specified renewable portfolio standard in some states, as decided by the state electricity regulator
 - Reduced wheeling charges as compared to conventional energy
 - 100% FDI investment allowed in renewable energy generation project
 - Special incentives provided for promotion of exports from India for various renewable energy technologies under renewable sector specific Special Economic Zones (SEZ)