Unit 4:- Wind Energy

Syllabus…Unit 4

- **Wind Energy:** Wind characteristics, resource assessment, horizontal and vertical axis wind turbines, electricity generation and water pumping, Micro/Mini hydro power system, water pumping and conversion to electricity, hydraulic pump.

Books …

- Gilbert M. Masters, *Renewable and Efficient Electrical Power Systems*, Wiley - IEEE
Press, August 2004.
- Godfrey Boyle, *Renewable Energy*, Third edition, Oxford University Press, 2012.
- Chetan Singh Solanki, *Solar Photovoltaics-Fundamentals, Technologies and Applications*, PHI Third Edition, 2015.

Supplementary Reading:

- D.P.Kothari, K.C.Singal, Rakesh Rajan, *Renewable Energy Sources and Emerging Technologies*, PHI Second Edition, 2011.

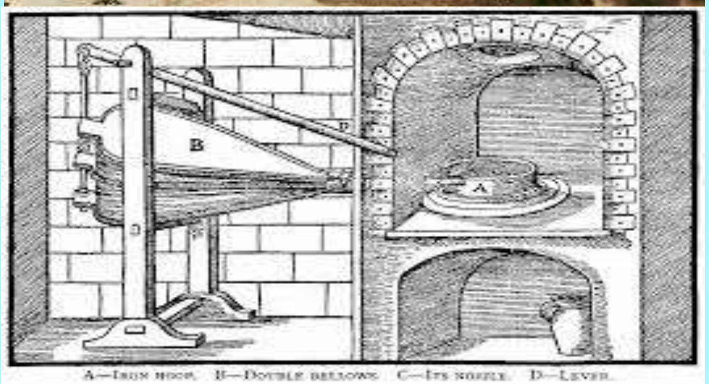
Lecture 1

- Wind Energy Sailing
- Wind Energy Furnace, Bellows & Kites
- Wind Energy Windmills
- Wind Turbine History
- Wind Energy History
- Wind Electricity History
- Brief History
- Wind Energy Time Line
- Brief History to Modern Era
- OPEC Crises 1970-1973
- Modern Era
- Wind Energy Statistics as per IRENA(2019)

Wind Energy Sailing

- As early as about 4000 B.C., the ancient Chinese were the first to attach sails to their primitive rafts
- Approximately at 3400 BC, the ancient Egyptians launched their first sailing vessels initially to sail on the Nile River, and later along the coasts of the Mediterranean
- Around 1250 BC, Egyptians built fairly sophisticated ships to sail on the Red Sea
- The wind-powered ships had dominated water transport for a long time until the invention of steam engines in the 19th century

Wind Energy Furnace, Bellows & Kites



- About 300 BC, ancient Sinhalese had taken advantage of the strong monsoon winds to provide furnaces with sufficient air for raising the temperatures inside furnaces in excess of 1100°C in iron smelting processes. This technique was capable of producing high-carbon steel
- The double acting piston bellows was invented in China and was widely used in metallurgy in the fourth century BC
- Kites were invented in China as early as the fifth or fourth centuries BC

Wind Energy Windmills

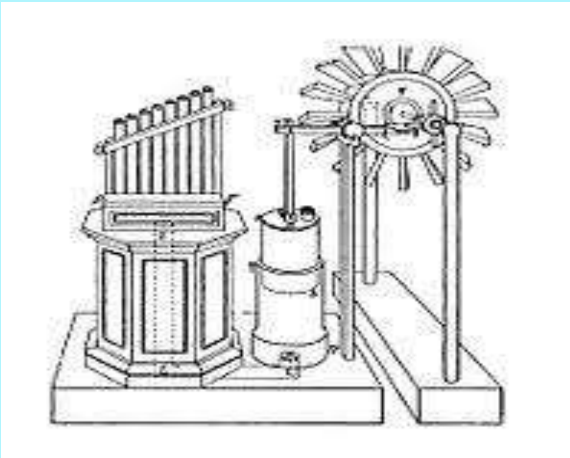
- China has long history of using windmills. The unearthed mural paintings from the tombs of the late Eastern Han Dynasty (25–220 AD) at Sandaohao, Liaoyang City, have shown the exquisite images of windmills, evidencing the use of windmills in China for at least approximately 1800 years
- The practical vertical axis windmills were built in Sistan (Eastern Persia) for grain grinding and water pumping, as recorded by a Persian geographer in the ninth century

Practical Vertical Axis Windmills Were Built In Sistan (Eastern Persia)

Wind Turbine History

Charles Brush
(1887-1888, Cleveland, Ohio)
1st Automatically Operating
Wind Turbine Generator
12kW, 17m Rotor Diameter
Ran for 20 Years To Charge
Batteries in Mansion Cellar
www.windpower.org/en/pictures/brush.htm

Wind Energy History



- In 1st Century A.D. Hero of Alexandria created wind driven wheel
- In 7th to 9th century wind mills were used in Sistan Region of Iran

- In 1000 A.D. wind mills were used for pumping sea water to make salt in China and Sicily.

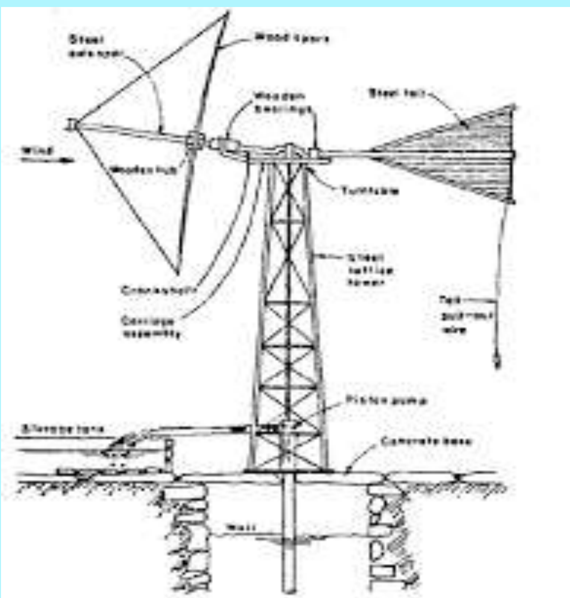


Figure 6. Greek sail rotor water pump

- In 1180 vertical wind mills were used in Europe for grinding flour.
- **1st Known wind turbine was built in 1887in Scotland by Prof. James Blyth for charge accumulators to power lighting**

Wind Electricity History



- In 1st electricity generating turbine in 1891.
- In 1st electricity power plant in 1895 at village Askov.
- 2500 windmills with combined 30MW used for grinding in 1900.
- 1st MW size single wind turbine was connected to local grid in 1941 blade size was 76 feet
- Now over 7000 wind turbines produces 6.5GW
- Expected 20 GW in 2020…

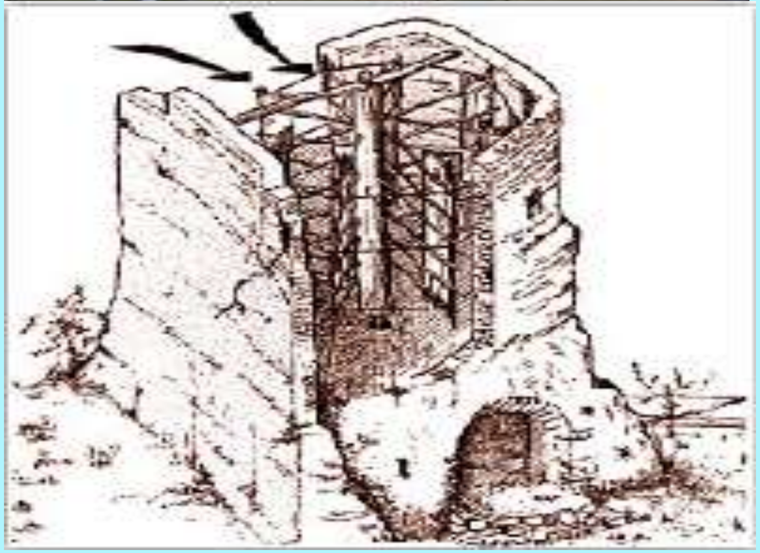
Brief History

1888: Charles Brush builds first large-size wind electricity generation turbine (17 m diameter wind rose configuration, 12 kW generator)

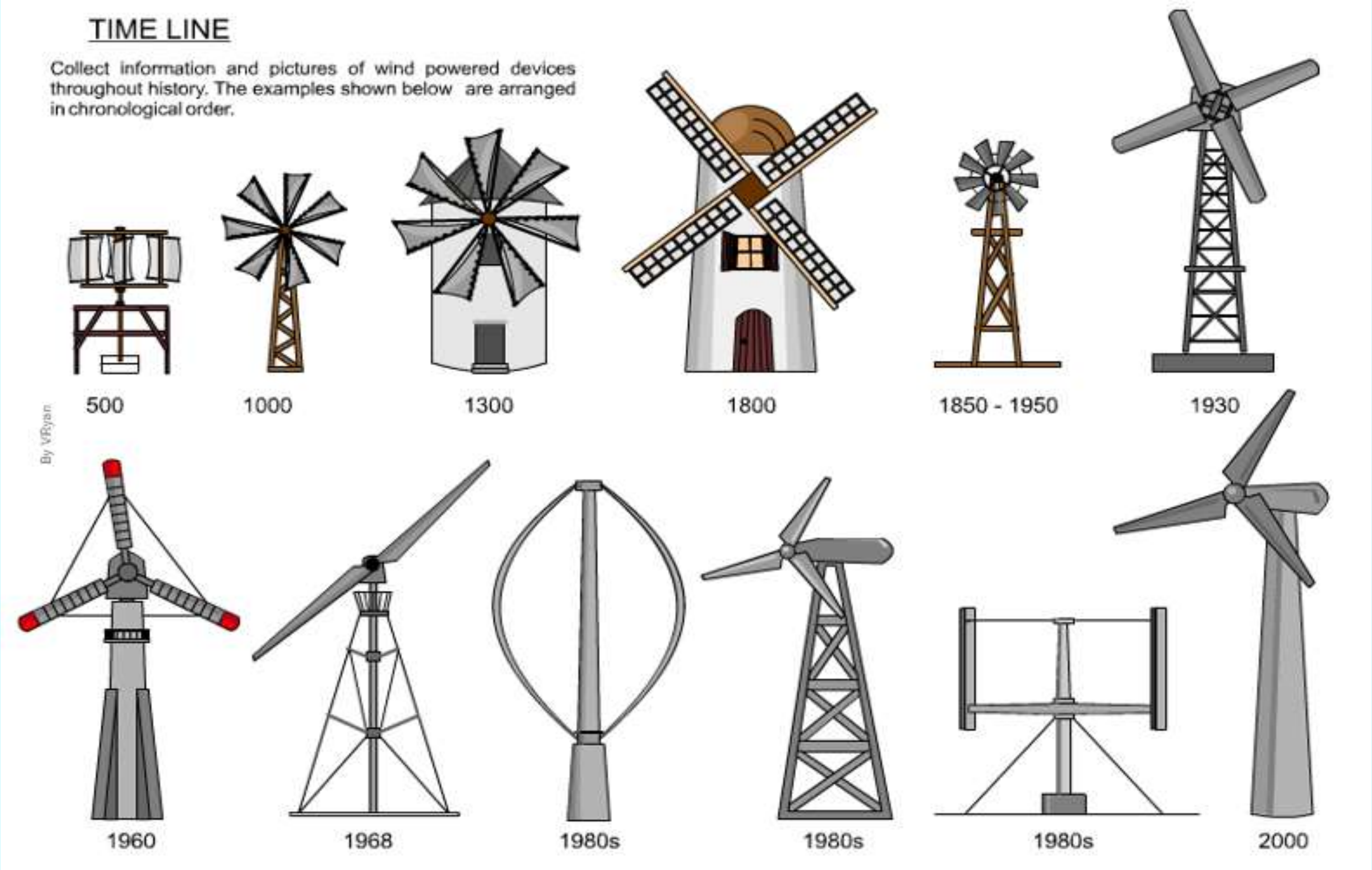
1890s: Lewis Electric Company of New York sells generators to retro-fit onto existing wind mills

1920s-1950s: Propeller-type 2 & 3-blade horizontal-axis **wind electricity conversion systems** (WECS)

1940s – 1960s: Rural Electrification in US and Europe leads to decline in WECS use



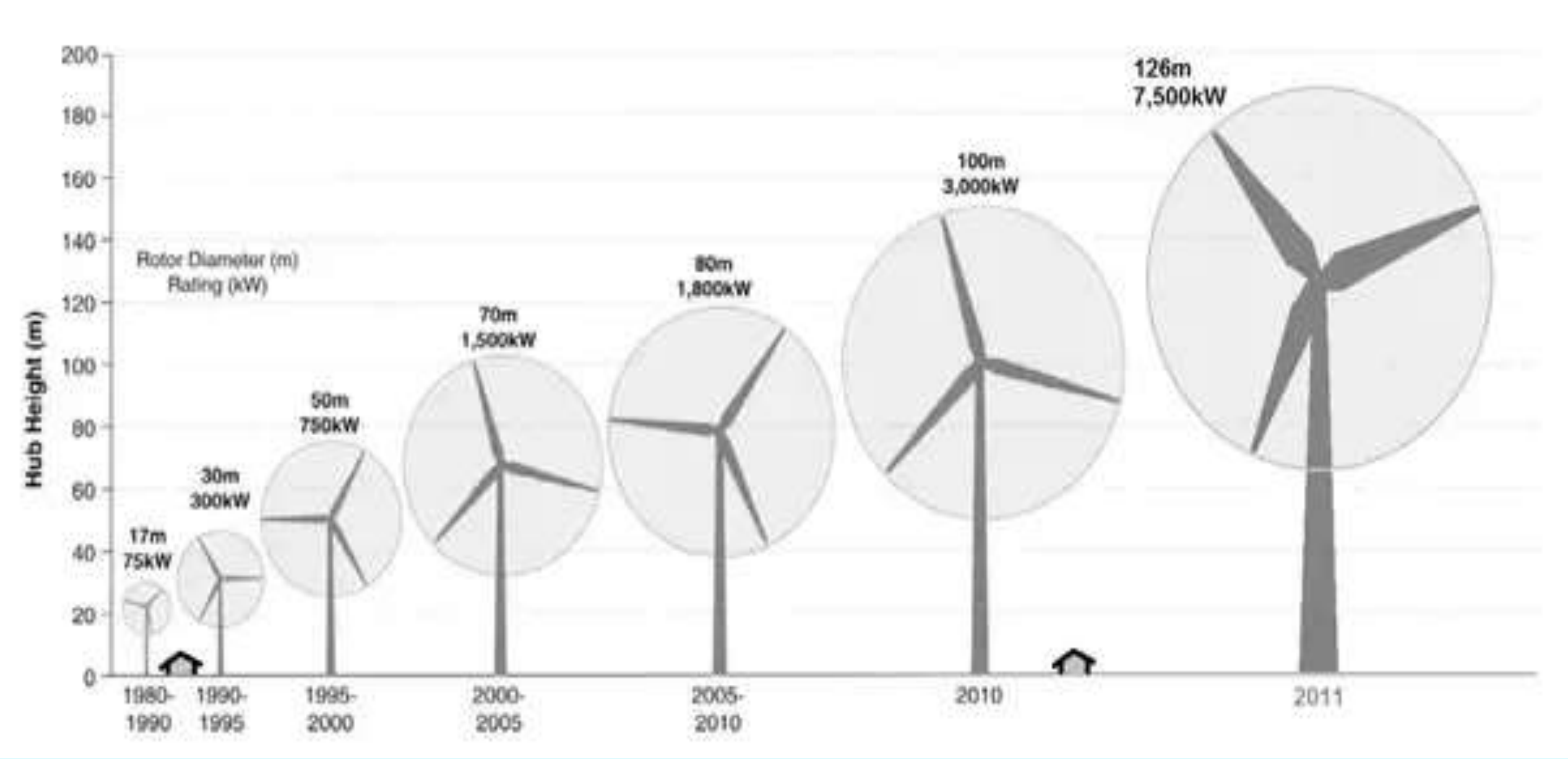
Wind Energy Time Line



Brief History to Modern Era

Key attributes of this period:

- Scale increase
- Commercialization
- Competitiveness
- Grid integration



Brief History to Modern Era

Catalyst for progress of wind energy: OPEC Crisis (1970s)

- Economics
- Energy independence
- Environmental benefits

OPEC Crises 1970-1973

1970 Oil Crisis

From 1970 the Organization of Oil Exporting Countries (OPEC) had steadily been expanding its share in the market, by 1973 OPEC was supplying 56% of the world's oil, up from 47% in 1965

1973 Oil Crisis...

Began on 17th October, 1973 when OPEC announced that they would not ship oil to US, European & Dutch Nations.

Netherlands supplied arms & Americans used Dutch airfields to supply guns.

The Arab oil embargo.

Price increase to reduce demand to the new lower level of supply.

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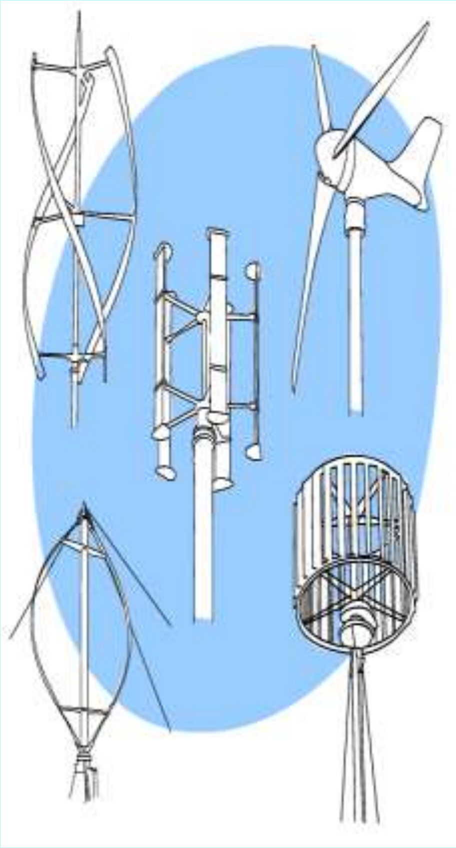
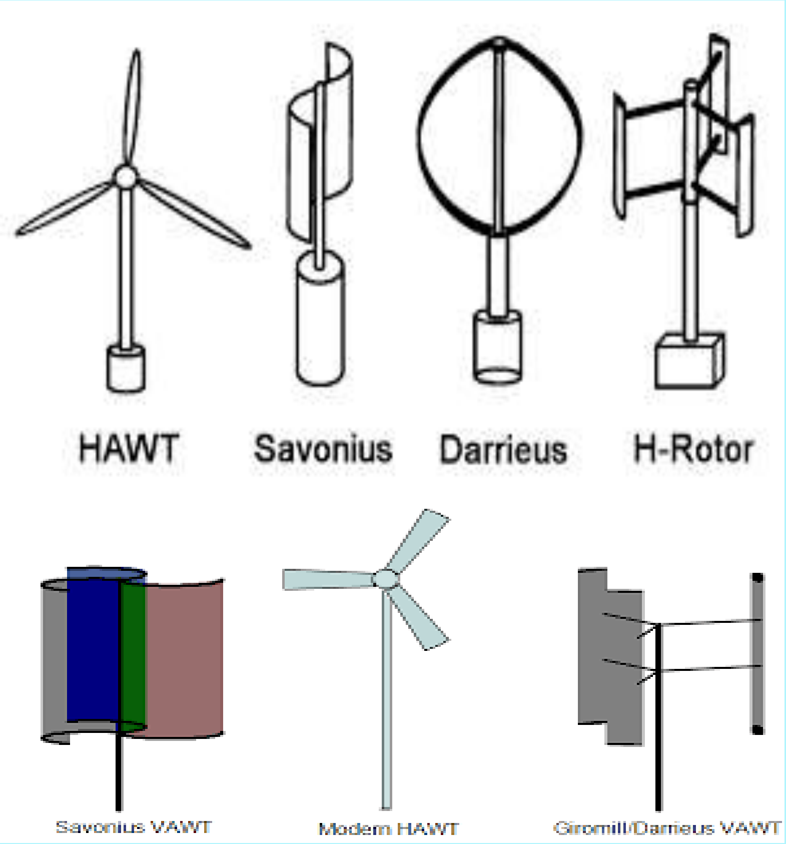
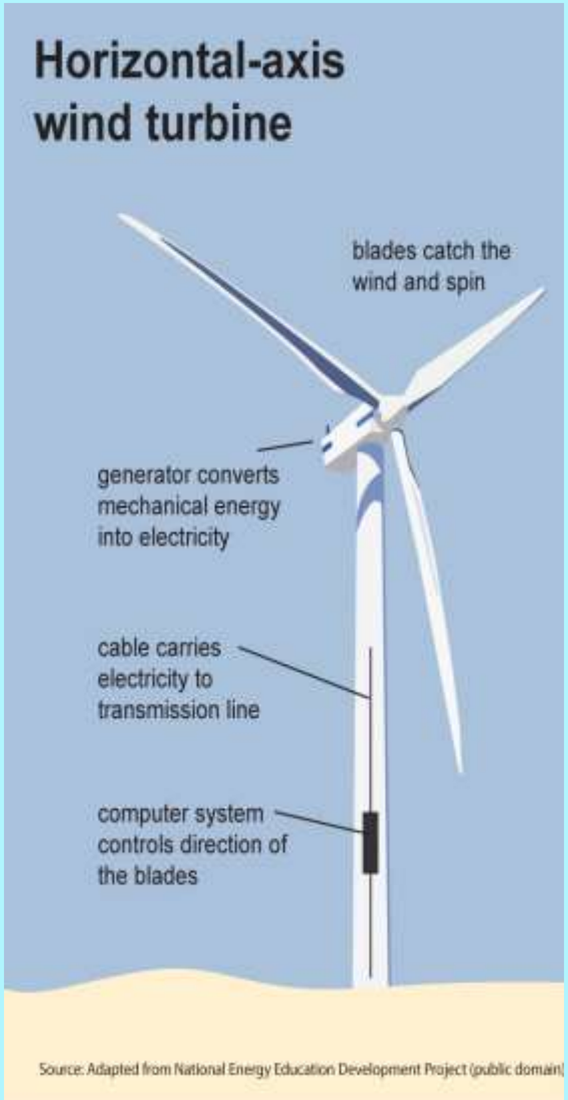
Modern Era

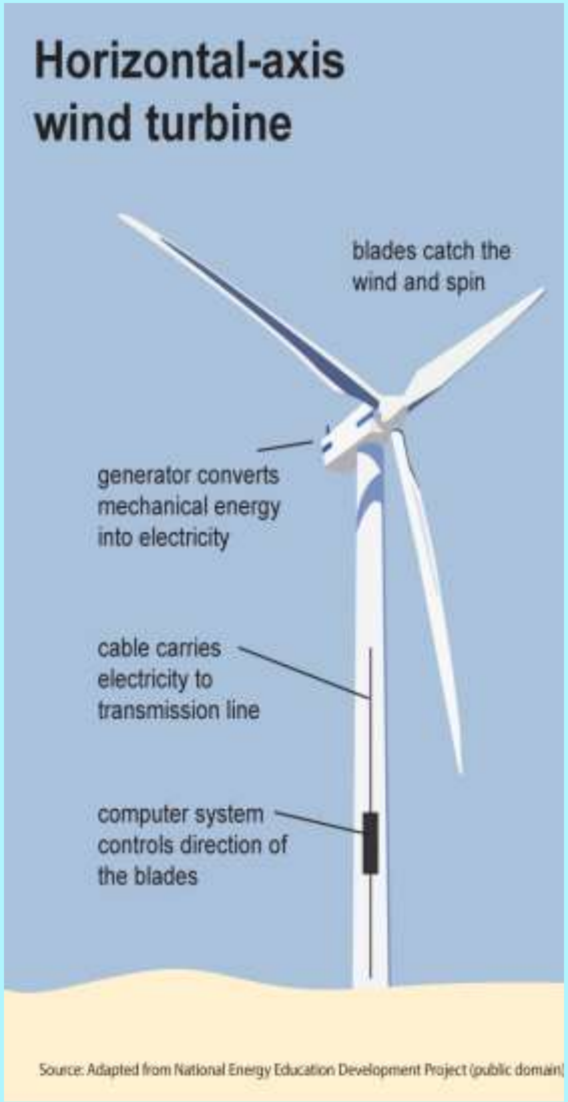
Turbine Standardization:
3-blade Upwind
Horizontal-Axis







Wind Energy Statistics as per IRENA(2019)



IRENA (International Renewable Energy Agency)

Decarbonisation Of The Energy Sector And The Reduction Of Carbon Emissions To Limit Climate Change Is At The Heart Of The International Renewable Energy Agency (Irena)'s Energy Transformation Roadmaps.

