Wind Energy & Wind turbines

WIND ENERGY

- How Wind Power Is Generated
- Wind Turbines
- Wind Turbine Types
- Turbine Components
- Turbine Configurations
- Wind Turbine Size and Power Ratings
- Advantages and Disadvantages

- **Wind Energy is an indirect form of solar energy which can be used continuously unlike solar energy**

- Wind energy classified in two types 1.- Planetary winds
  2.- Local winds.

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Planetary winds are cause due to greater heating of earth’s surface near the equator as compared to solar heating near the south & north poles.

Local winds are caused due to differential heating of land & water in coastal areas these are also caused due to uneven heating in hills & mountain along the slopes.

- Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern wind turbines, can be used to generate electricity.

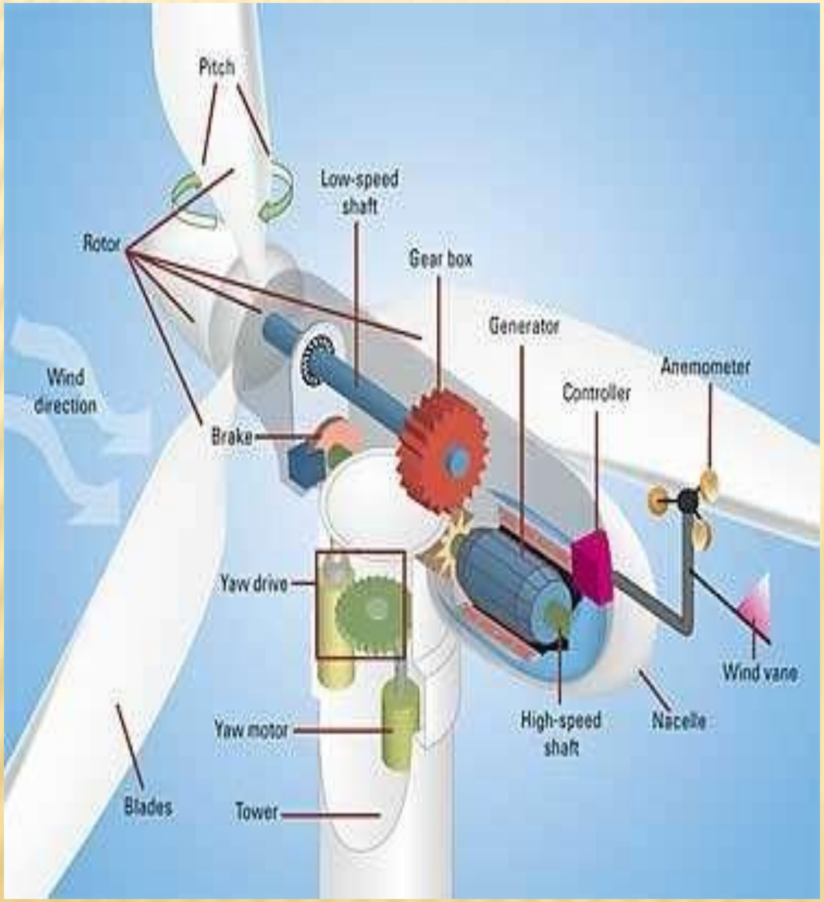
WIND MILLS

HOW WIND POWER IS GENERATED

- The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or 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 to power homes, businesses, schools,and the like.

WIND TURBINES



- Wind turbines, like aircraft propeller blades, turn in the moving air and power an **electric** ***generator*** that supplies an electric current.

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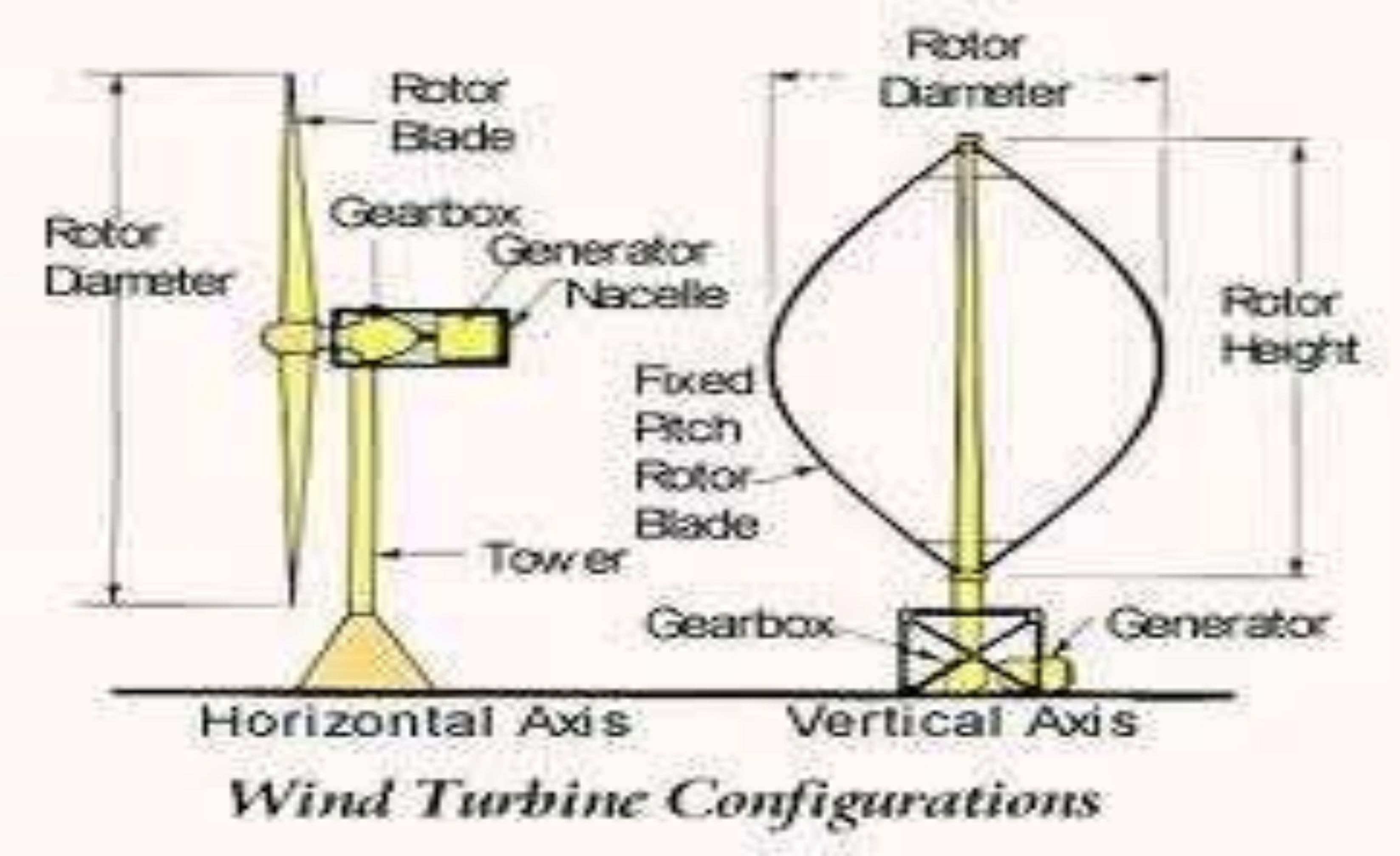