This Report Outlines The Role Of Wind Power In The Transformation Of The Global Energy System Based On Irena's Climate-resilient Pathway (Remap Case),

Wind Energy Statistics as per IRENA(2019)

IRENA Key Findings

- Deployment of wind power when coupled with deep electrification would contribute to more than one quarter of the total emissions reductions needed (nearly 6.3 Giga tonnes of carbon dioxide (Gt CO_2) annually) in 2050.
- Global cumulative installed capacity of *Onshore* wind power by 2030 to 1 787 GW and by 2050 to 5 044 GW compared to installed capacity in 2018 to 542 GW
- For offshore wind power, the global cumulative installed capacity would increase almost ten-fold by 2030 to 228 GW and substantially towards 2050, with total offshore installation nearing 1 000 GW by 2050

Wind Energy Statistics as per IRENA(2019)

IRENA Key Findings

- Asia (mostly China) would continue to dominate the onshore wind power industry, with more than 50% of global installations by 2050, followed by North America (23%) and Europe (10%)
- For offshore wind, Asia would take the lead in the coming decades with more than 60% of global installations by 2050, followed by Europe (22%) and North America (16%).
- Increase in wind turbine size for onshore applications is set to continue, from an average of 2.6 megawatts (MW) in 2018 to 4 to 5 MW for turbines commissioned by 2025
- Offshore applications, the largest turbine size of around 9.5 MW to day will become 12 MW in 2025 and Research and development will likely lead to a potential to increase this to 15 to 20 MW in a decade or two.

Wind Energy Statistics as per IRENA(2019)

IRENA Key Findings

- improved wind turbine technologies, deployment of higher hub heights and longer blades with larger swept areas leads to increased capacity factors for a given wind resource.
- For onshore wind plants, global weighted average capacity factors would increase from 34% in 2018 to a range of 30% to 55% in 2030 and 32% to 58% in 2050. For offshore wind farms, even higher progress would be achieved, with capacity factors in the range of 36% to 58% in 2030 and 43% to 60% in 2050, compared to an average of 43% in 2018.

Wind Energy Statistics as per IRENA(2019)

CO$_2$ EMISSIONS (ENERGY-RELATED) AND REDUCTION POTENTIAL BY WIND POWER

	2010	2018	2030	2050	ON/OFF TRACK
Energy-related CO$_2$ emissions under current plans and planned policies (Reference Case) (Gt CO$_2$/yr)	29.7	34.5	35	33.1	
Energy-related CO$_2$ emissions under IRENA's climate resilient pathway (REmap Case) (Gt CO$_2$/yr)	29.7	34.5	24.9	9.8	Off track
Avoided emissions due to accelerated deployment of wind power coupled with deep electrification (Gt CO$_2$/yr)				6.3	

Wind Energy Statistics as per IRENA(2019)

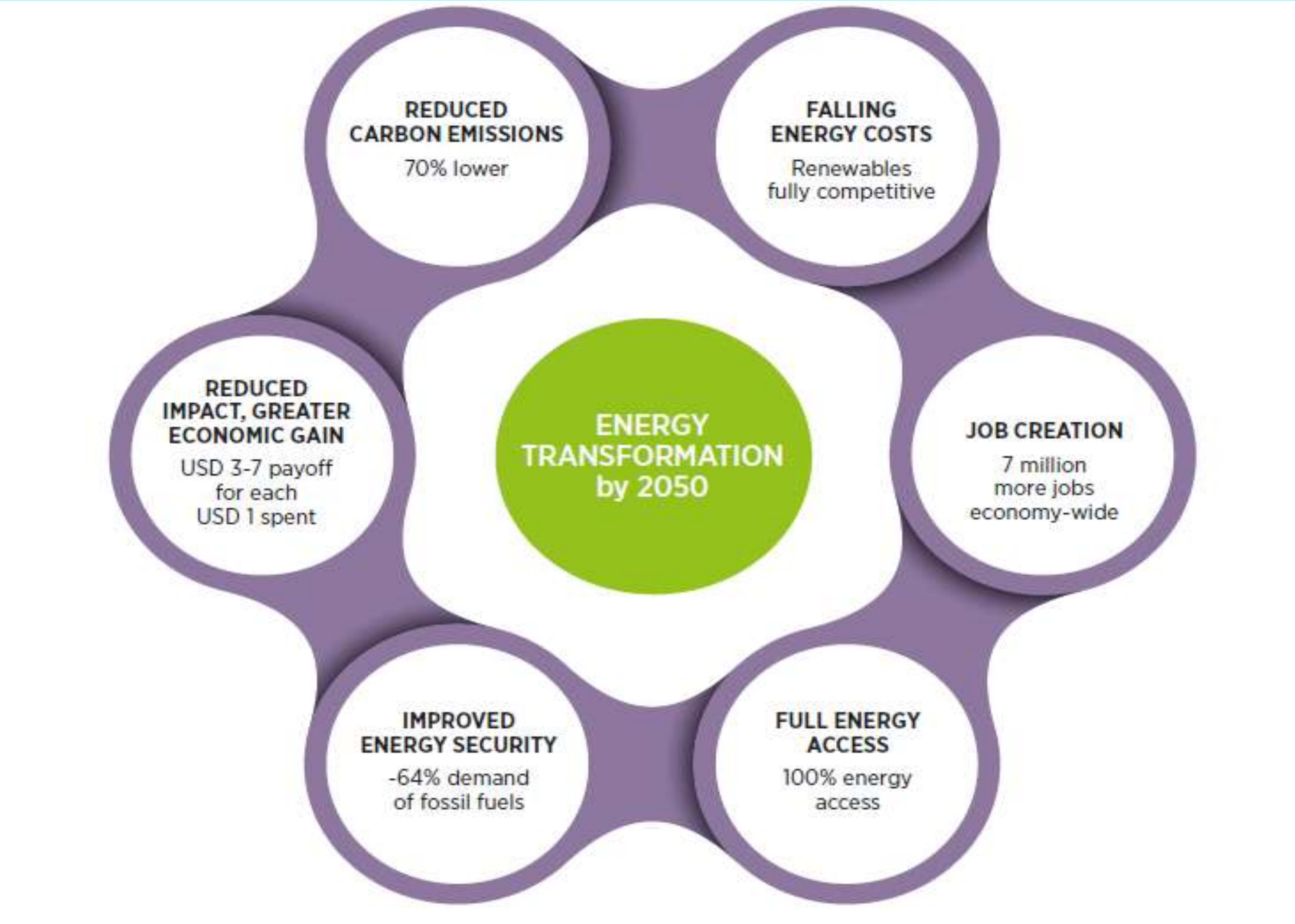
	2010	2018	2030	2050	ON/OFF TRACK
WIND POWER IN TOTAL GENERATION MIX					
Onshore and offshore wind generation share (%)	1.7%	6%	21%	35%	Progress
TOTAL INSTALLED CAPACITY					
Onshore wind (GW)	178	542	1 787	5 044	Off track
Offshore wind (GW)	3	23	228	1 000	Progress

Wind Energy Statistics as per IRENA(2019)

CAPACITY FACTORS

	2010	2018	2030	2050	ON/OFF TRACK
Onshore wind (%)	27 (average)	34 (average)	30–55 (average range)	32–58 (average range)	Progress
Offshore wind (%)	38 (average)	43 (average)	36–58 (average range)	43–60 (average range)	On track

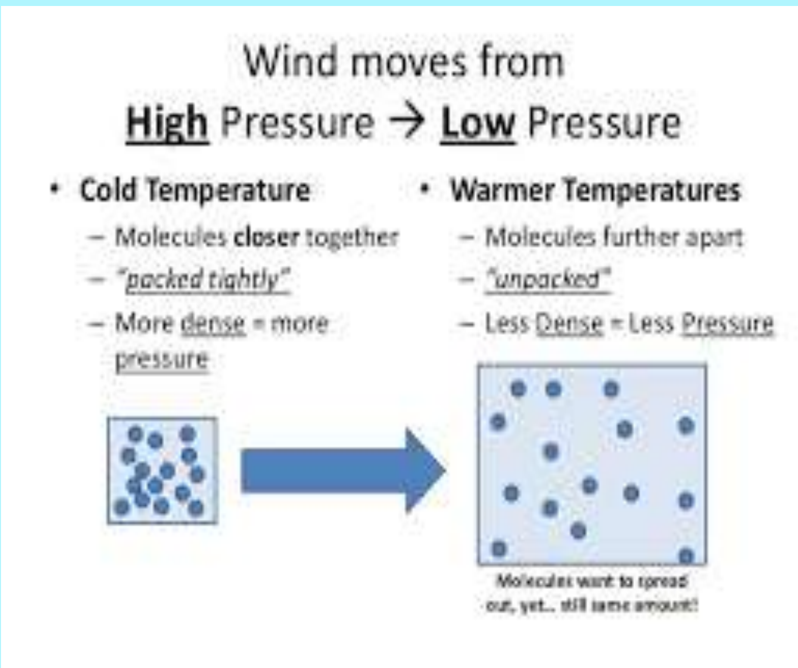
Wind Energy Statistics as per IRENA(2019)



Origin of Wind

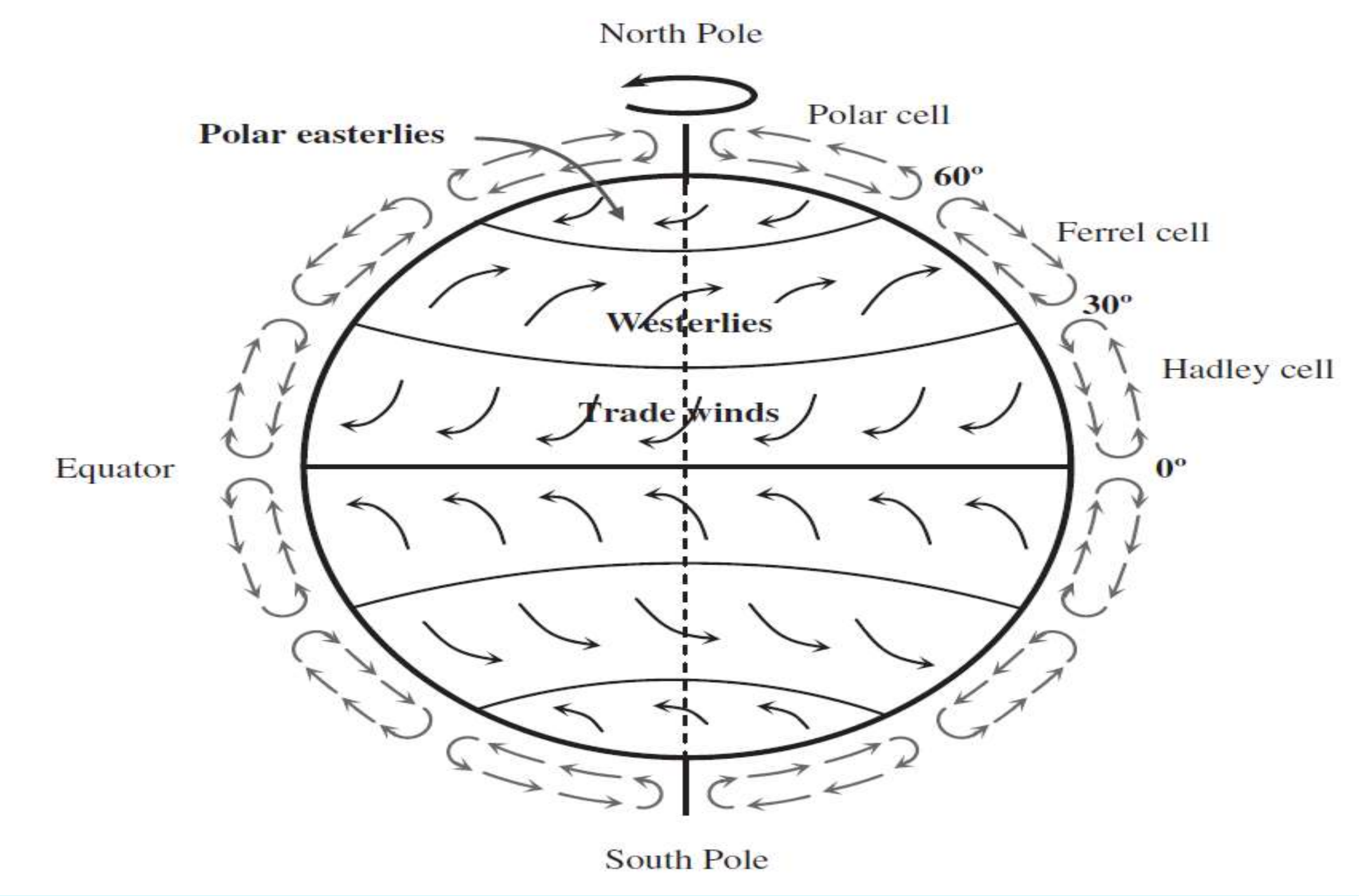
- Solar energy is produced by the nuclear fusion of hydrogen (H) into helium (He) in its core. It creates heat and electromagnetic radiation streams in all directions.
- Estimated total solar power received by the earth is approximately 1.8×10^{11} MW. Out of only 2% (i.e. 3.6×10^{9} MW) is converted into wind energy and about 35% of wind energy is dissipated within the earth's surface
- Therefore, the wind power that can be converted into an energy is approximately 1.26×10^{9} MW.
- This is about 20 times the present global energy consumption,
- Hence, wind energy in principle could meet entire energy needs of the world.

Causes of Wind



- Wind results from the movement of air due to atmospheric pressure gradients.
- Wind flows from regions of higher pressure to regions of lower pressure.
- The larger the atmospheric pressure gradient, the higher the wind speed
- The most important factors for wind generation are
  - ✓ Uneven solar heating
  - ✓ Coriolis force i.e. Effect of the earth's self-rotation
  - ✓ Local geographical conditions

Winds Over Earth Surface



Uneven Heating of Earth Surface

- The equator receives the greatest amount of energy per unit area, with energy dropping off toward the poles
- Due to the spatial uneven heating on the earth, it forms a temperature gradient from the equator to the poles and a pressure gradient from the poles to the equator.
- Hot air with lower air density at the equator rises up to the high atmosphere and moves towards the poles and cold air with higher density flows from the poles towards the equator along the earth's surface.
- The earth's self-rotation induced Coriolis force, the air circulation at each hemisphere forms a single cell, defined as the meridional circulation.

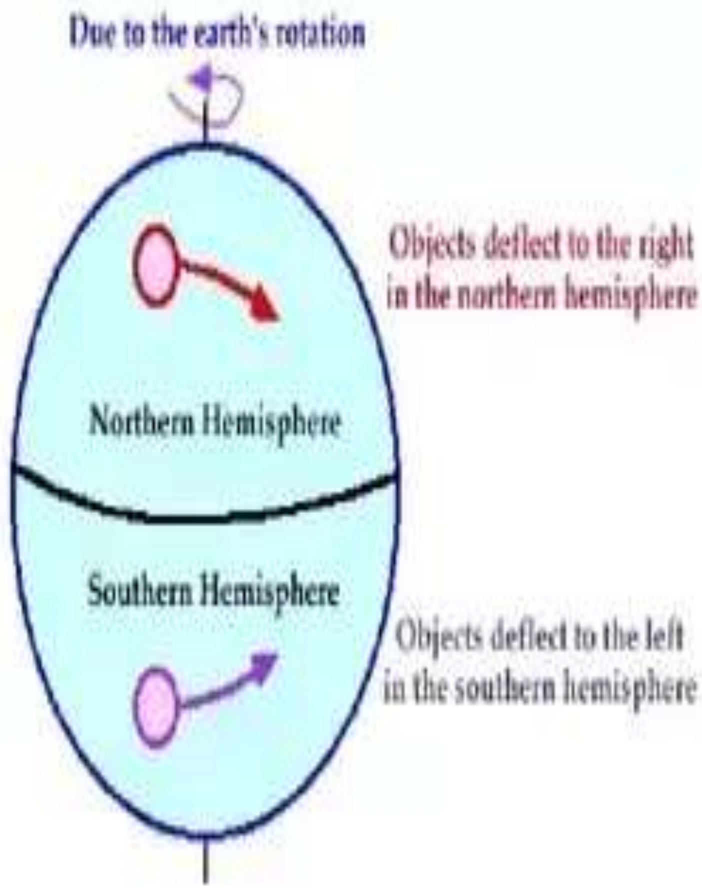
Uneven Heating of Earth Surface

- The earth's self-rotating axis has a tilt of about 23.5° with respect to its ecliptic plane. It is the tilt of the earth's axis during the revolution around the sun that results in cyclic uneven heating, causing the yearly cycle of seasonal weather changes.
- The earth's surface is covered with different types of materials such as vegetation, rock, sand, water, ice/snow, etc. Each of these materials has different reflecting and absorbing rates to solar radiation, leading to high temperature on some areas (e.g. deserts) and low temperature on others (e.g. iced lakes), even at the same latitudes.
- Uneven heating of solar radiation is due to the earth's topographic surface. There are a large number of mountains, valleys, hills, etc. on the earth, resulting in different solar radiation on the sunny and shady sides

Coriolis Effect

Coriolis Effect

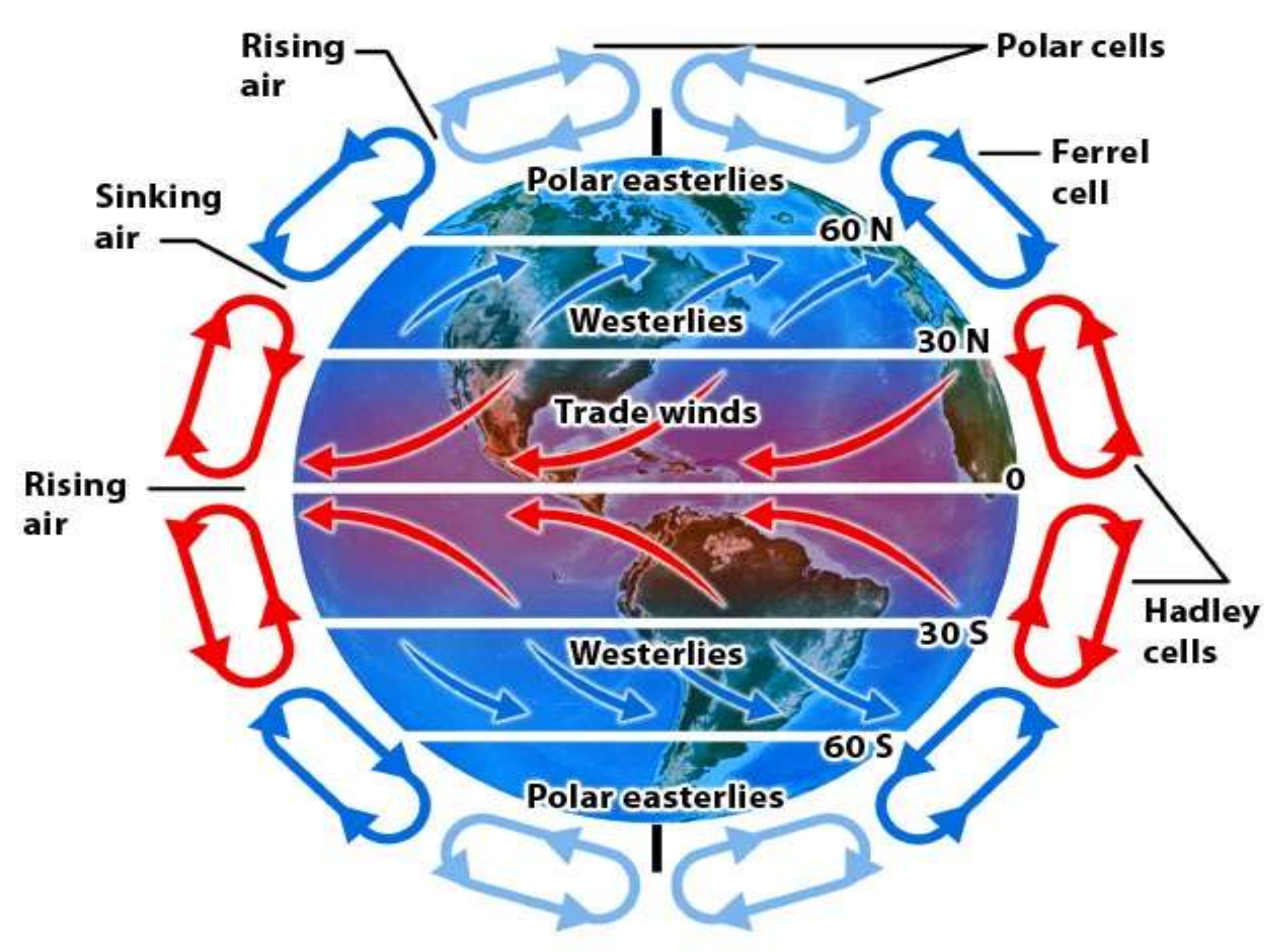
- The rotation of the Earth causes all moving objects in the Northern Hemisphere, including air mass, to deflect to the right and those in the Southern Hemisphere to move to the left.
- This Coriolis effect is absent at the Equator.
- Coriolis Force- prevents a direct simple flow from the Equator to the Poles.
- This is also known as 'Ferrel's Law'.



Coriolis Effect

- The Coriolis force, which is generated from the earth's self-rotation, deflects the direction of atmospheric movements.
- In the north atmosphere wind is deflected to the right and in the south atmosphere to the left
- The Coriolis force depends on the earth's latitude; it is zero at the equator and reaches maximum values at the poles.
- The amount of deflection on wind also depends on the wind speed; slowly blowing wind is deflected only a small amount, while stronger wind deflected more.
- The combination of the pressure gradient due to the uneven solar radiation and the Coriolis force due to the earth's self rotation causes the single meridional cell to break up into three convectional cells in each hemisphere: *Hadley cell*, *Ferrel cell*, and *Polar cell*. Each cell has its own characteristic circulation pattern

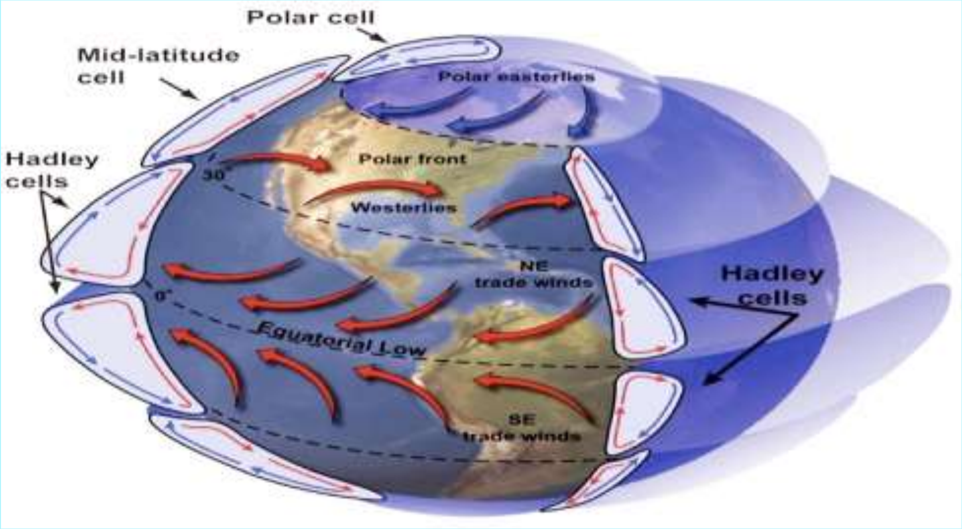
Coriolis Regions



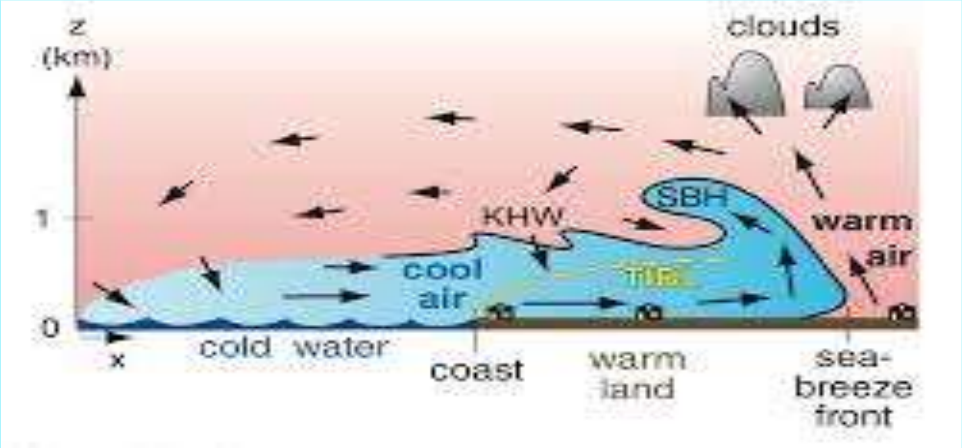
Wind Special Scales

Planetary scale: global circulation, trade winds
Synoptic scale: weather systems cyclones etc.
(It is also known as large scale or cyclonic scale. It is a horizontal length scale of the order of 1000 kilometers or more.)
Mesoscale: local topographic thunder storms, tornados etc.
(It is the study of atmospheric phenomena with typical spatial **scales** between 10 and 1000 km)
Micro scale: urban topography
Chaotic motions dust devils, small localized breezes

Wind Types

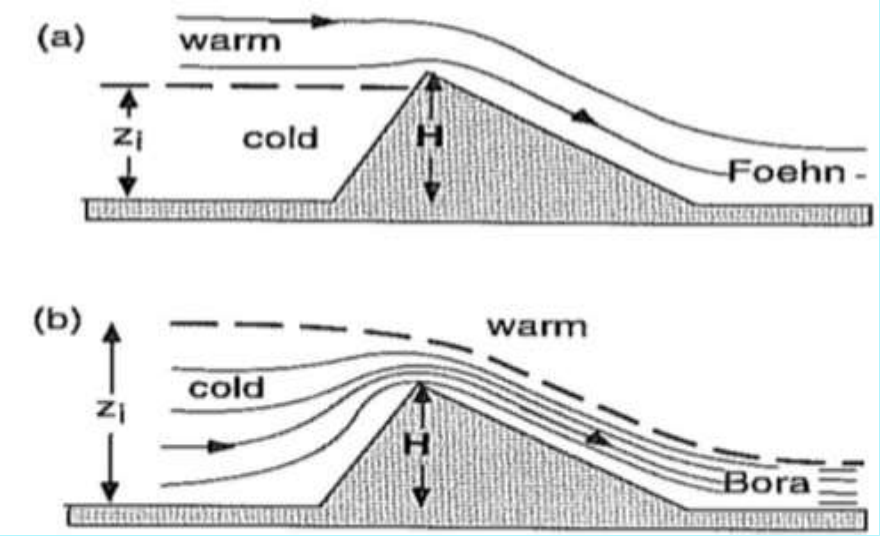


- **Planetary** circulations:
  - ➢ Jet streams
  - ➢ Trade winds
  - ➢ Polar jets



- **Geostrophic** winds
  - ➢ Thermal winds
  - ➢ Gradient winds

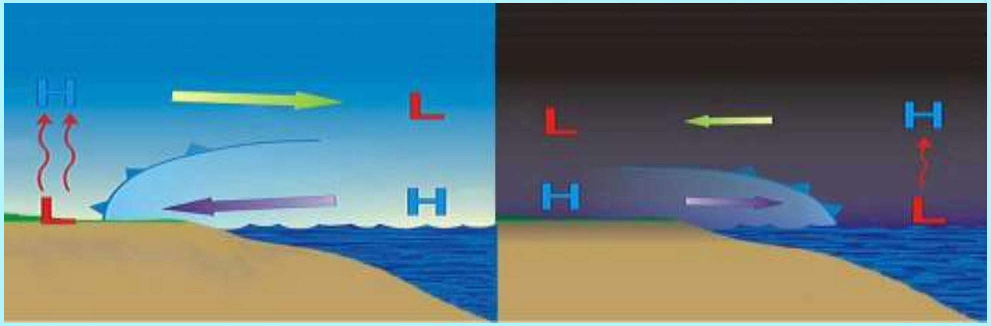
Wind Types

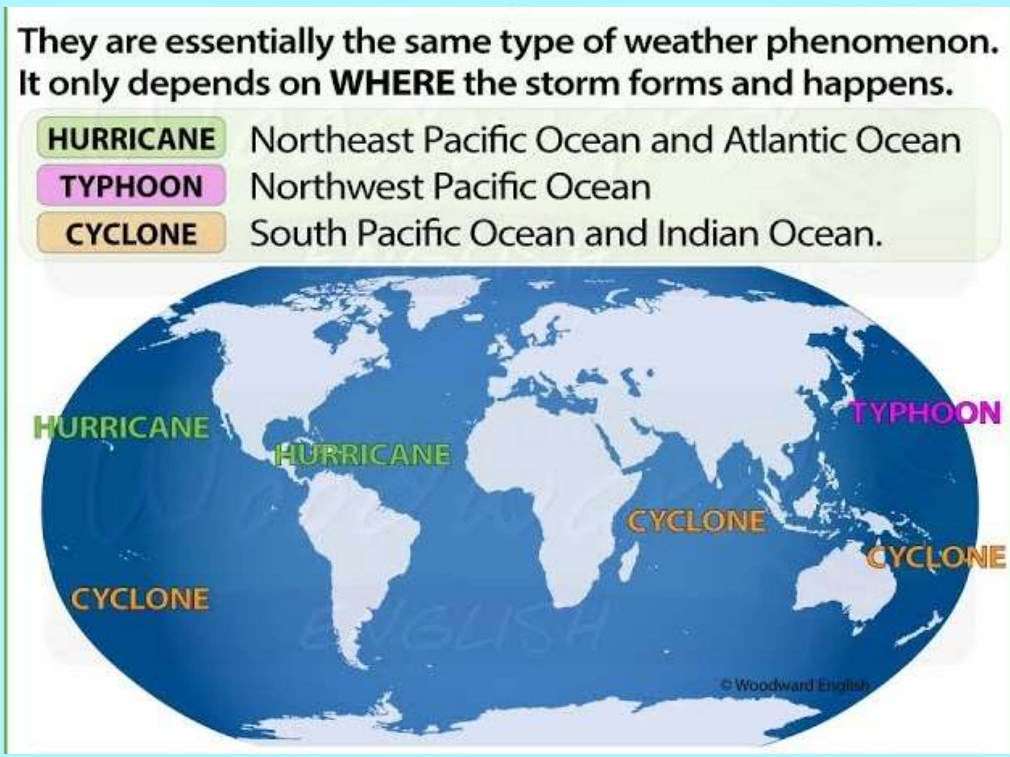


- Katabatic / Anabatic winds – topographic winds

- Bora / Foehn / Chinook – downslope wind storms

Wind Types





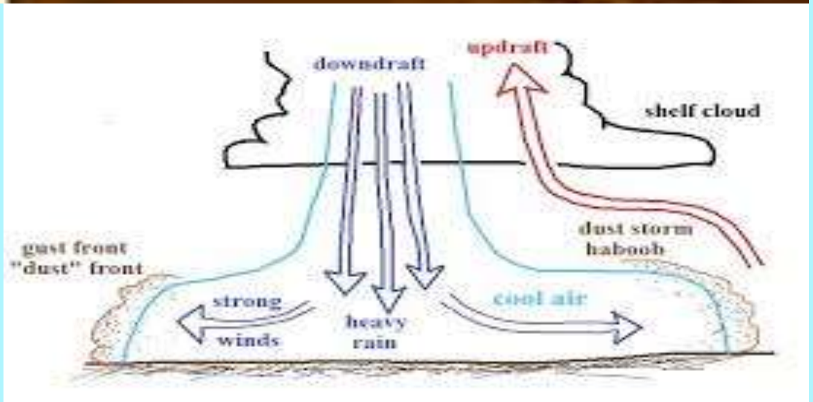
• Sea Breeze / Land Breeze

Convective storms / Downdrafts

• Hurricanes/ Typhoons /Cyclone

Wind Types

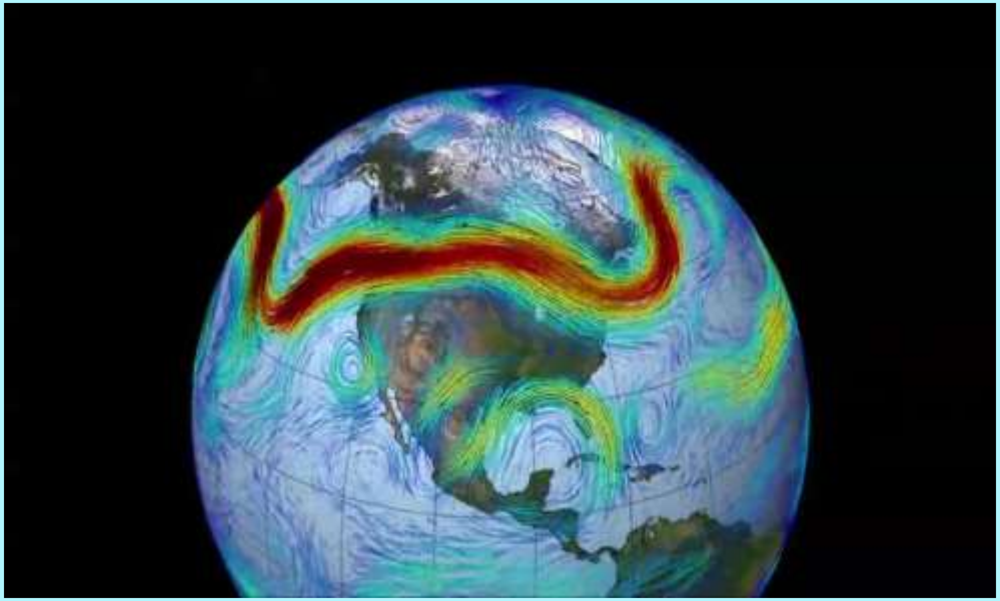
Tornadoes



- Gusts

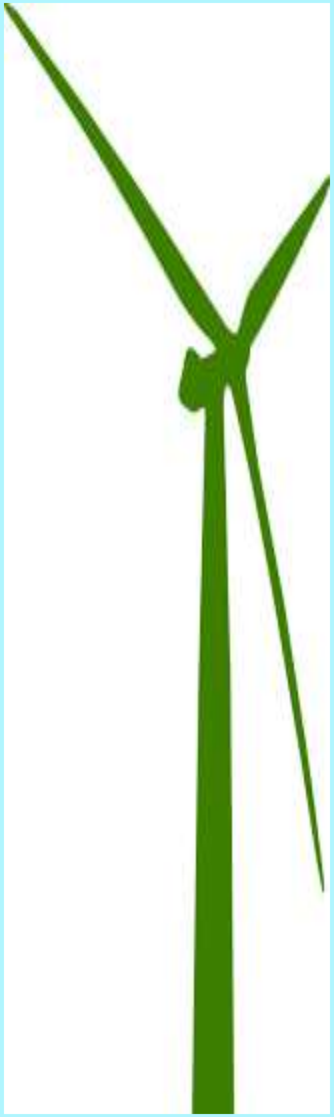
Dust devils / Microbursts

Wind Types



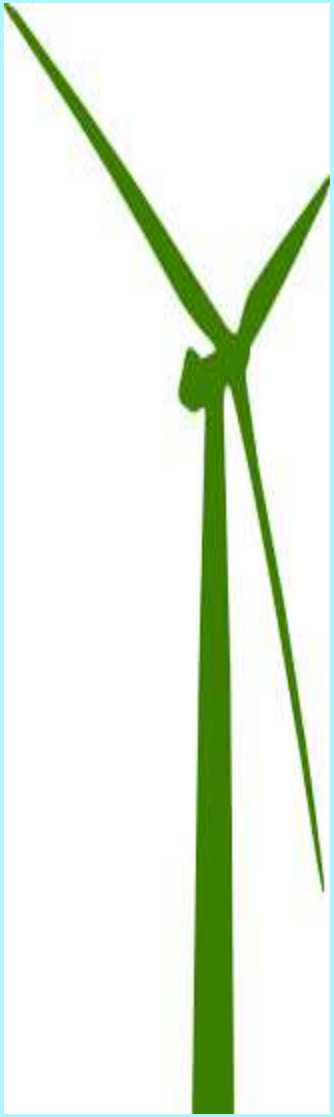
Nocturnal Jets
• Atmospheric Waves

Wind Energy Advantages



1)Wind Energy is an inexhaustible source of energy and is virtually a limitless resource.
2) Energy is generated without polluting environment.
3) This source of energy has tremendous potential to generate energy on large scale.
4) Like solar energy and hydropower, wind power taps a natural physical resource.
5) Windmill generators don’t emit any emissions that can lead to acid rain or greenhouse effect.
6) Wind Energy can be used directly as mechanical energy.
7) In remote areas, wind turbines can be used as great resource to generate energy.

Wind Energy Advantages

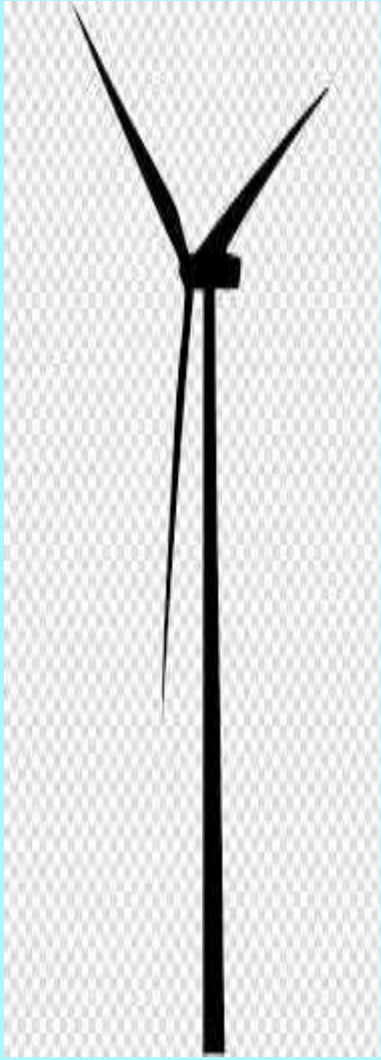


8) In combination with Solar Energy they can be used to provide reliable as well as steady supply of electricity.

9) Land around wind turbines can be used for other uses, e.g. Farming.

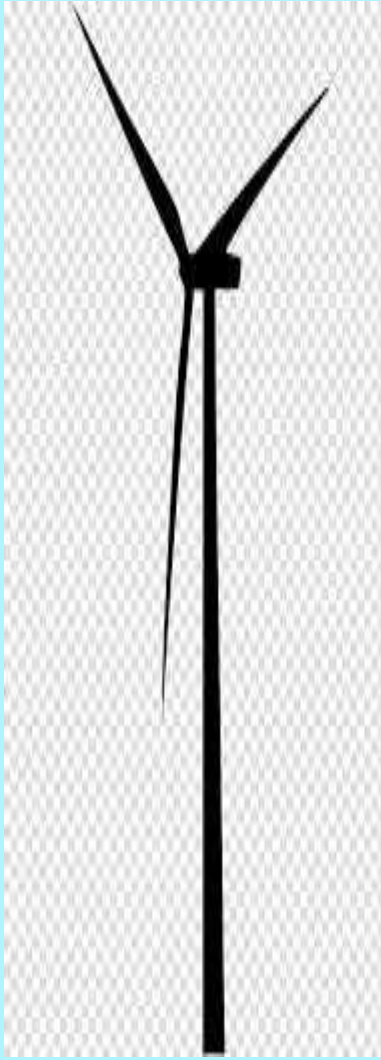
To generate electricity on a large scale, a number of windmills are set up over a large area, called a wind energy farm. Such areas need a wind speed min. of 15kmph.

Wind Energy Disadvantages



1) Wind energy requires expensive storage during peak production time.
2) It is unreliable energy source as winds are uncertain and unpredictable.
3) There is visual and aesthetic impact on region
4) Requires large open areas for setting up wind farms.
5) Noise pollution problem is usually associated with wind mills.
6) Wind energy can be harnessed only in those areas where wind is strong enough and weather is windy for most parts of the year.

Wind Energy Disadvantages



7) Usually places, where wind power set-up is situated, are away from the places where demand of electricity is there. Transmission from such places increases cost of electricity.

8) The average efficiency of wind turbine is very less as compared to fossil fuel power plants. We might require many wind turbines to produce similar impact.

9) It can be a threat to wildlife. Birds do get killed or injured when they fly into turbines.

10) Maintenance cost of wind turbines is high as they have mechanical parts which undergo wear and tear over the time.

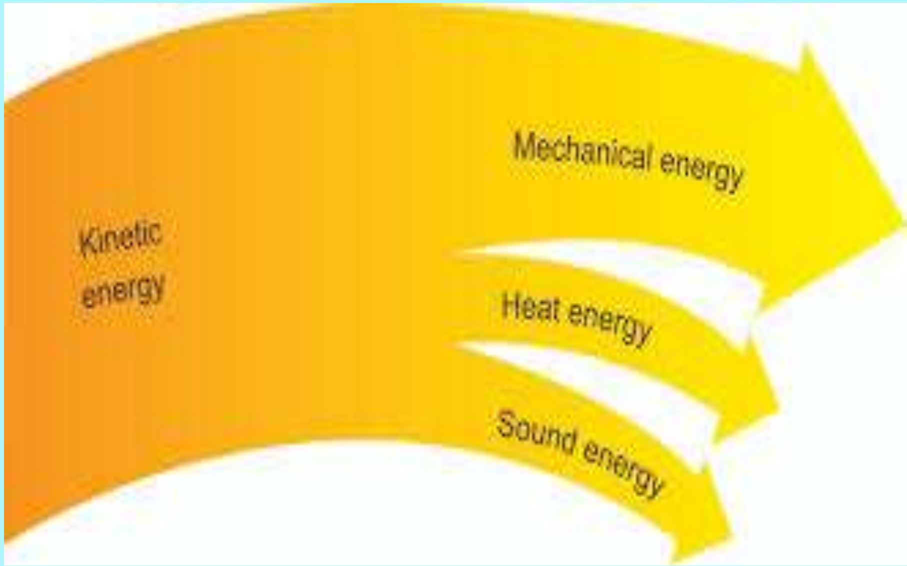
Fundamentals of wind energy

Wind energy is a special form of kinetic energy in air as it flows

- Kinetic energy exists whenever an object of a given mass is in motion with a translational or rotational speed. When air is in motion, the kinetic energy in moving air can be determined as

$$E_k = \frac{1}{2} m \bar{u}^2$$

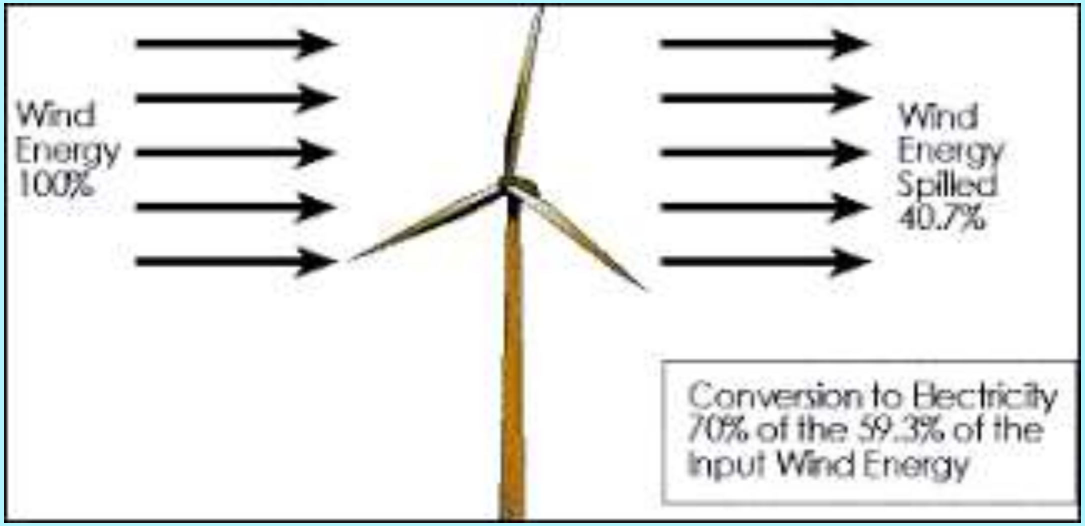
where *m* is the air mass and u^- is the mean wind speed over a suitable time period.



Power of wind energy

The wind power can be obtained by differentiating the kinetic energy in wind with respect to time, i.e.

$$P_w = \frac{dE_k}{dt} = \frac{1}{2}\dot{m}\bar{u}^2$$



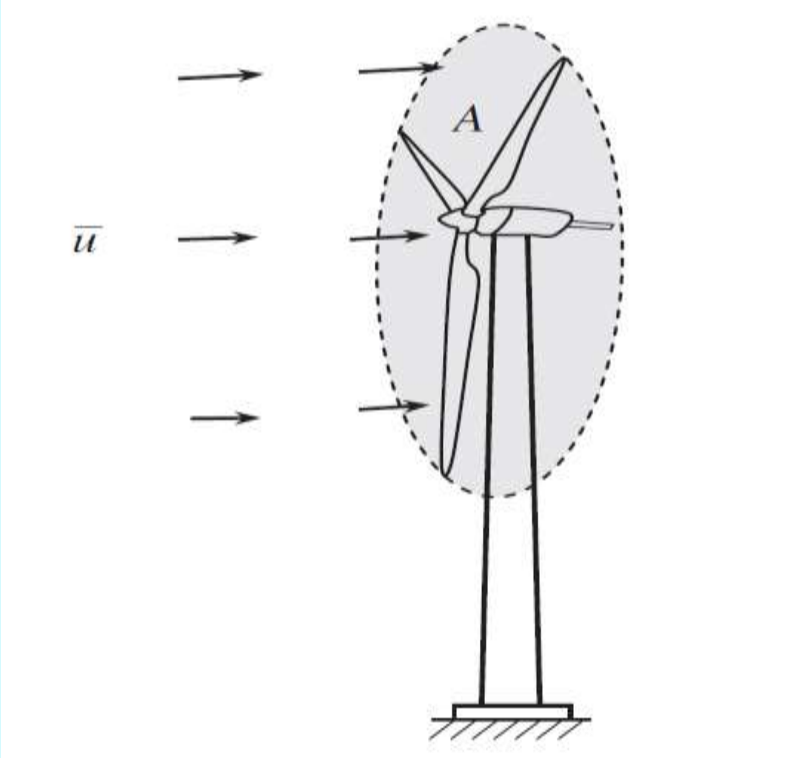
However, only a small portion of wind power can be converted into electrical power.

Wind Mass Flow Rate

However, only a small portion of wind power can be converted into electrical power.

When wind passes through a wind turbine and drives blades to rotate, the corresponding *Wind Mass Flow Rate* is

$$\dot{m} = \rho A \overline{u}$$



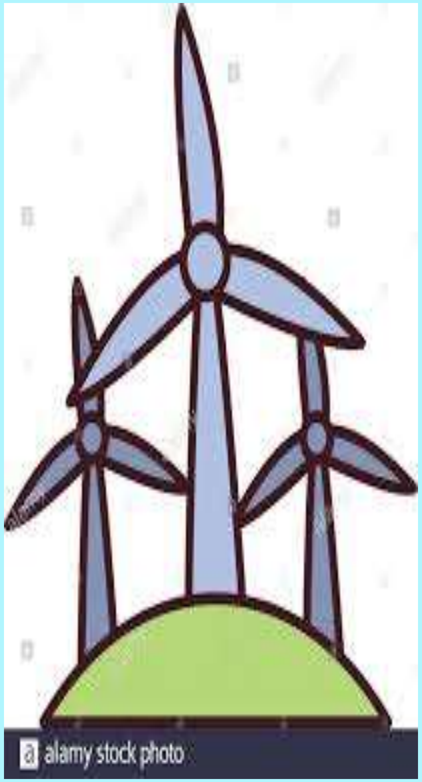
where ρ is the air density and A is the swept area of blades

Wind Power

Substituting above equation in earlier equation, the available power in wind P_w can be expressed a

$$P_w = \frac{1}{2}\rho A\overline{u}^3$$

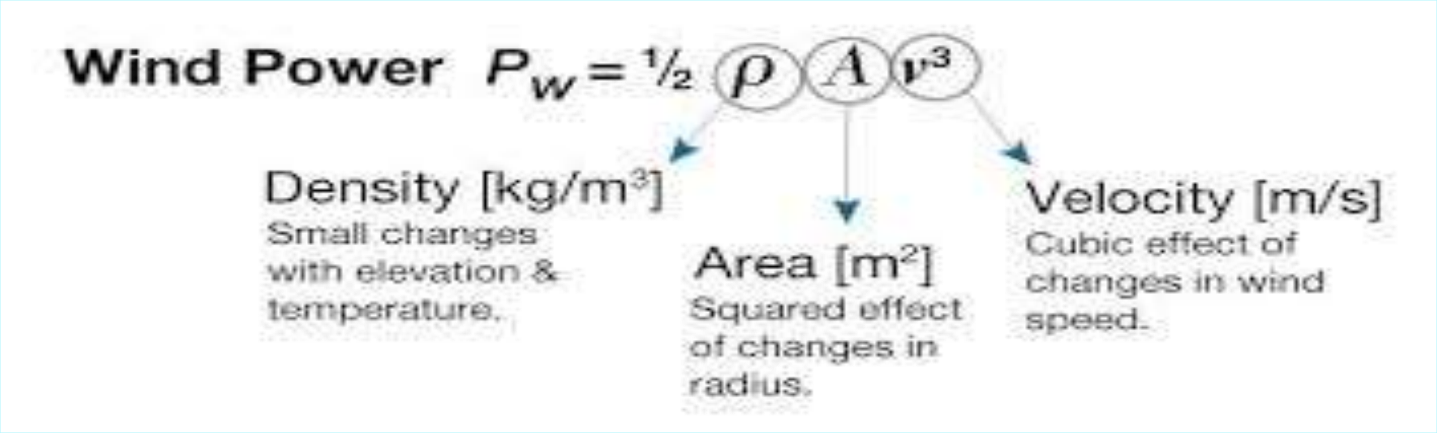
To obtain a higher wind power, it requires a higher wind speed, a longer length of blades for gaining a larger swept area, and a higher air density.



Factors Controlling Power

- Power ~ cube of velocity
- Power ~ air density
- Power ~ rotor swept area A= $\boldsymbol{\pi} r^2$

Because the wind power output is proportional to the cubic power of the mean wind speed, a small variation in wind speed can result in a large change in wind power.



Blade Swept Area

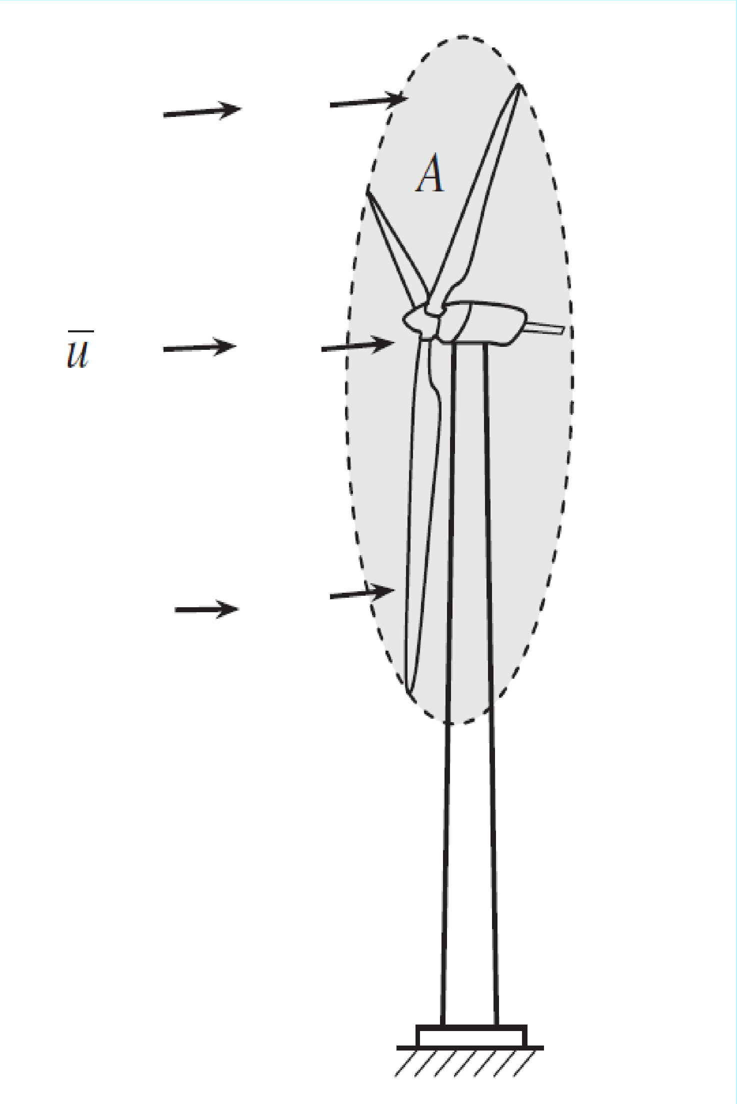
The blade swept area can be calculated from the formula

$$A = \pi\left[(l+r)^2 - r^2\right] = \pi l\,(l+2r)$$

where l is the length of wind blades and r is the radius of the hub.

Thus, by doubling the length of wind blades, the swept area can be increased by the factor up to 4. When $l >> 2\,r$

$$A \approx \pi\, l^2.$$

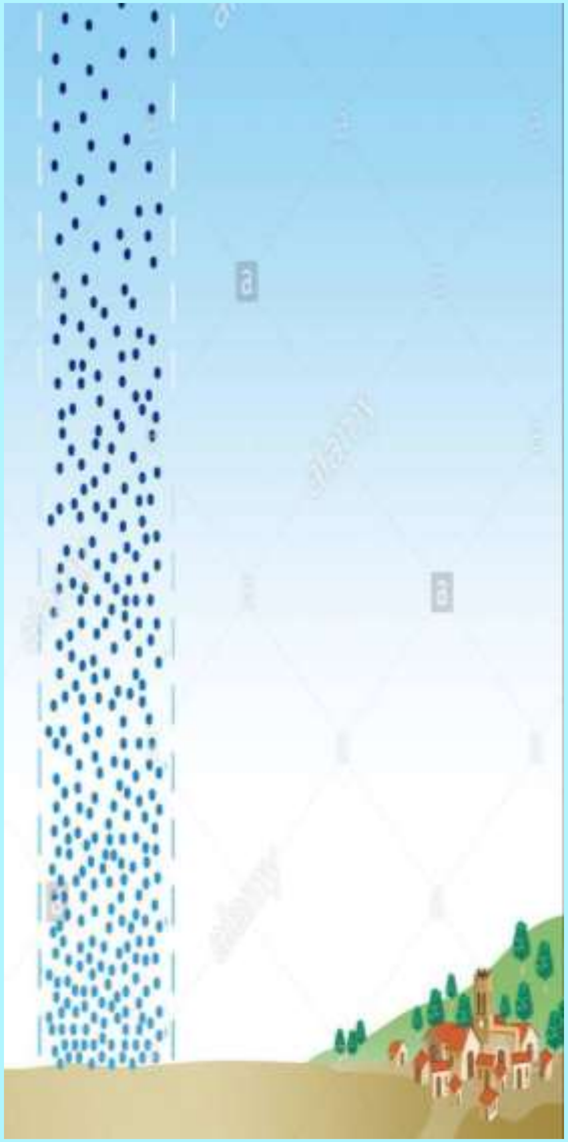


Air Density

Another important parameter that directly affects the wind power generation is the density of air, which can be calculated from the equation of state:

$$\rho = \frac{p}{RT}$$

where p is the local air pressure, R is the gas constant (287 J/kg-K for air), and T is the local air temperature in K.

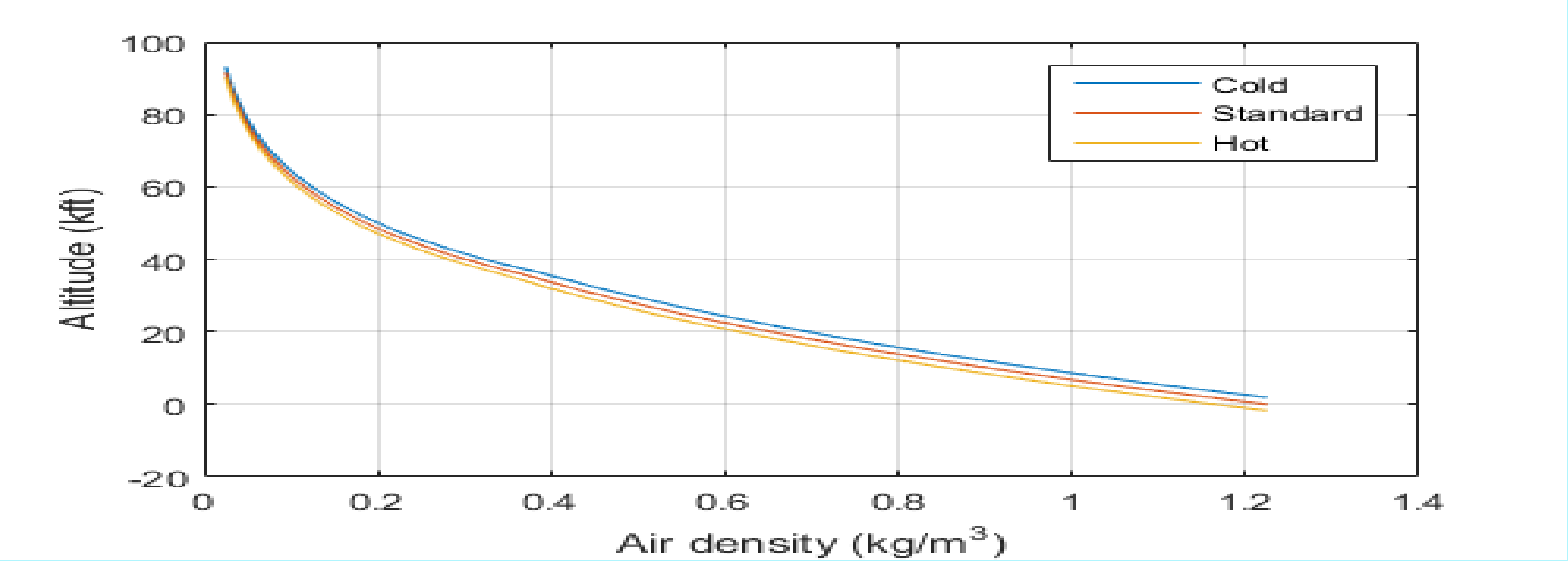


Air Density and Altitude

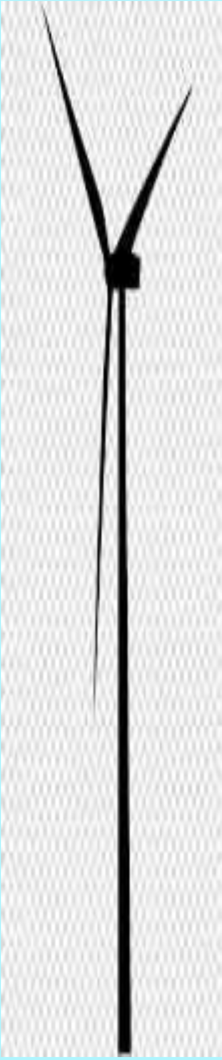
The below equation indicates that the *density of air decreases nonlinearly* with the height above the sea level.

$$\rho = \rho_0 \left(\frac{T}{T_0} \right)^{-(g/cR+1)} = \rho_0 \left(1 + \frac{cz}{T_0} \right)^{-(g/cR+1)}$$

where *p* 0 and *T* 0 are the air pressure, and temperature at the ground and *g* is the acceleration of gravity



Wind Power Density



Wind Power Density is a comprehensive index in evaluating the wind resource at a particular site. It is the available wind power in airflow through a perpendicular cross-sectional unit area in a unit time period.

The classes of wind power density at two standard wind measurement heights are listed in Table

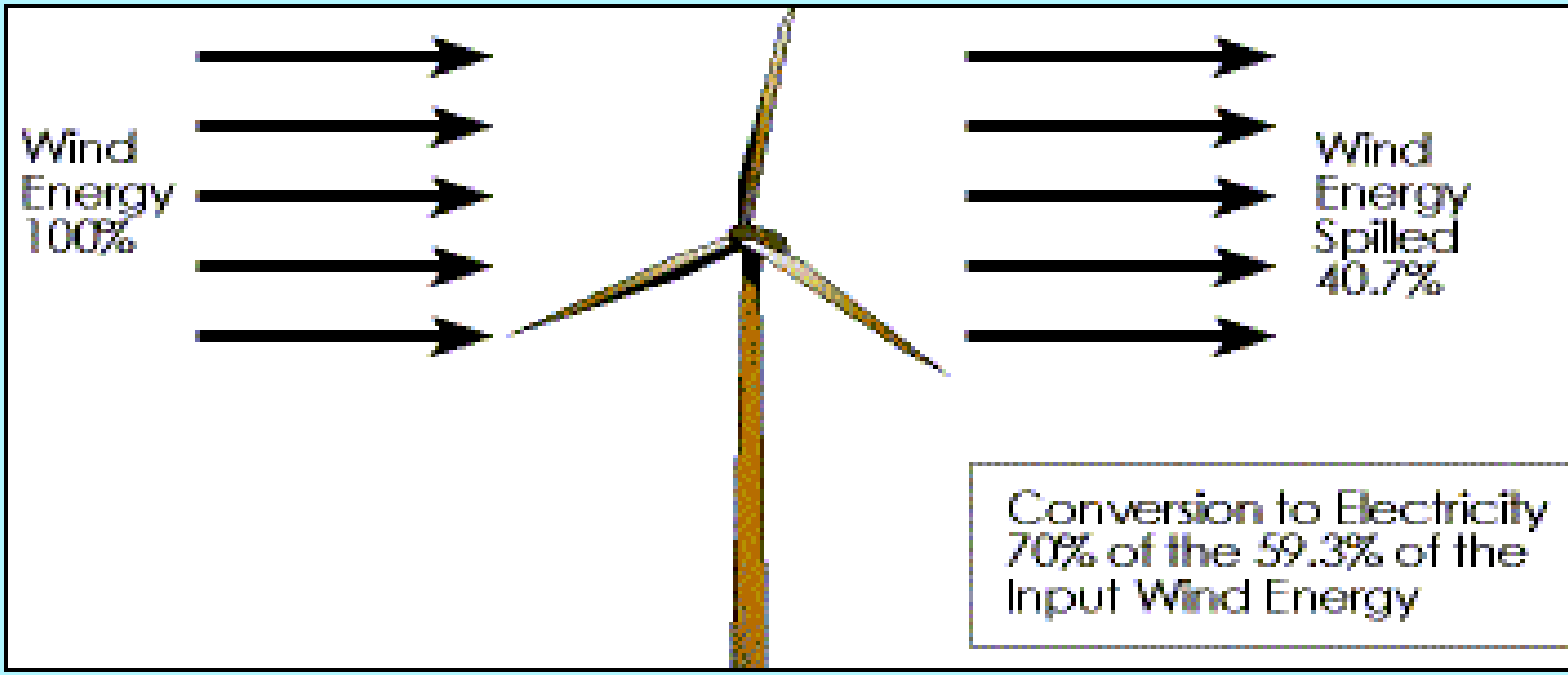
	10 m height		50 m height	
Wind power class	Wind power density (W/m^2)	Mean wind speed (m/s)	Wind power density (W/m^2)	Mean wind speed (m/s)
1	<100	<4.4	<200	<5.6
2	100–150	4.4–5.1	200–300	5.6–6.4
3	150–200	5.1–5.6	300–400	6.4–7.0
4	200–250	5.6–6.0	400–500	7.0–7.5
5	250–300	6.0–6.4	500–600	7.5–8.0
6	300–350	6.4–7.0	600–800	8.0–8.8
7	>400	>7.0	>800	>8.8

Power Coefficient

Power Coefficient, **Cp**, is the ratio of power extracted by the turbine to the total contained in the wind resource

Cp = PT/PW

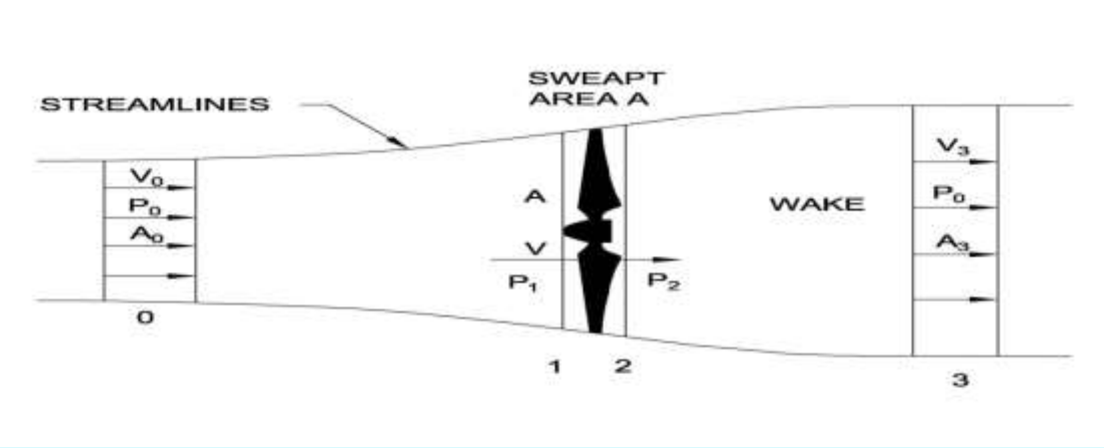
$$\text{Power coefficient } C_p = \frac{P}{\frac{1}{2}\rho A V^3}$$



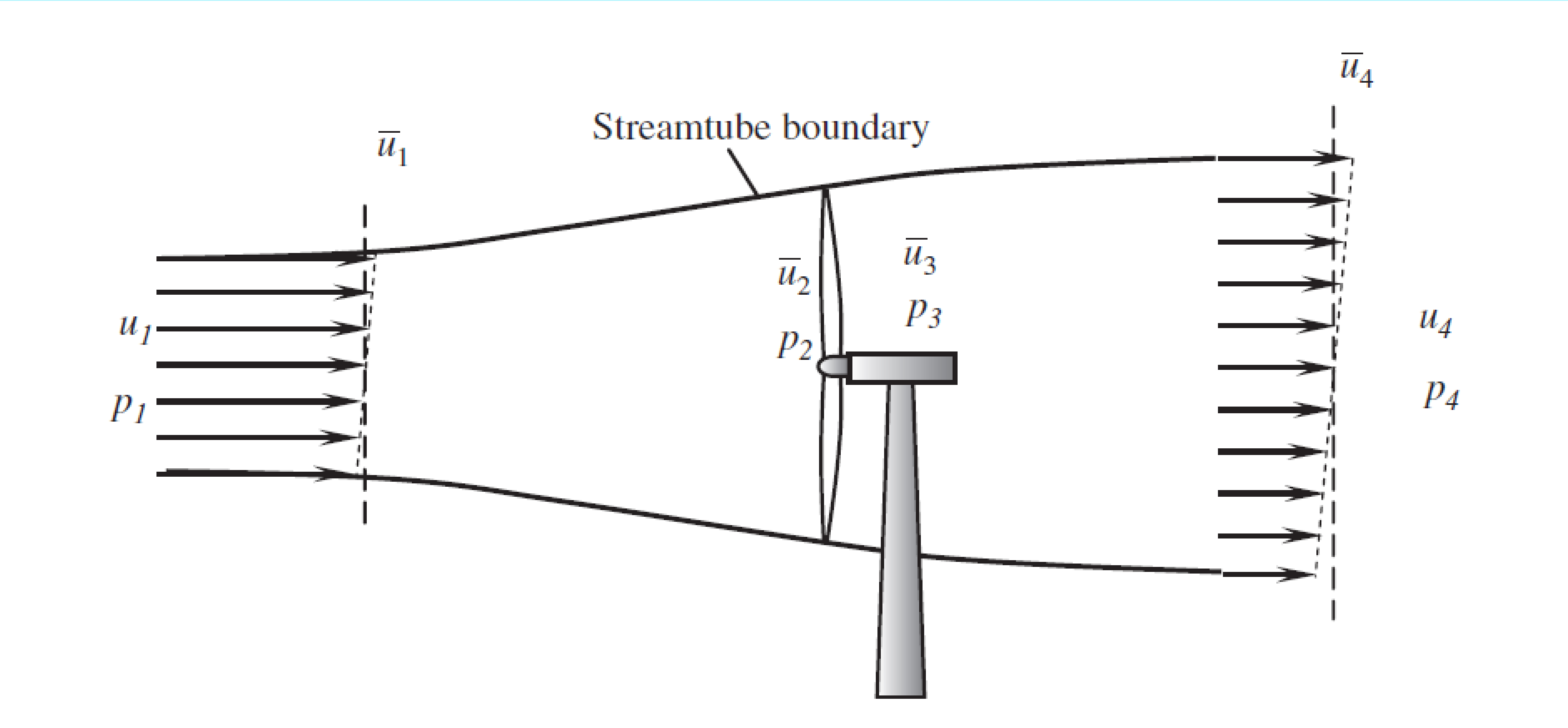
Betz Limit & Power Coefficient

The theoretical maximum efficiency of an ideal wind turbomachine was derived by Lanchester in 1915 and Betz in 1920. It was revealed that no wind turbo-machines could convert more than 16/27 (59.26%) of the kinetic energy of wind into mechanical energy. This is known as Lanchester–Betz limit (or Lanchester–Betz law) today.

59% efficiency is the **BEST** a conventional wind turbine can do in extracting power from the wind



Betz Limit & Power Coefficient



Betz Limit & Power Coefficient

$\bar{u}_1$ and $\bar{u}_4$ are mean velocities far upstream and downstream from the wind turbine; $\bar{u}_2$ and $\bar{u}_3$ are just at wind rotating blades, respectively. By assuming that the pressures far upstream and downstream from the wind turbine are equal to the static pressure of the undisturbed airflow (i.e. $p_1 = p_4 = p$), it can be derived that

$$p_2 - p_3 = \tfrac{1}{2}\rho(\bar{u}_1^2 - \bar{u}_4^2)$$

$$P_{\mathrm{me,out}} = \tfrac{1}{2}\rho A\bar{u}_2(\bar{u}_1^2 - \bar{u}_4^2) = \tfrac{1}{2}\rho A\bar{u}_1^3 4a(1-a)^2$$

$$\bar{u}_2 = \bar{u}_3 = \tfrac{1}{2}(\bar{u}_1 + \bar{u}_4)$$

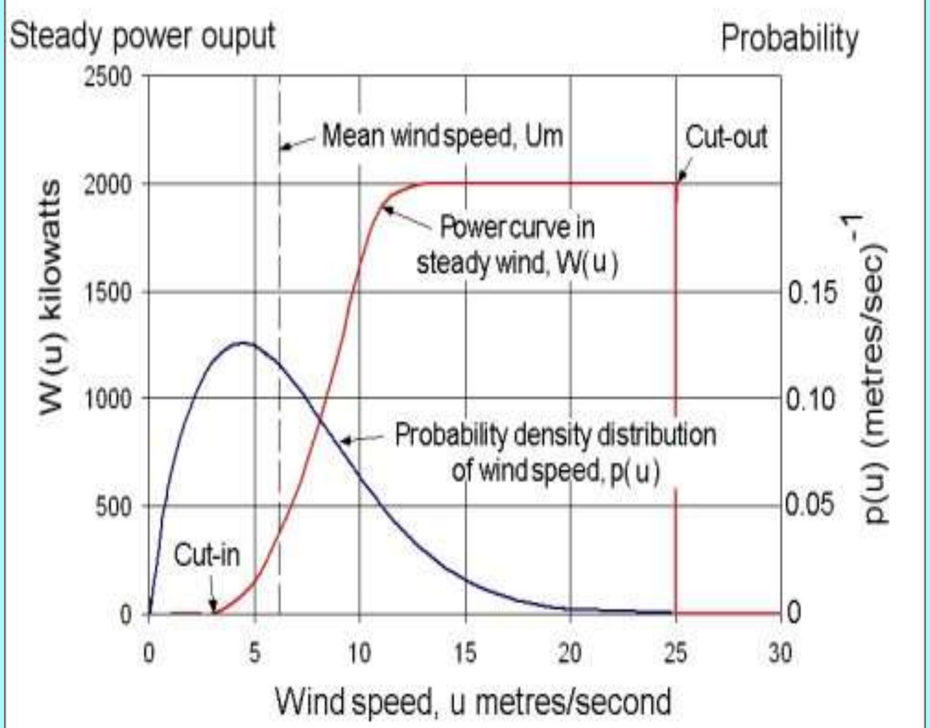
$$a = \frac{\bar{u}_1 - \bar{u}_2}{\bar{u}_1}$$

$$C_{\mathrm{p}} = 4a(1-a)^2$$

where a is the axial induction factor .the power coefficient is only a function of the axial induction factor a . the maximum power coefficient reaches its maximum value of 16/27 when $a = 1/3$

Capacity Factor (CF):

- The fraction of the year the turbine generator is operating at rated (peak) power
- The average power produced by wind generator is smaller as it never run at peak speed all the time.

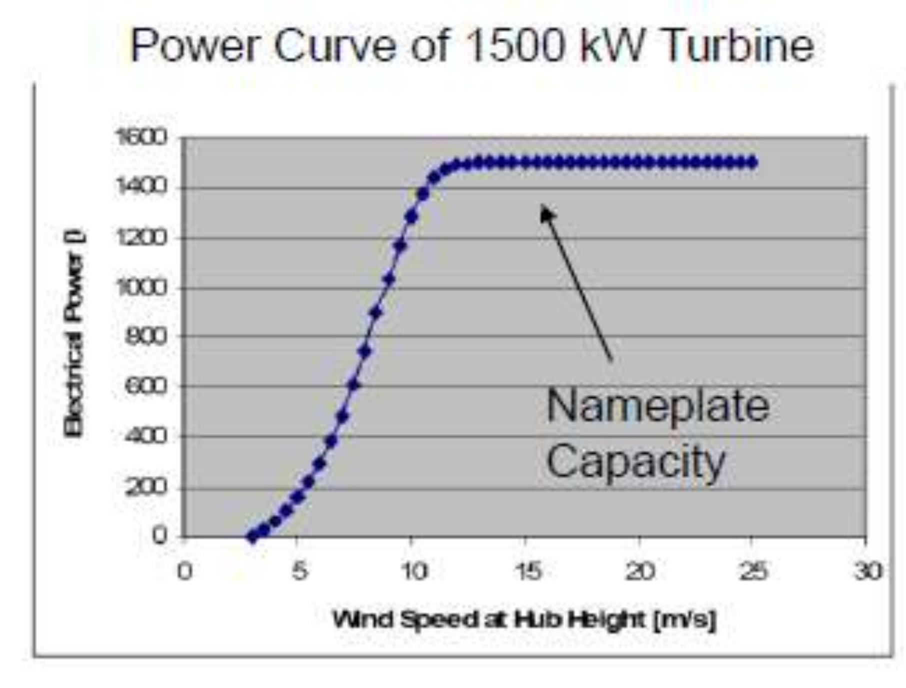


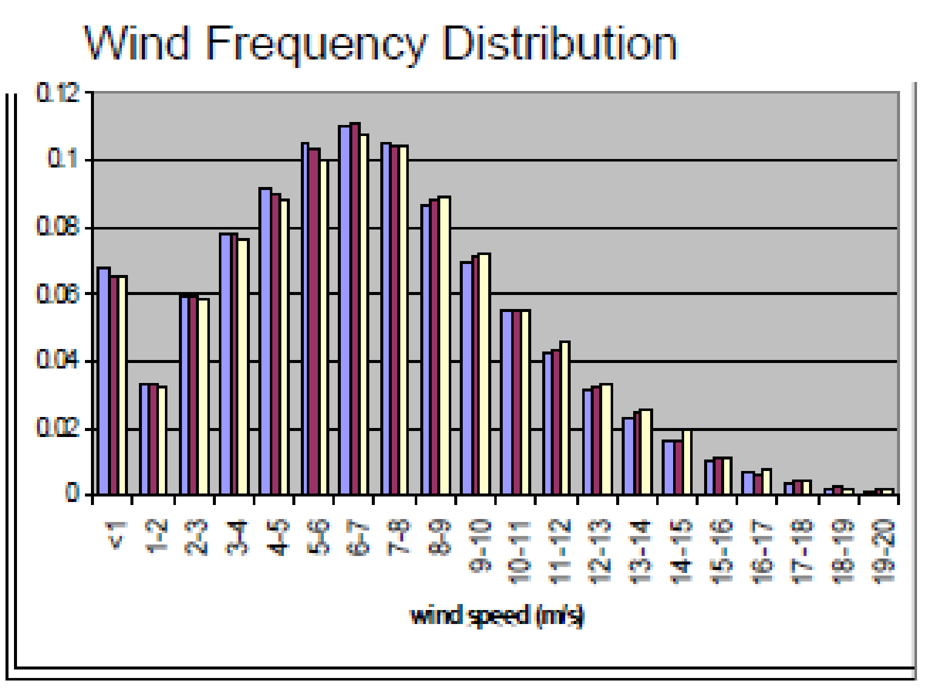
Steady wind power curve and wind speed probability density

- Capacity Factor = Average Output / Peak Output $\approx$ 30%
- CF is based on both the characteristics of the turbine and the site characteristics (typically 0.3 or above for a good site)

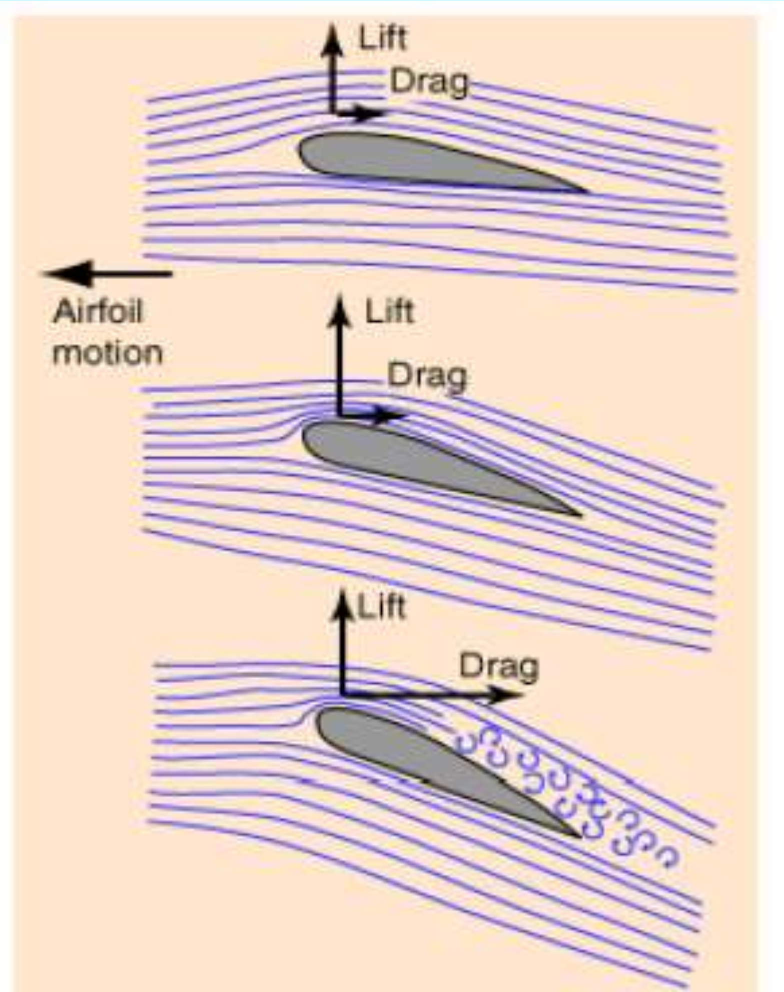
Capacity Factor (CF):

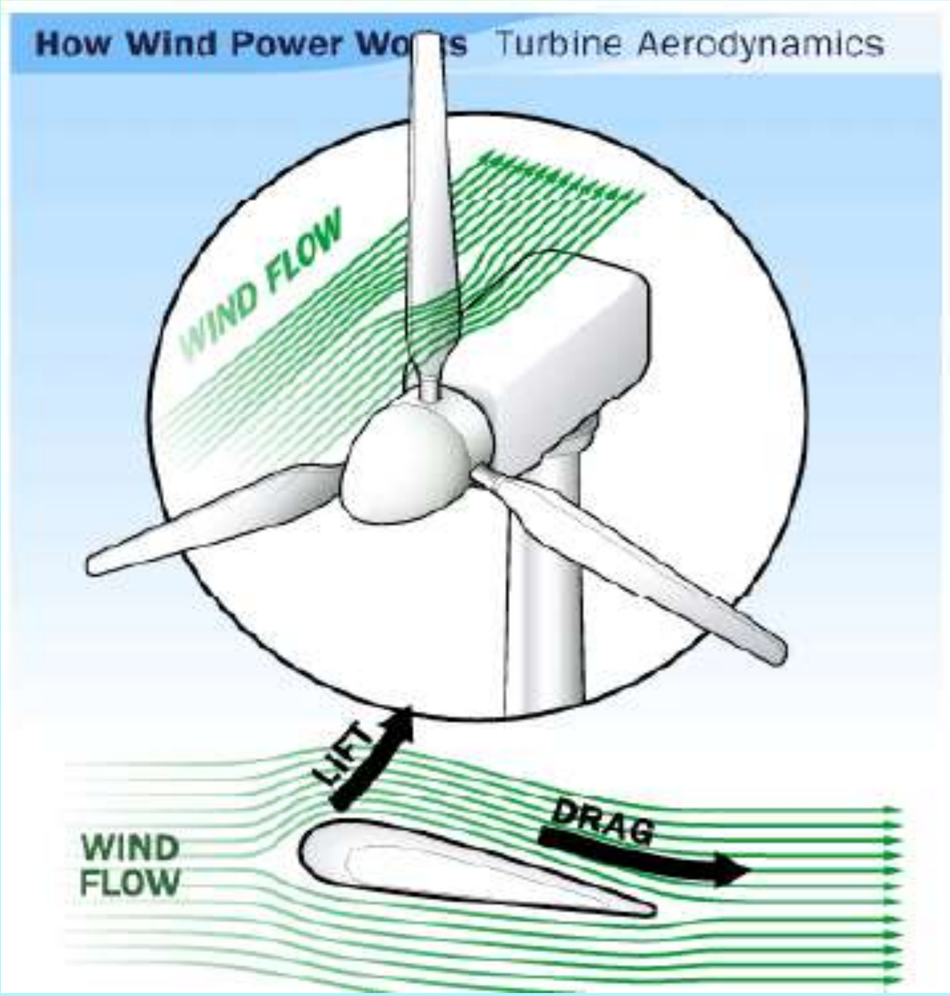
$$\text{Capacity Factor} = \frac{\text{Actual ENERGY Generated (MWh)}}{\text{CAPACITY (MW)} \times \text{TIME Period (h)}}$$





Lift and Drag in Wind Turbine Blade





Wind Characteristics

Wind varies with the geographical locations, time of day, season, and height above the earth's surface, weather, and local landforms. The understanding of the wind characteristics will help optimize wind turbine design, develop wind measuring techniques, and select wind farm sites

- **Wind speed**

Wind speed is a random parameter, measured wind speed data are usually dealt with using statistical methods.
The diurnal variations of average wind speeds are often described by sine waves. As an example, the diurnal variations of hourly wind speed values, which are the average values calculated based on the data between 1970 and 1984, at Dhahran.
Saudi Arabia have shown the wavy pattern

Wind Characteristics

- **Weibull distribution:**

The variation in wind speed at a particular site can be best described using the Weibull distribution function, which illustrates the probability of different mean wind speeds occurring at the site during a period of time.

- **Wind turbulence**

Wind turbulence is the fluctuation in wind speed in short time scales, especially for the horizontal velocity component. The wind speed $u(t)$ at any instant time t can be considered as having two components:
mean wind speed u– and the instantaneous speed fluctuation $u'(t)$,
i.e.: $u(t) = u + u'(t)$

Wind Characteristics

- **Wind gust**

Wind gust refers to a phenomenon that a wind blasts with a sudden increase in wind speed in a relatively small interval of time. In case of sudden turbulent gusts, wind speed, turbulence, and wind shear may change drastically. Reducing rotor imbalance while maintaining the power output of wind turbine generator constant. During such sudden turbulent gusts calls for relatively rapid changes of the pitch angle of the blades.

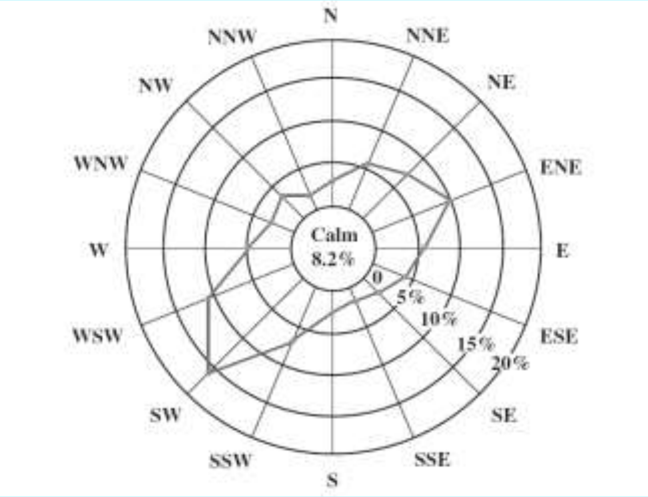
- **Wind shear**

Wind shear is a meteorological phenomenon in which wind increases with the height above the ground. The effect of height on the wind speed is mainly due to roughness on the earth's surface and can be estimated using the Hellmann power equation that relates wind speeds at two different heights

Wind Characteristics

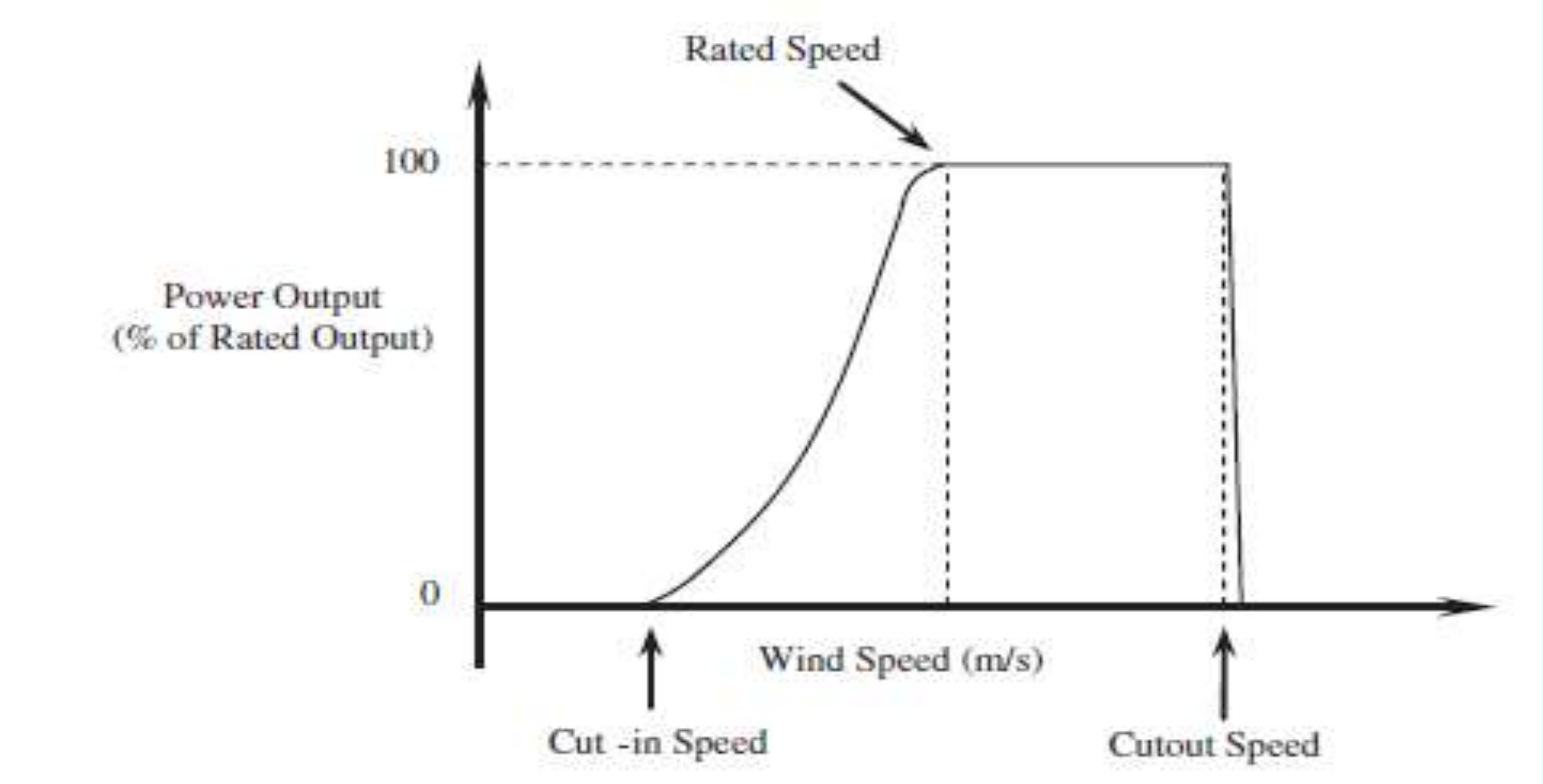
- **Wind direction**

Wind direction is one of the wind characteristics. Statistical data of wind directions over a long period of time is very important in the site selection of wind farm and the layout of wind turbines in the wind farm. The wind rose diagram is a useful tool of analyzing wind data that are related to wind directions at a particular location over a specific time period (year, season, month, week, etc.)



Wind Power Curve

The power curve of a wind turbine displays the power output (either the real electrical power output or the percentage of the rated power) of the turbine as a function of the mean wind speed.



Wind Power Curve

- The wind turbine starts to produce power at a low wind speed, called *cut-in speed*.
- The power output increases continuously with the increase of the wind speed until reaching a saturated point and reaches its maximum value called as *Rated Power Output.*
- The speed at this point is Called *Rated Speed*.
- Above this speed will not increase the power output due to the activation of the power control.
- When the wind speed becomes too large to potentially damage the wind turbine, This wind speed is defined as the cut-out speed

Wind Power Technology

Turbines

• Almost all electrical power on Earth is produced with a turbine of some type. It is converting rectilinear flow motion to shaft rotation through rotating airfoils

	Type of Generation	Combustion Type	Turbine Type Gas	Steam	Water	Aero	Primay Power	Electrical Conversion
3	Traditional Boiler	External		•			Shaft	Generator
3	Fluidized Bed	External		•			Shaft	Generator
	Combustion						–	–
	Integrated Gasification	Both	•	•			Shaft	Generator
	Combined-Cycle						–	–
	Combustion Turbine	Internal	•				Shaft	Generator
	Combined Cycle	Both	•	•			Shaft	Generator
3	Nuclear			•			Shaft	Generator
	Diesel Genset	Internal					Shaft	Generator
	Micro-Turbines	Internal	•				Shaft	Generator
	Fuel Cells						Direct	Inverter
	Hydropower				•		Shaft	Generator
3	Biomass & WTE	External		•			Shaft	Generator
	Windpower					•	Shaft	Generator
	Photovoltaics						Direct	Inverter
3	Solar Thermal			•			Shaft	Generator
3	Geothermal			•			Shaft	Generator
	Wave Power		•				Shaft	Generator
	Tidal Power				•		Shaft	Generator
3	Ocean Thermal			•			Shaft	Generator

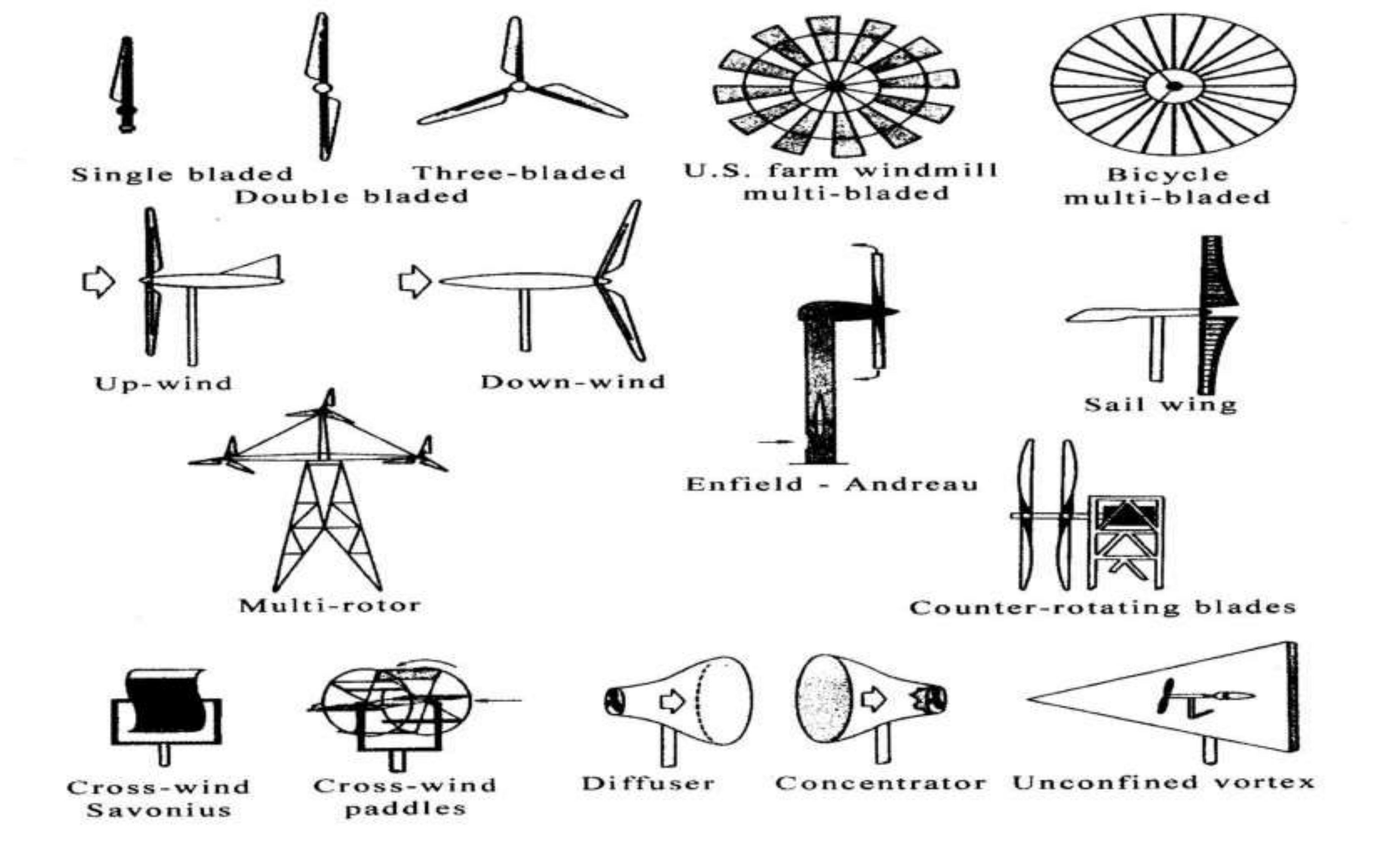
Wind Turbine Classification :Horizontal-axis

Wind turbines can be classified according to the turbine generator configuration, airflow path relatively to the turbine rotor, turbine capacity, the generator-driving pattern, the power supply mode, and the location of turbine installation.

➢ **Horizontal-axis Wind Turbines**

- Most commercial wind turbines today belong to the *Horizontal-axis type*, in which the rotating axis of blades is parallel to the wind stream.
- The advantages of this type of wind turbines include the high turbine efficiency, high power density, low cut-in wind speeds, and low cost per unit power output.

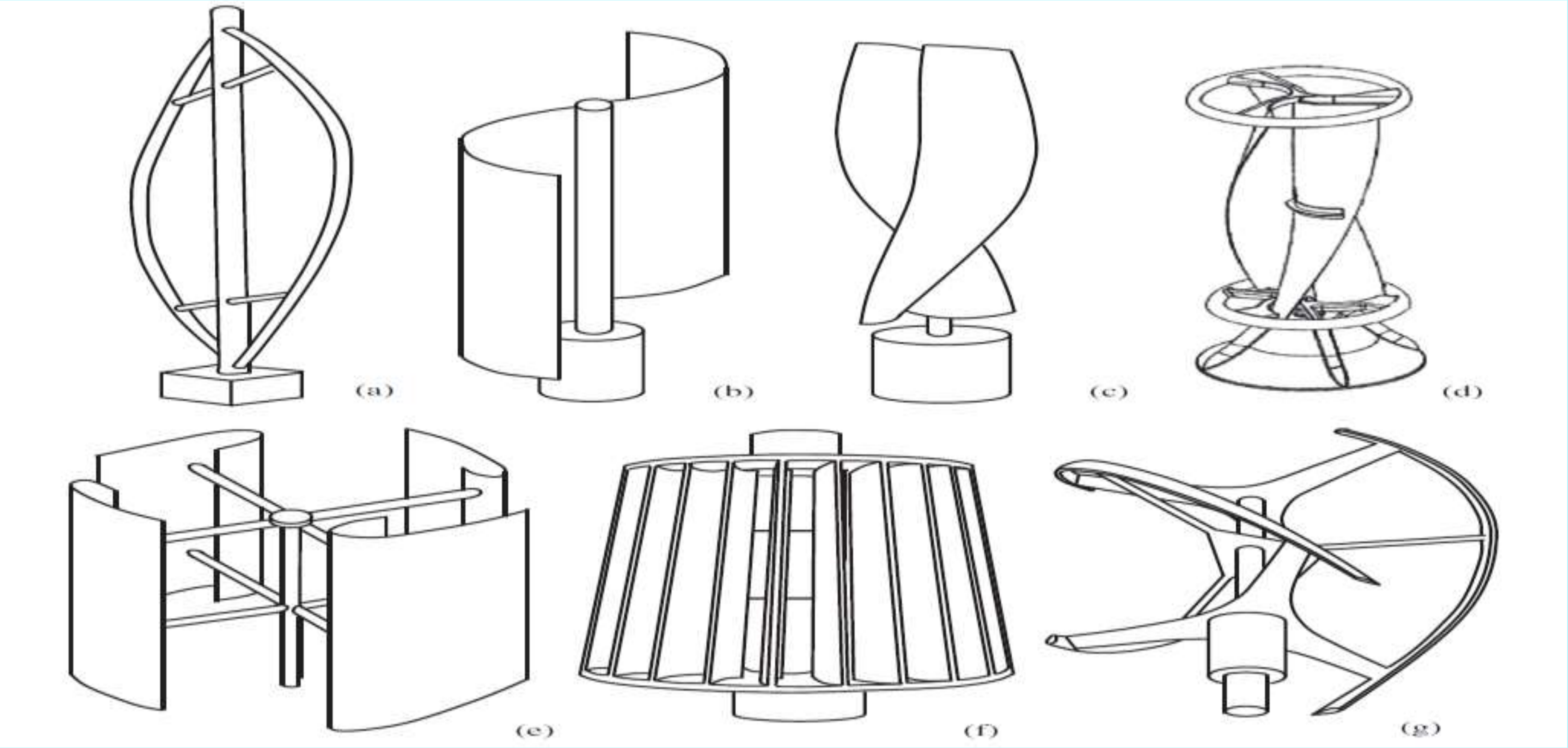
Horizontal-axis Wind Turbines



Vertical-axis Wind Turbine

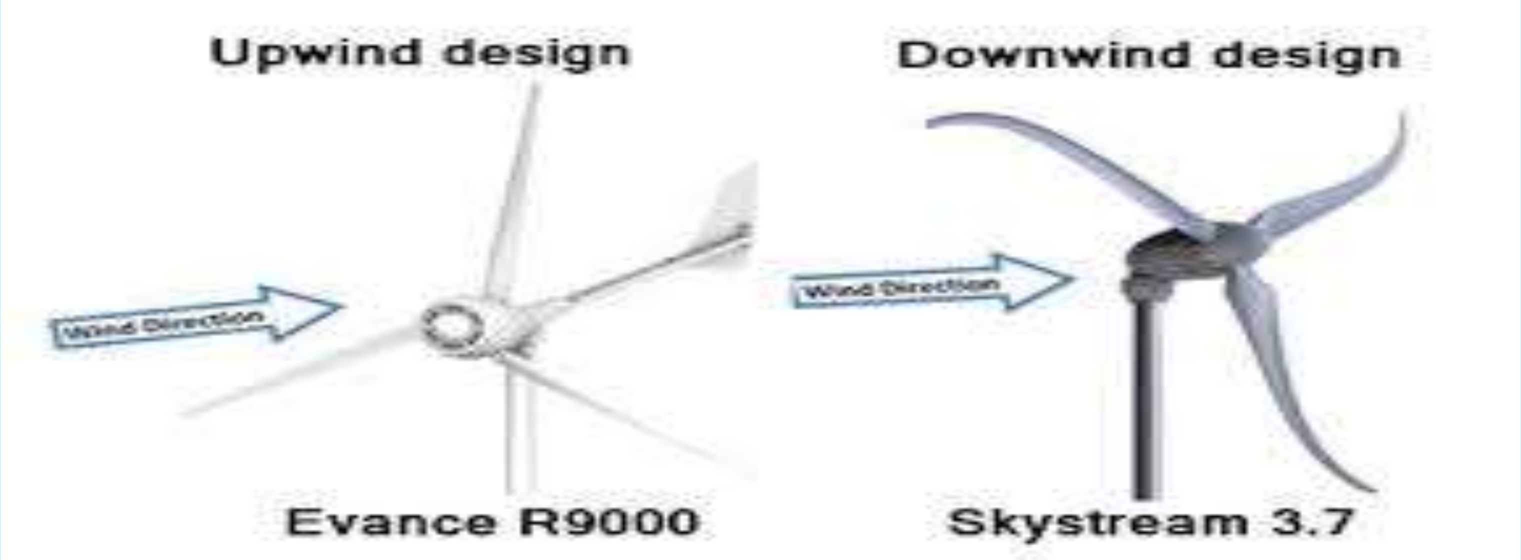
- The blades of the vertical-axis wind turbines are perpendicular to the ground.
- A significant advantage of vertical-axis wind turbine is that the turbine can accept wind from any direction and thus no yaw control is needed.
- The wind generator, gearbox, and other main turbine components can be set up on the ground, hence simplifies the tower design. And hence reduces the turbine cost.
- However, these turbines uses an external energy source to rotate the blades during initialization. Because the axis of the wind turbine is supported only on one end at the ground.
- Its also reduces maximum practical height of turbine.
- Due to the lower wind power efficiency, vertical-axis wind turbines today make up only a small percentage of usage.

Vertical-axis wind turbines



Several typical types of vertical-axis wind turbines:
(a) Darrius (b) Savonius (c) Solarwind (d) Helical (e) Noguchi
(f) Maglev (g) Cochrane

Upwind and Downwind Wind Turbines



Upwind and Downwind Wind Turbines

- Based on the configuration of the wind rotor with respect to the wind flowing direction, the horizontal-axis wind turbines can be further classified as upwind and downwind wind turbines
- The majority of horizontal-axis wind turbines being used today are ***Upwind Turbines***, in which the wind rotors face the wind.
- The main advantage of upwind designs is to avoid the distortion of the flow field as the wind passes though the wind tower and nacelle.
- For a ***Downwind Turbine***, wind blows first through the nacelle and tower and then the rotor blades. In this type the rotor blades are made more flexible without considering tower strike.
- However, due to distorted unstable wakes behind the tower and nacelle, the power output fluctuates and greatly unstable, have more aerodynamic losses and more fatigue loads on the turbine. The blades may produce higher impulsive or thumping noise .

Wind Turbines Capacity

Wind turbines can be divided as per their rated capacities: Micro, Small, Medium, Large, And Ultra-large Wind Turbines

Turbine Type	Output Power Capacity	Remarks
Micro Turbines	Less than several KWs	For Non grid Application Can be used on a per-structure basis, such as street lighting
Small Turbines	Less than 100 kW	extensively used at residential houses, farms, and other individual remote applications
Medium Turbines	100KW to 1MW	Either on-grid or off-grid systems, for villages, hybrid systems and distributed power etc.
Large wind turbines	Up to 10 MW	Most wind farms, especially in offshore wind farms
Ultra-large wind turbines	More than 10 MW	Still in the earlier stages of research and development

Direct Drive And Geared Drive Wind Turbines

Direct Drive Wind Turbines

- The generator shaft is directly connected to the blade rotor
- The direct-drive concept is more superior in terms of energy efficiency, reliability, and design simplicity.

Geared Drive Wind Turbines

- To increase the generator speed to gain a higher power output, a regular geared drive wind turbine typically uses a multi-stage gearbox. It changes speed from the low-speed shaft of the blade rotor into the high-speed shaft of the generator rotor.
- The **advantages** of geared generator systems include lower cost and smaller size and weight.
- The **disadvantage** of a gearbox is significantly lower wind turbine reliability and increase turbine noise and mechanical losses.

On-Grid and Off-Grid Wind Turbines

- Wind turbines can be used for either on-grid or off-grid applications
- Most medium-size and almost all large-size wind turbines are used in grid tied applications.
- The main advantages for on-grid wind turbine systems is that there is no energy storage problem
- Most of small wind turbines are off-grid for residential homes, farms, telecommunications, and other applications
- off-grid wind turbines are usually used in connection with batteries, diesel generators, and photovoltaic systems for improving the stability of wind power supply

Onshore and Offshore Wind Turbines

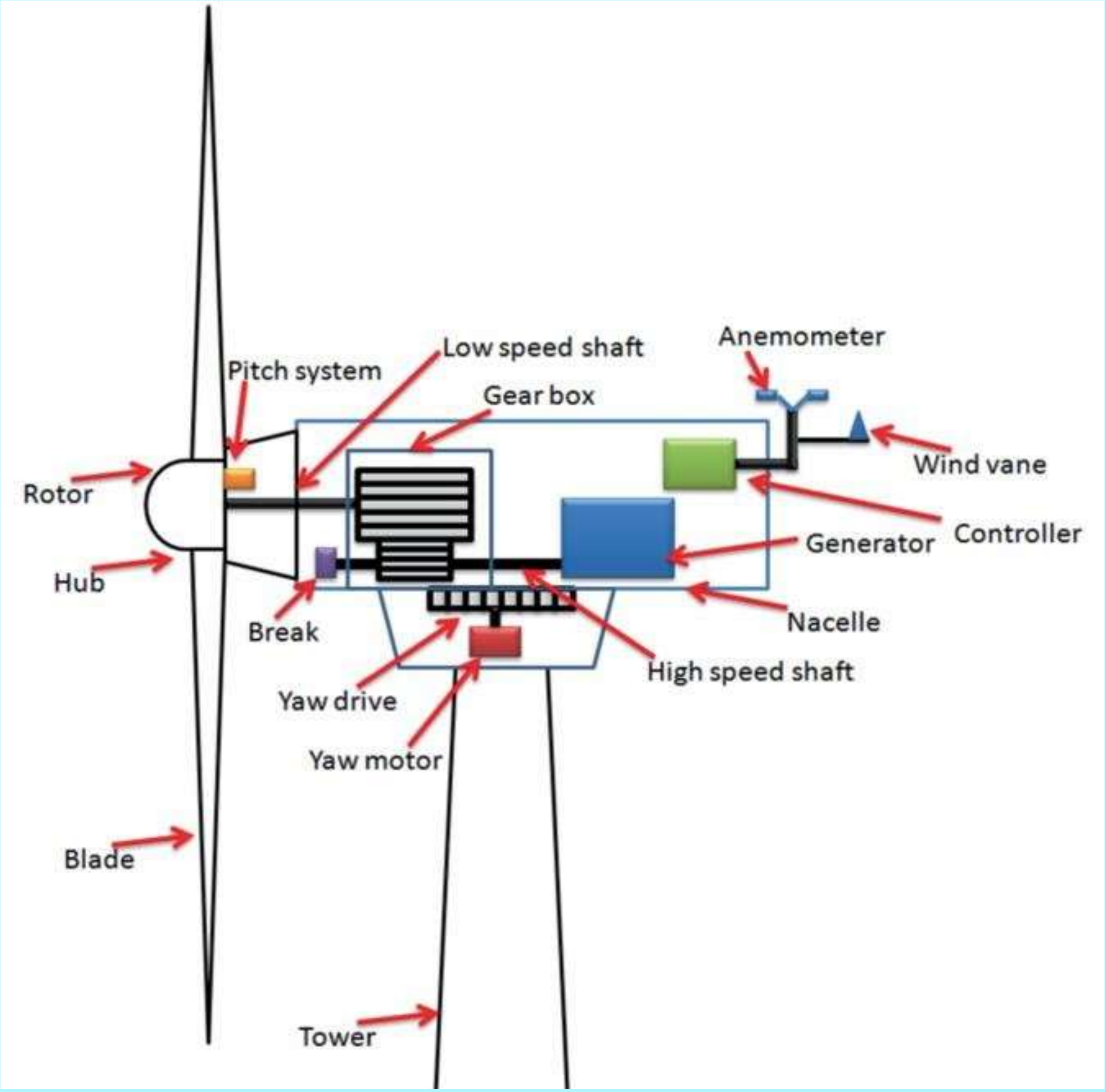
Onshore and Offshore Wind Turbines

- ***Onshore Turbines*** have a number of advantages including lower cost of foundations, easier integration with the electrical-grid network, lower cost in tower building and turbine installation, and more convenient access for operation and maintenance

- ***Offshore Turbines*** have developed faster than onshore since the 1990s due to the excellent offshore wind resource, in terms of wind power intensity and continuity.
- A wind turbine installed offshore can make higher power output and operate more hours each year compared with the same turbine installed onshore
- Environmental restrictions are more lax at offshore sites than at onshore sites. Turbine noise is never an issue for offshore wind turbines

Components of Wind Turbine

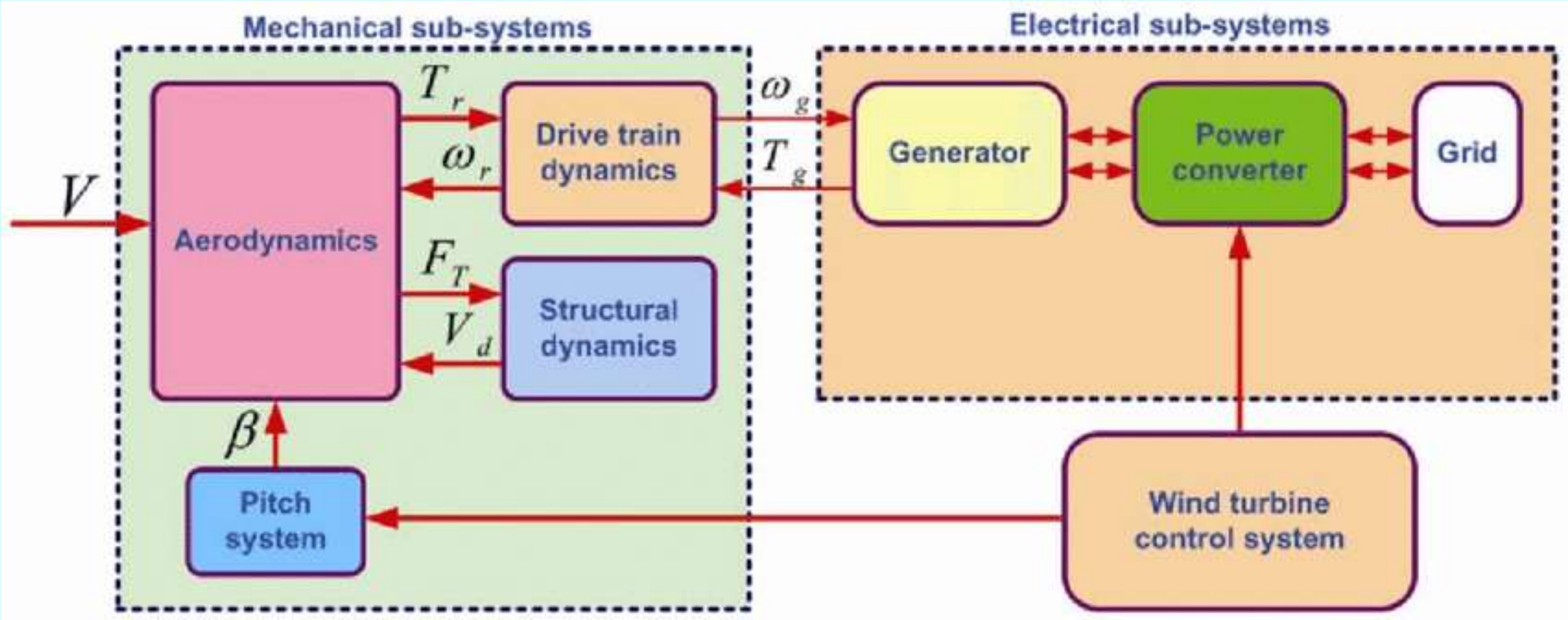
- Foundation, Tower
- Nacelle,
- Hub & Rotor
- Drivetrain
- Gearbox
- Generator
- Electronics & Controls
- Yaw
- Pitch
- Braking
- Power Electronics
- Cooling
- Diagnostics



Wind Turbine Subsystems

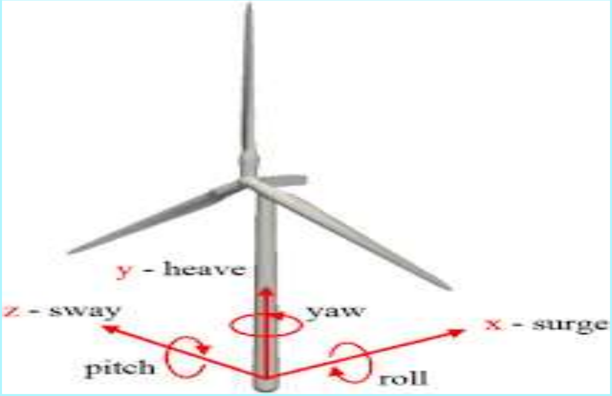
Mechanical Sub-systems: The mechanical sub-systems contain 1) the wind turbine rotor, 2) the drive train, 3) the nacelle structure, and 4) the tower.

Electrical Sub-Systems: The electrical sub-systems contain 1) the generator and 2) power electronic converter.

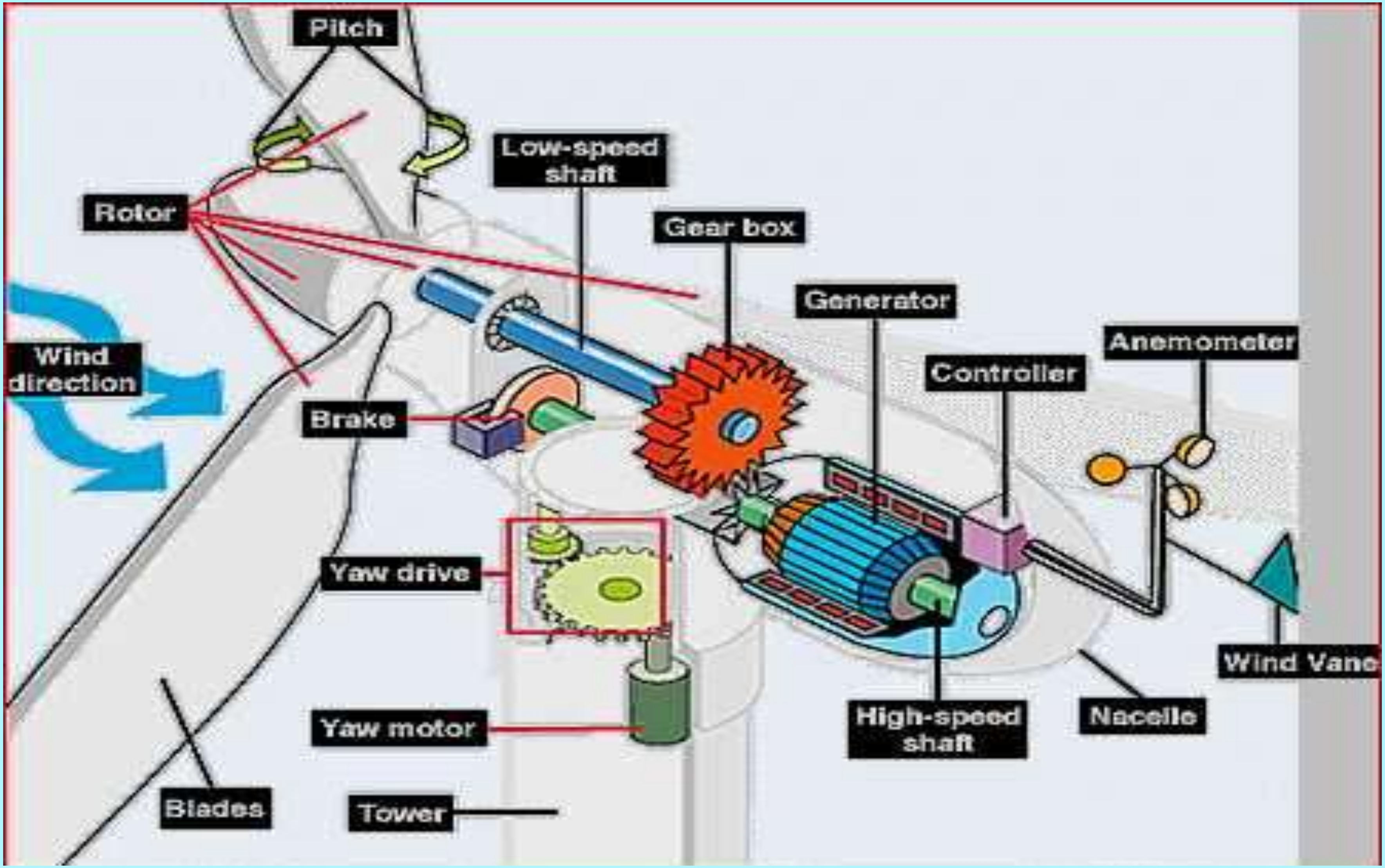


Functions of Subsystems

System	Function
Yaw	Track incoming wind direction
Pitch	Control blade position
Drivetrain	Shift torque and speed characteristic
Generator	Convert from mechanical to electrical energy
Power system interconnection	Interface generator with load or power grid
SCADA	Monitor performance, control set-points, human interface

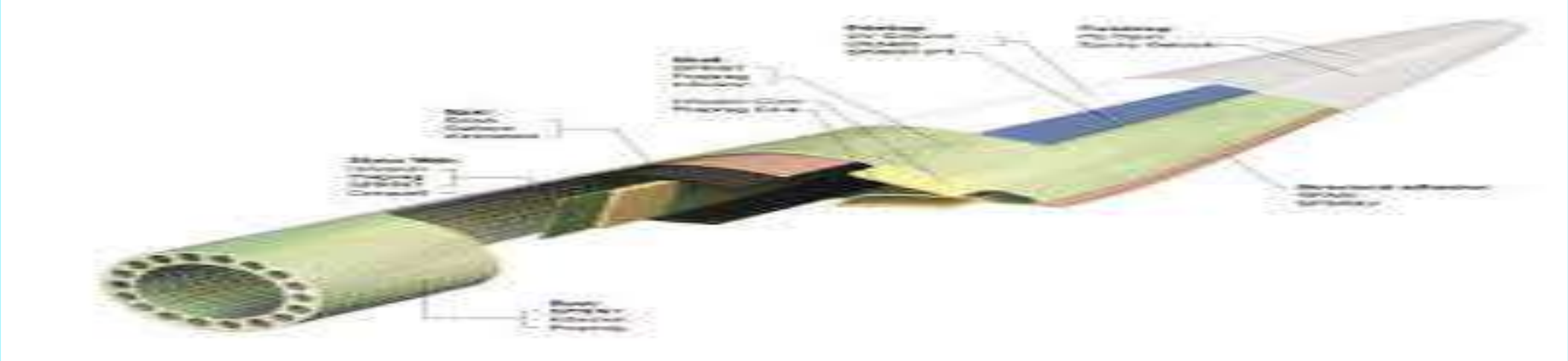


Turbine Parts

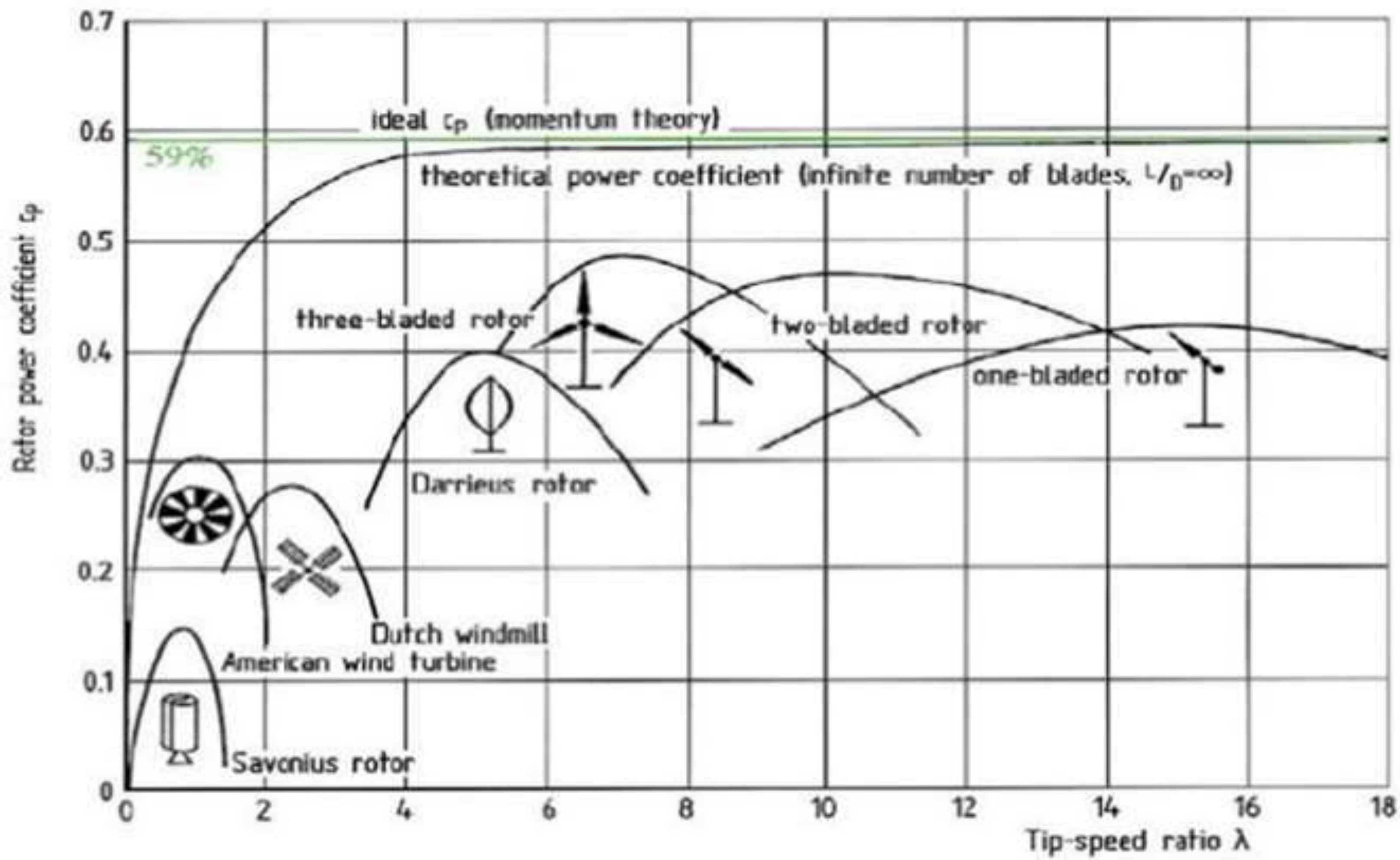


Rotor Design Methodology

1. Determine basic configuration: orientation and blade number
2. Take site wind speed and desired power output
3. Calculate rotor diameter (accounting for efficiency losses)
4. Select tip-speed ratio (if higher more complex airfoils, noise) and blade number (higher efficiency with more blades)
5. Design blade including angle of attack, lift and drag characteristics
6. Combine with theory or empirical methods to determine optimum blade shape



Blade Type and Wind Turbines Efficiency



Coefficient of Performance (efficiency) of wind rotors of various designs

Pitch Control Wind Turbines

- The pitch control system is important because it not only continually regulates the wind turbine's blade but also controls pitch angle to enhance the efficiency of wind energy conversion and power generation stability. It also serves as the security system in case of high wind speeds or emergency situations.
- It requires that even in the event of grid power failure, the rotor blades can be still driven into their feathered positions by using either the power of backup batteries or capacitors.

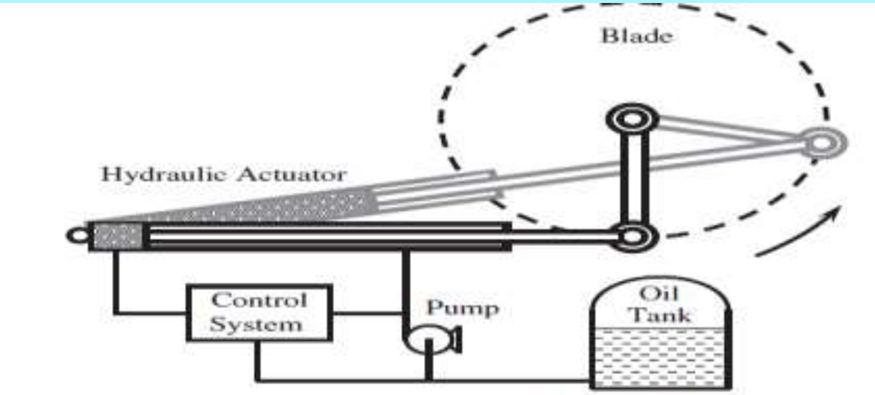


Figure 11: Hydraulic pitch control system.

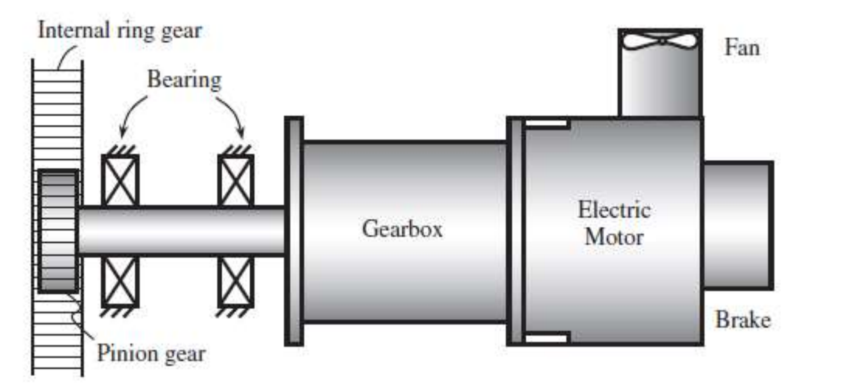


Figure 12: Electric pitch control system.

Pitch Control Wind Turbines

- Early techniques of active blade pitch control applied hydraulic actuators to control all blades together.
- However, these collective pitch control techniques could not completely satisfy all requirements of blade pitch angle regulation, especially for MW wind turbines with the increase in blade length and hub height.
- More superior individual blade pitch control techniques have been developed and implemented, allowing control of asymmetric aerodynamic loads on the blades, as well as structural loads in the non-rotating frame such as tower side-side bending. In such a control system, each blade is equipped with its own pitch actuator, sensors and controller.

Stall Control & Yaw control

Stall control

Besides pitch control, stall control is another approach for controlling and protecting wind turbines. The concept of stall control is that the power is regulated through stalling the blades after rated speed is achieved.

Yaw control

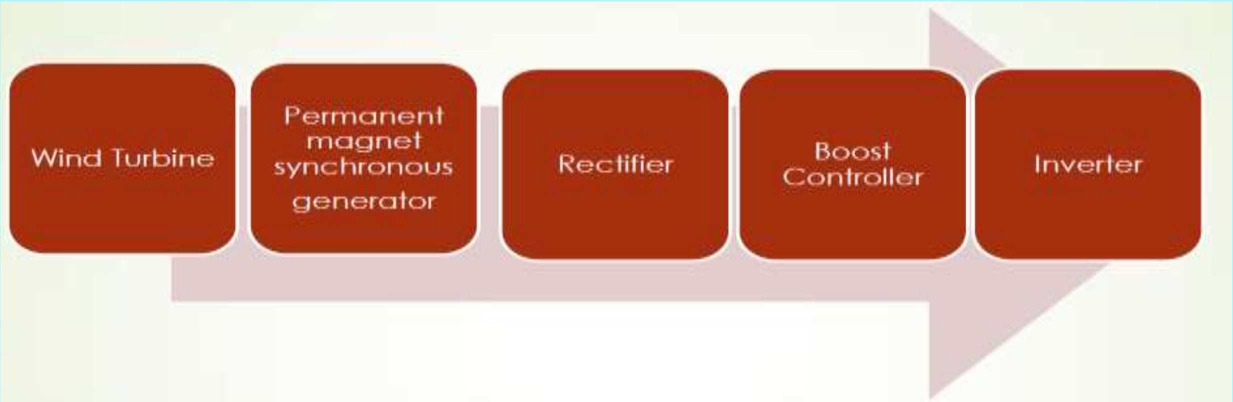
In order to maximize the wind power output and minimize the asymmetric loads acting on the rotor blades and the tower, a horizontal-axis wind turbine must be oriented with rotor against the wind by using an active yaw control system

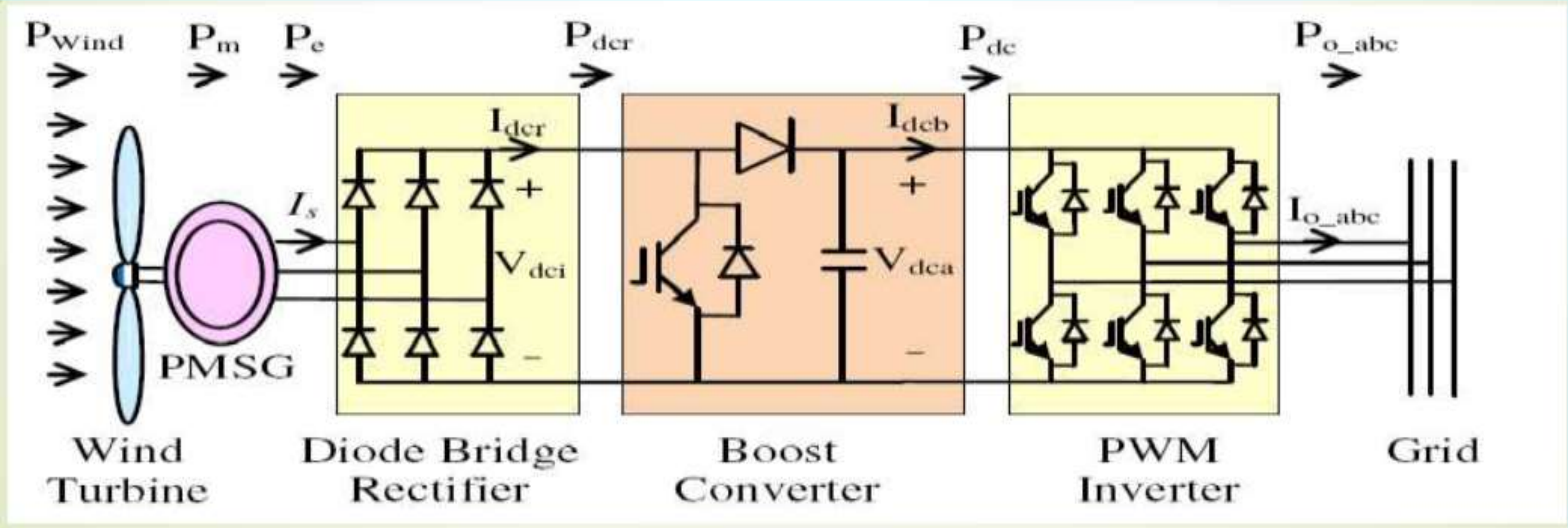
Wind Energy Storage

Today developing advanced, cost-effective storage technologies of electric energy still remains a challenge, which may limit the widespread application of wind energy. The technologies to convert wind energy into various forms of energies are

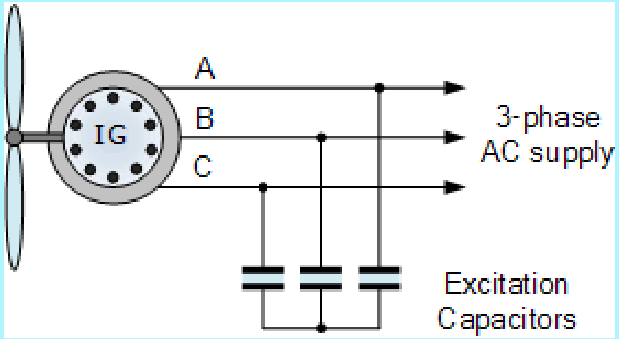
- Electrochemical energy in batteries and super capacitors
- Magnetic energy in superconducting magnetic energy storage (SMES)
- Kinetic energy in rotating flywheels
- Potential energy in pumped water at higher altitudes
- Mechanical energy in compressed air in vast geologic vaults
- Hydrogen energy by decomposing water

Wind Turbine Generation System





Wind Energy Electrical Generators

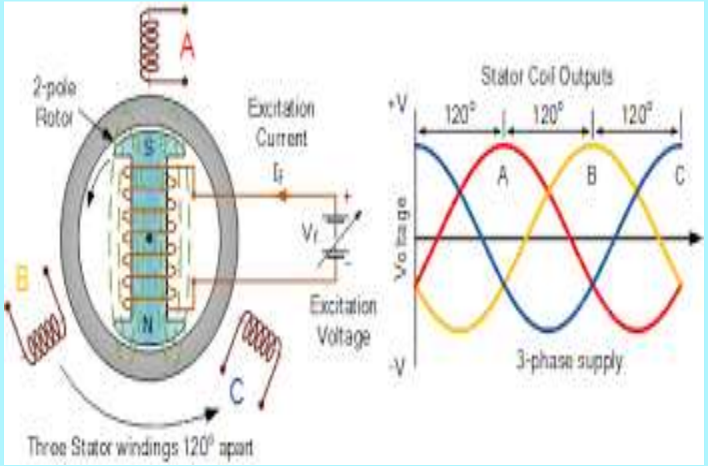


- Asynchronous Induction Generator
- Double Fed Induction Generator (DFIG)

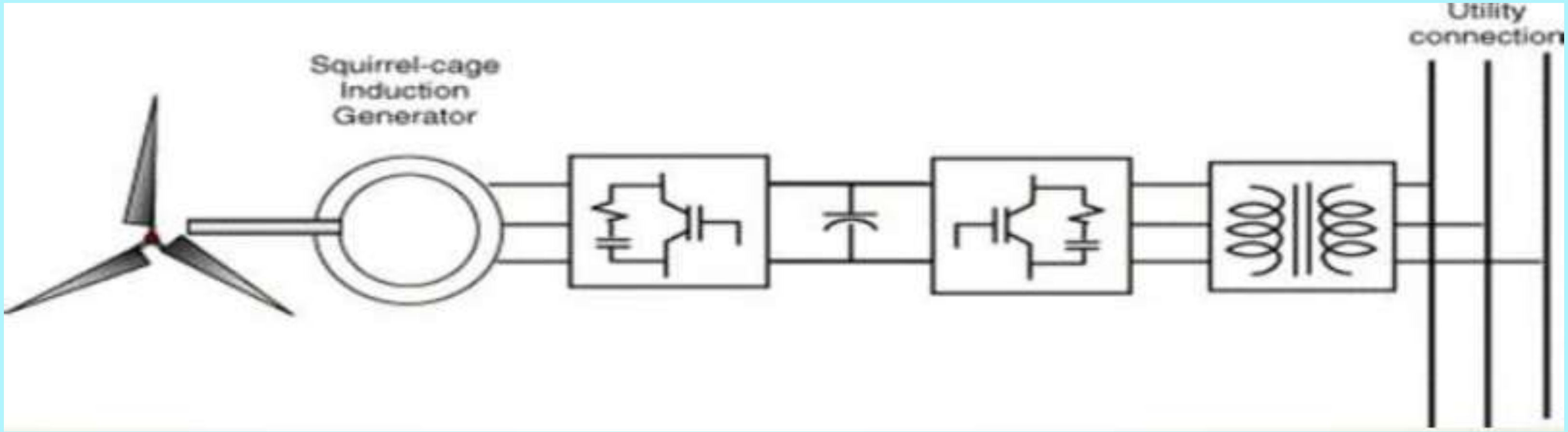
  Used for modern Large Wind Turbines

- Synchronize Generator
- Permanent magnet Generator

  Used for Small Wind Turbines

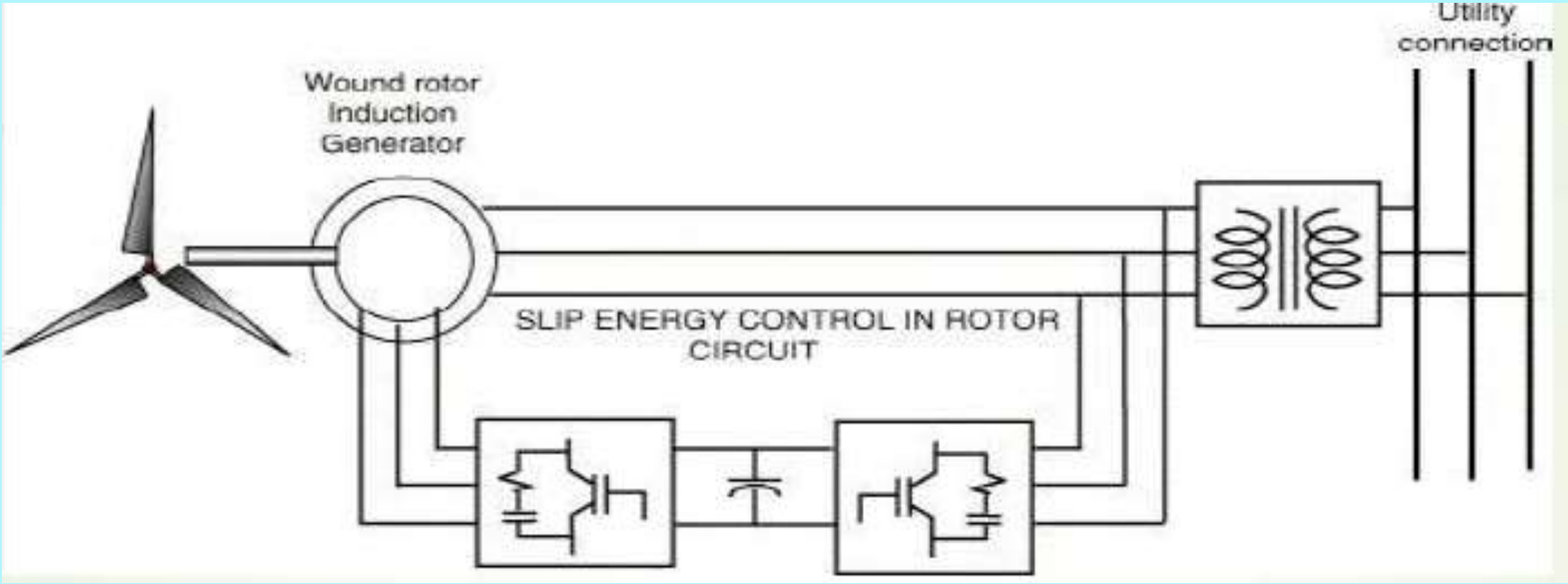


Squirrel Cage Induction Generators



- Stator of the SCIG is connected to grid through back to back power electronic converter bridges
- **Advantages**
  - To make best use of wind energy available
  - No need of capacitor bank
- **Disadvantage**
  - Expensive

Wound Rotor Induction Generators



Power Convertor size reduced by using it on rotor side of WRIG

- This is variable speed system using a wound rotor generator
- The power converter is now connected between the rotor and grid , so it needs to carry only the slip power.

Wound Rotor Induction Generators

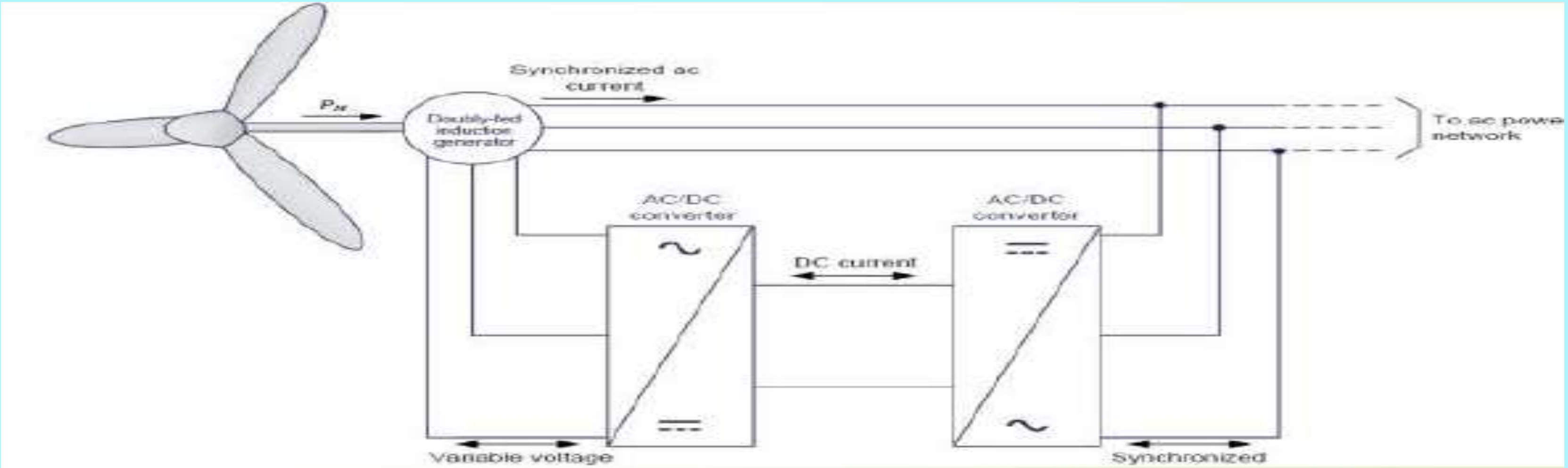
Advantages

- For utility scale wind power generation it outweighs squirrel cage machine.
- Offers a lot of flexibility for wide range of speed control
- Used in high power applications in which a large amount of slip power could be recovered
- Speed of WRIM was changed by mechanically varying external rotor circuit resistance(simplest way)

Disadvantage

- This system is having low efficiency due to additional loses in resistor connected in the rotor circuit.

Doubly Fed Induction Generators



Two power converter bridges connected back-to-back by means of a dc link can accommodate the bidirectional rotor power flow.

- The purpose of the grid side converter is to maintain the dc link voltage constant.
- It has control over the active and reactive power transfer between the rotor and the grid.
- The rotor side converter is responsible for control of the flux, and thus, the stator active and reactive powers .

Doubly Fed Induction Generators

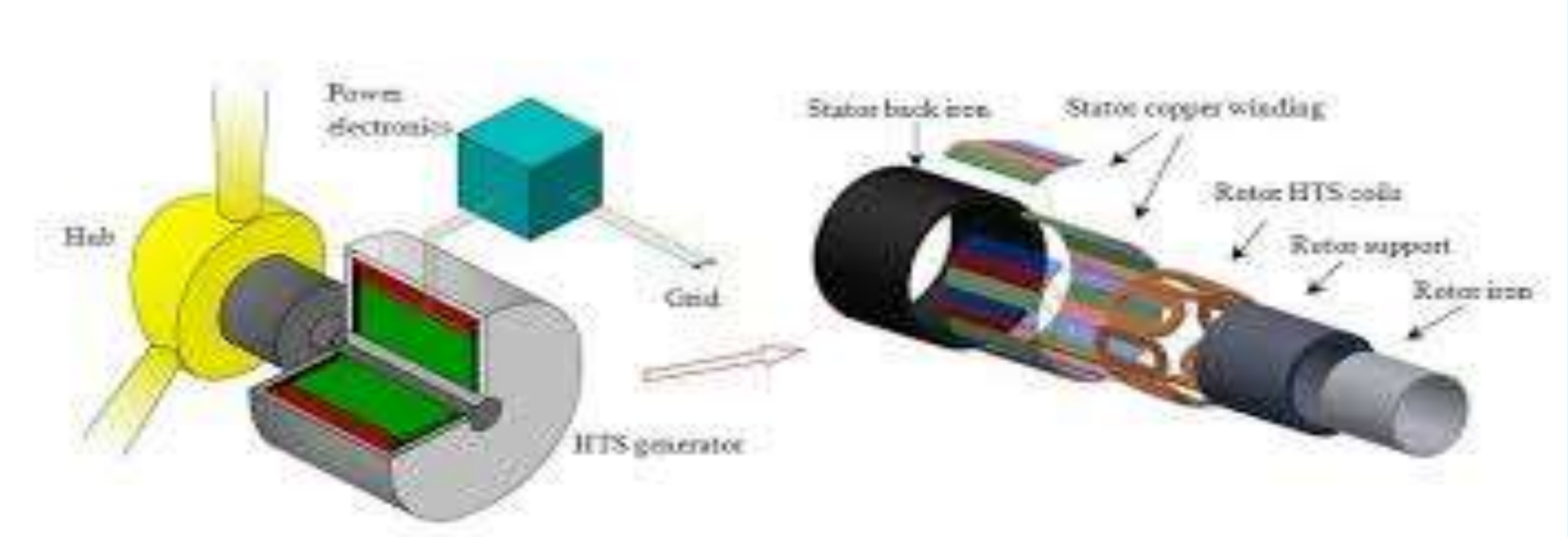
Advantages

- Operation at variable rotor speed while the amplitude and frequency of the generated voltages remain constant.
- Optimization of the amount of power generated as a function of the wind available up to the nominal output power of the wind turbine generator.
- Virtual elimination of sudden variations in the rotor torque and generator output power.
- Generation of electrical power at lower wind speeds.

Disadvantages

- Control of the power factor (e.g., in order to maintain the power factor at unity).
- Complicated and High Maintenance

HTS Wind Generators
(High Temperature Superconductivity)



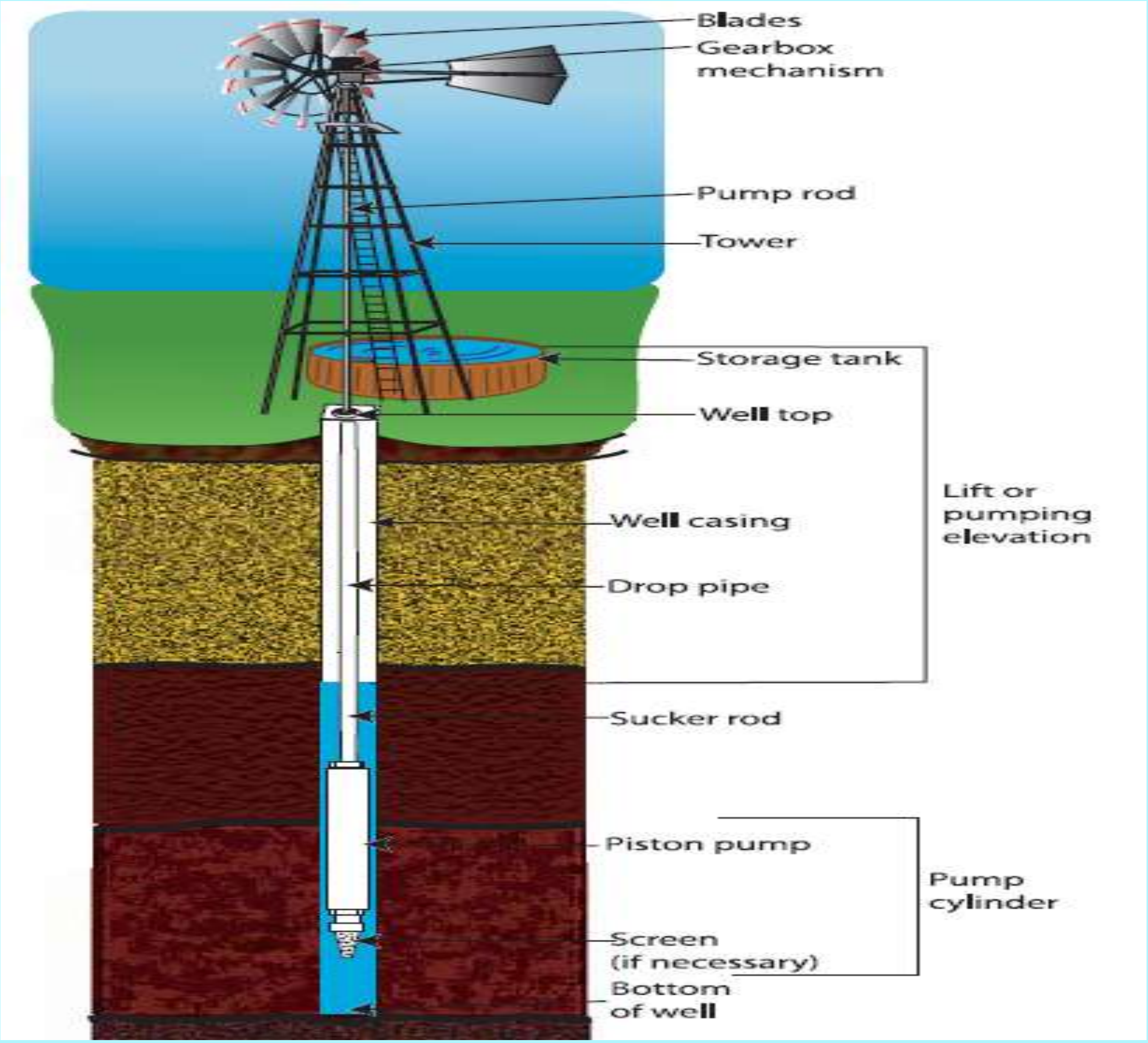
- Homopolar HTSG
- Axial Bipolar HTSG
- Bipolar Linear HTSG
- Transversal Flux HTSG

HTS Wind Generators
(High Temperature Superconductivity)

Advantages

- Increase machine efficiency beyond 99%, reducing losses by as much as 50% over conventional generators
- Energy savings
- Reduced pollution per unit of energy produced
- Lower life-cycle costs
- Enhanced grid stability
- Reduced capital cost
- Reduced installation expenses

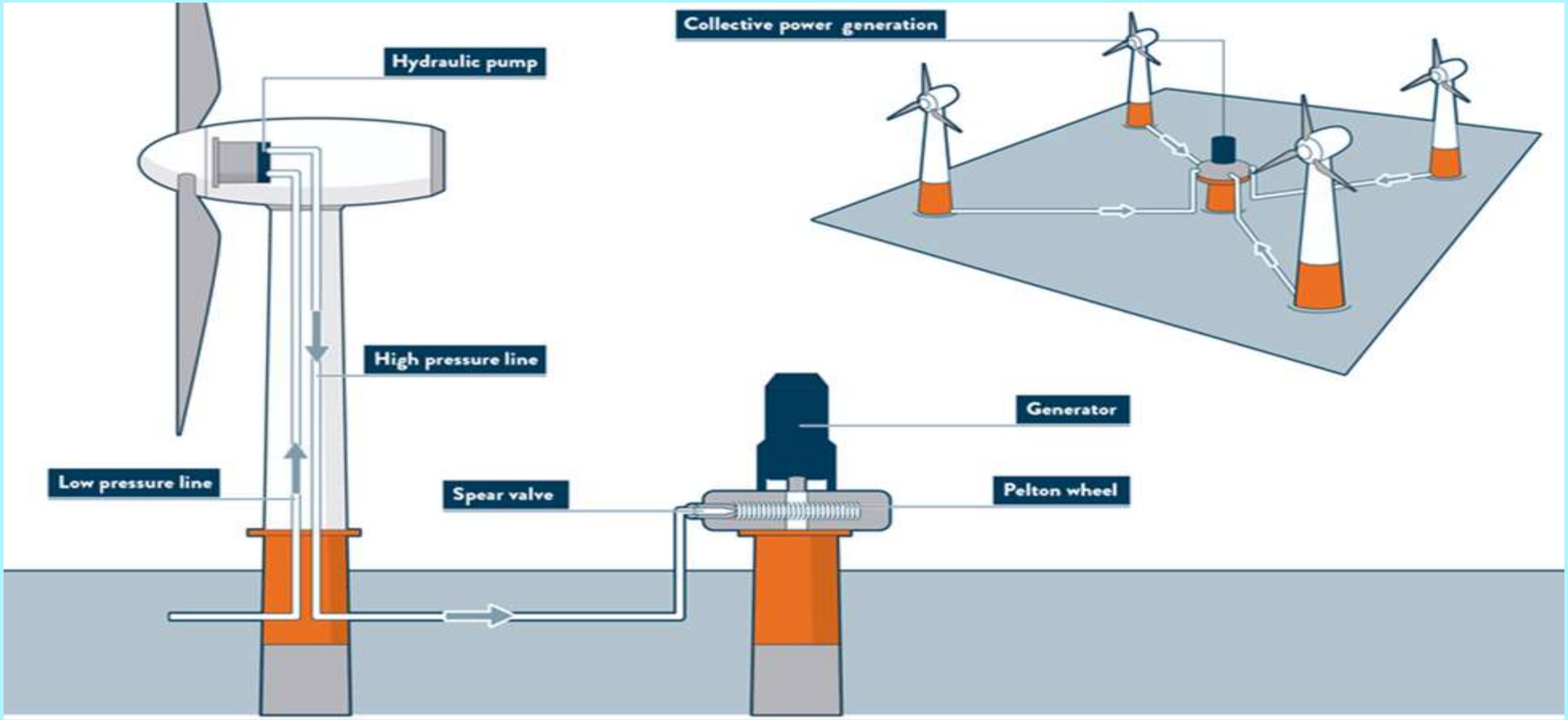
Wind Water Pumping System



Using wind energy water pumping is also possible.

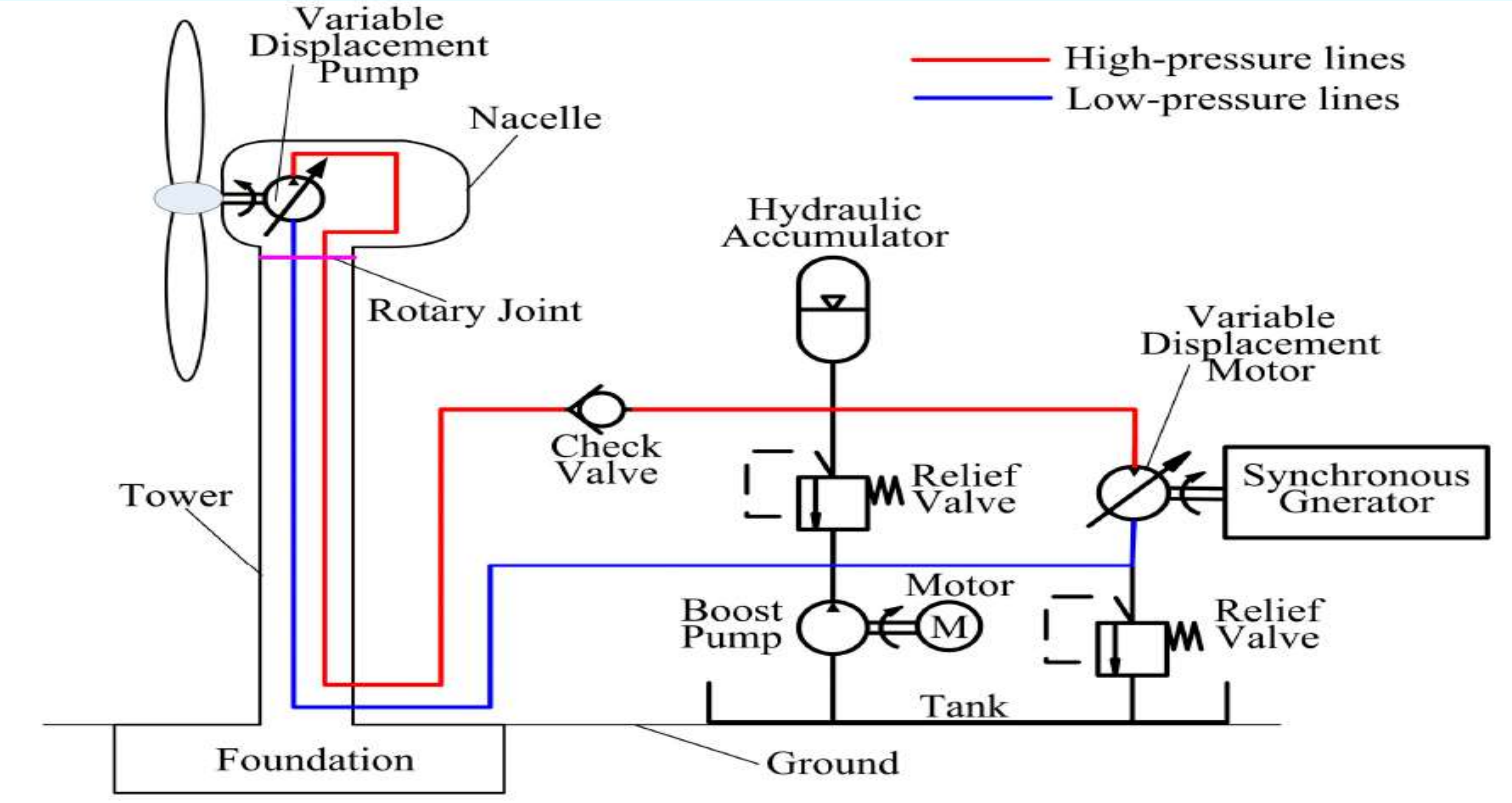
Hydraulic Wind Turbine System

Wind turbines actually rely on **hydraulics** to produce the density and provide the durability they need for generating **electricity**. **Hydraulics** produce high pressure that helps the blades of large two-ton and three-ton **turbines** spin.

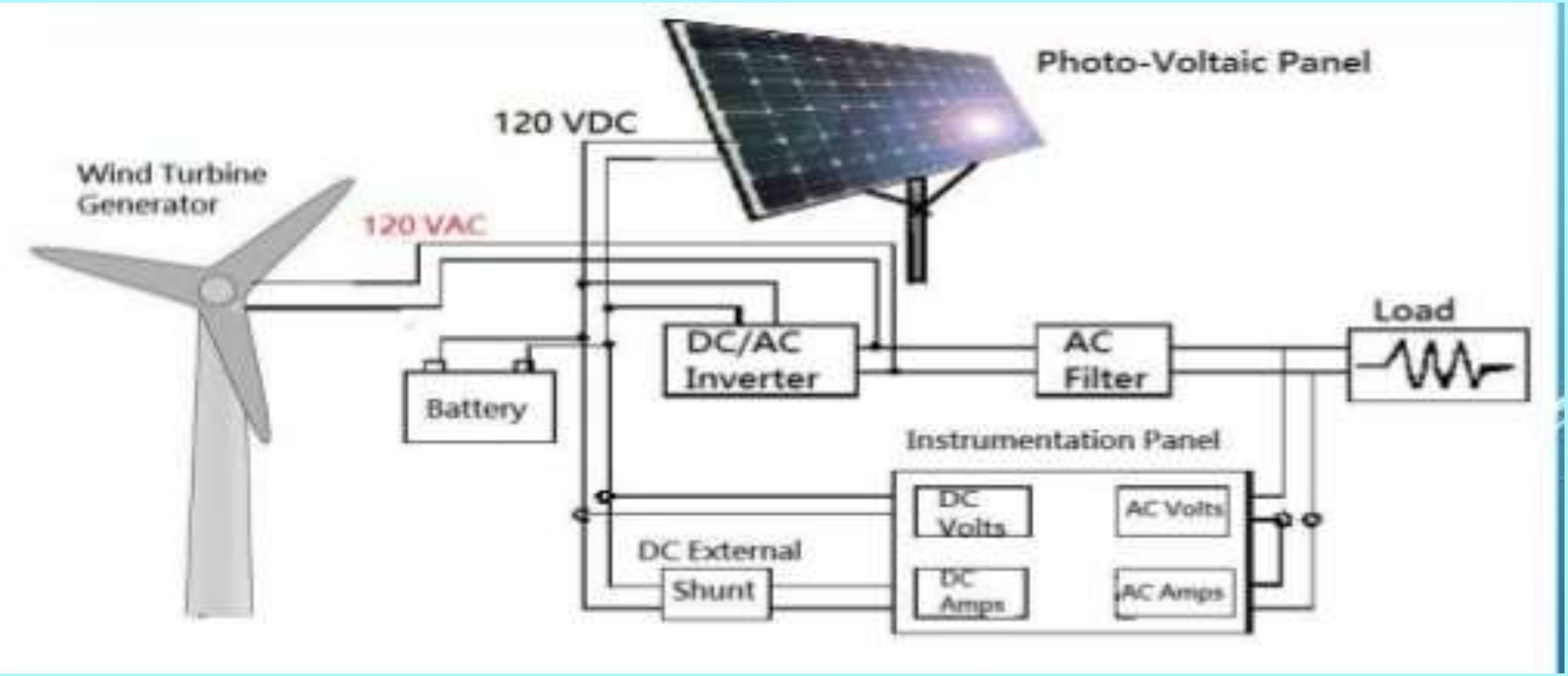


Hydraulic Wind Turbine System

600 kW Closed Hydraulic Wind Turbine with an Energy Storage System

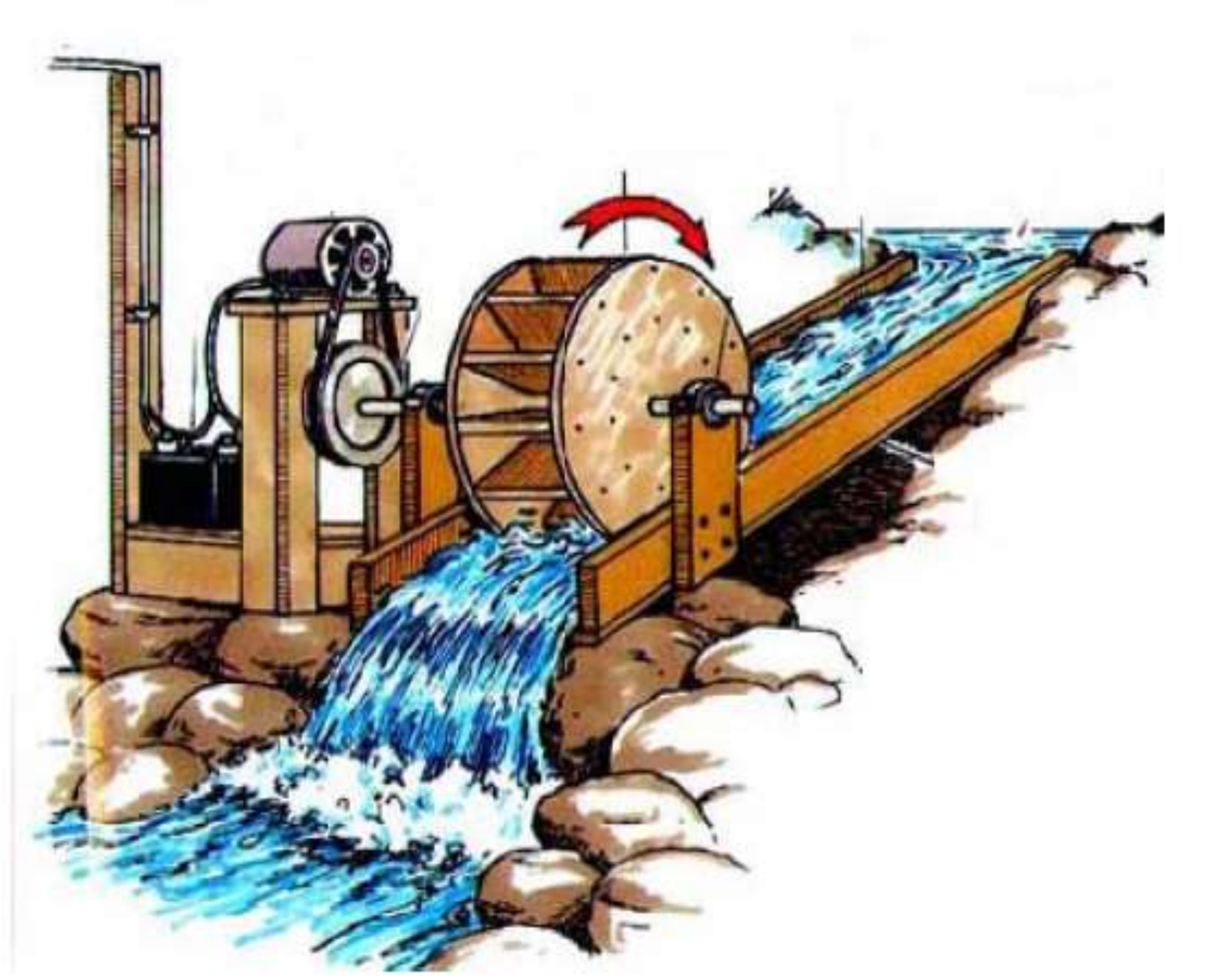


Hybrid Power System



Wind speeds are low in the summer when the sun shines brightest and longest. The wind is strong in the winter when less sunlight is available. Because the peak operating times for wind and solar systems occur at different times of the day and year, hybrid systems are more likely to produce power when you need it.

Renewable Hydro Power



A small hydropower generating unit is identified as a power supply that feeds a distant or a local load from a small hydroelectric source, which could either be run-of river, or have a small impoundment.

Small Hydro Power India

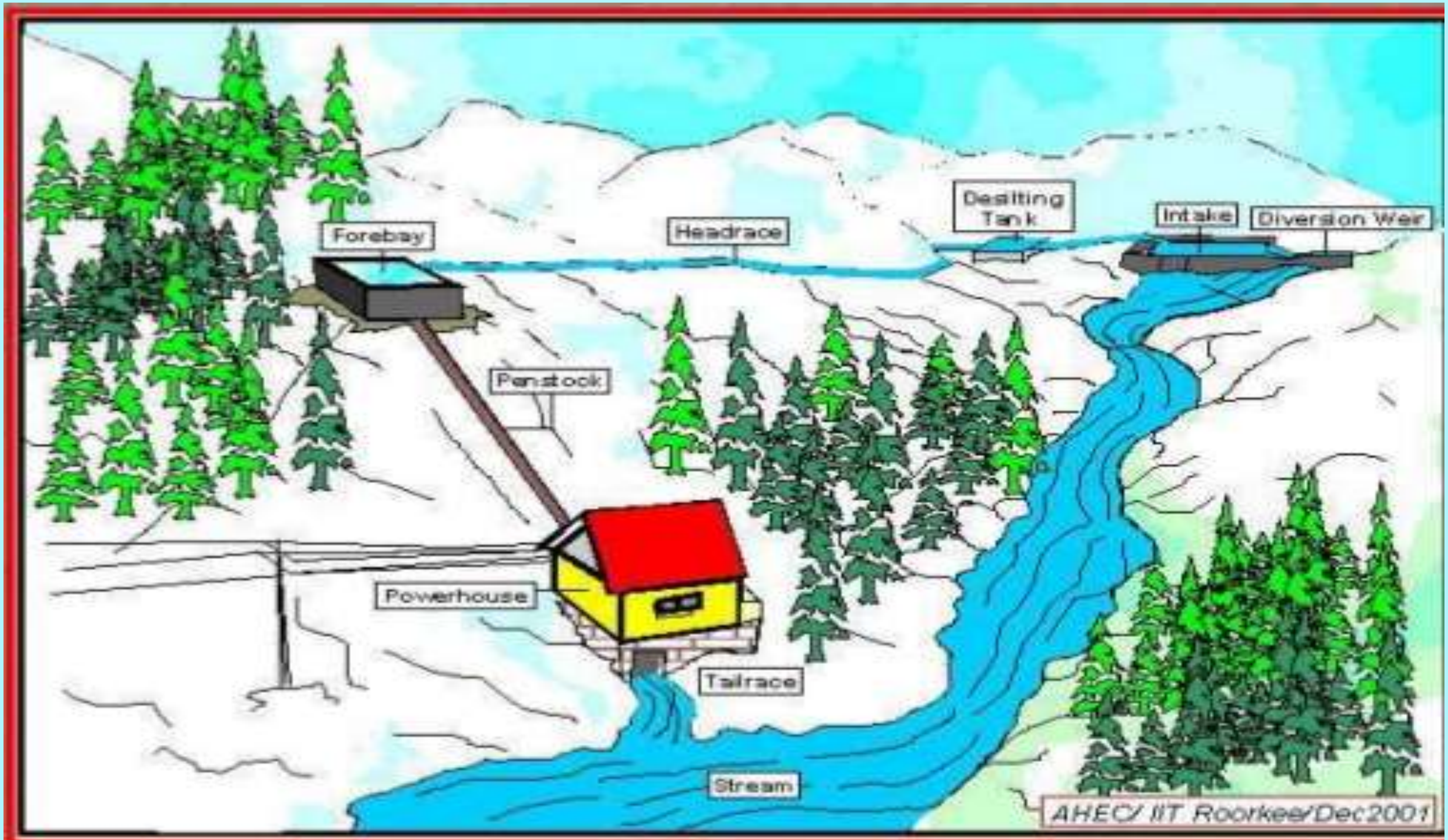
India is the 7th largest producer of hydroelectric power in the world. As of 30 April 2017, India's installed hydroelectric capacity was 44,594 MW, or 13.5% of its total utility power generation capacity. Different countries have different size criteria to classify small hydro power project capacity ranging from 10MW to 50 MW. In India, hydro power plants of 25MW or below capacity are classified as small hydro. In India Small Hydro projects up to 3MW comes under Ministry of New and Renewable Energy (MNRE) rest all projects comes under Ministry of Power Govt. Of India.

Difference :Micro, Mini & Small Hydro Power

Hydro Category	Power Range	No. of Homes Powered
Pico	0 kW – 5 kW	0 – 5
Micro	5 kW – 100 kW	5 – 100
Mini	100 kW – 1 MW	100 – 1,000
Small	1 MW – 10 MW	1,000 – 10,000
Medium	10 MW – 100 MW	10,000 – 100,000
Large	100 MW+	100,000+

Renewables First operates in the micro hydro and mini hydro categories, so from 5 kW to 1 MW power output, because so many refer to this scale of hydro as ‘small’, all use this designation a lot.

Small Hydro Power Plant



Typical Arrangement of Small Hydro Power Station

Small Hydro Power

Mini Hydro Power

Mini Hydro Power

Micro Hydro Power

Pico Hydro Power

Pico Hydro Power

Pico Hydro Power

Advantages of Mini Hydro Power

1. When compared with an equivalent coal-fired power station output, this mini hydro system saves around 950 tones of CO_2, 12 tones of SOX, and 5 tones of NOX.
2. The calculated payback period of the scheme is reasonable considering the estimated life expectancy of the power plant.
3. Lower operation and maintenance costs are expected owing to fewer and less complicated electrical and mechanical equipment in the powerhouse.
4. This scheme is an easy and reliable solution to tackle federal policies like Non-Fossil Fuel Obligation (NFFO)
5. The design can be implemented with minimal visual impact on the environment and be in harmony with the unique nature of rural communities.

Disadvantages of Mini Hydro Power

1. Sensing equipment is needed to detect any build-up of material on the screened mesh at the intake chamber, and timely cleaning of the screen is required to maintain optimum flow to the turbine. This is routine maintenance.
2. Telemetry linked to the power station is required to ensure reliable monitoring of critical hydro parameters.
3. Although operating and maintenance costs are minimal periodic checks are required. If these checks are overlooked, sudden failure of the hydro system can result.

Environmental Issues

1Emission of dust and materials into water could result in the short-term increase of suspended particles in the water thereby affecting the aquatic species and reducing the natural attractiveness of the river.

2. Construction equipment used at the site also releases pollutants temporarily, although the total amount is very small.
3. Small hydro impact from any development is site specific.
4. Small hydro schemes, if not carefully engineered, may also change the level of suspended solids in the water thereby affecting the erosion and siltation of the river. This might can effect natural flow patterns of the river which could impact activities downstream.
5. The use of biocides and anti fouling preparations for the cleaning of pipes can pollute the discharge water. However, good operating practices minimize the use of such chemicals.

Thank You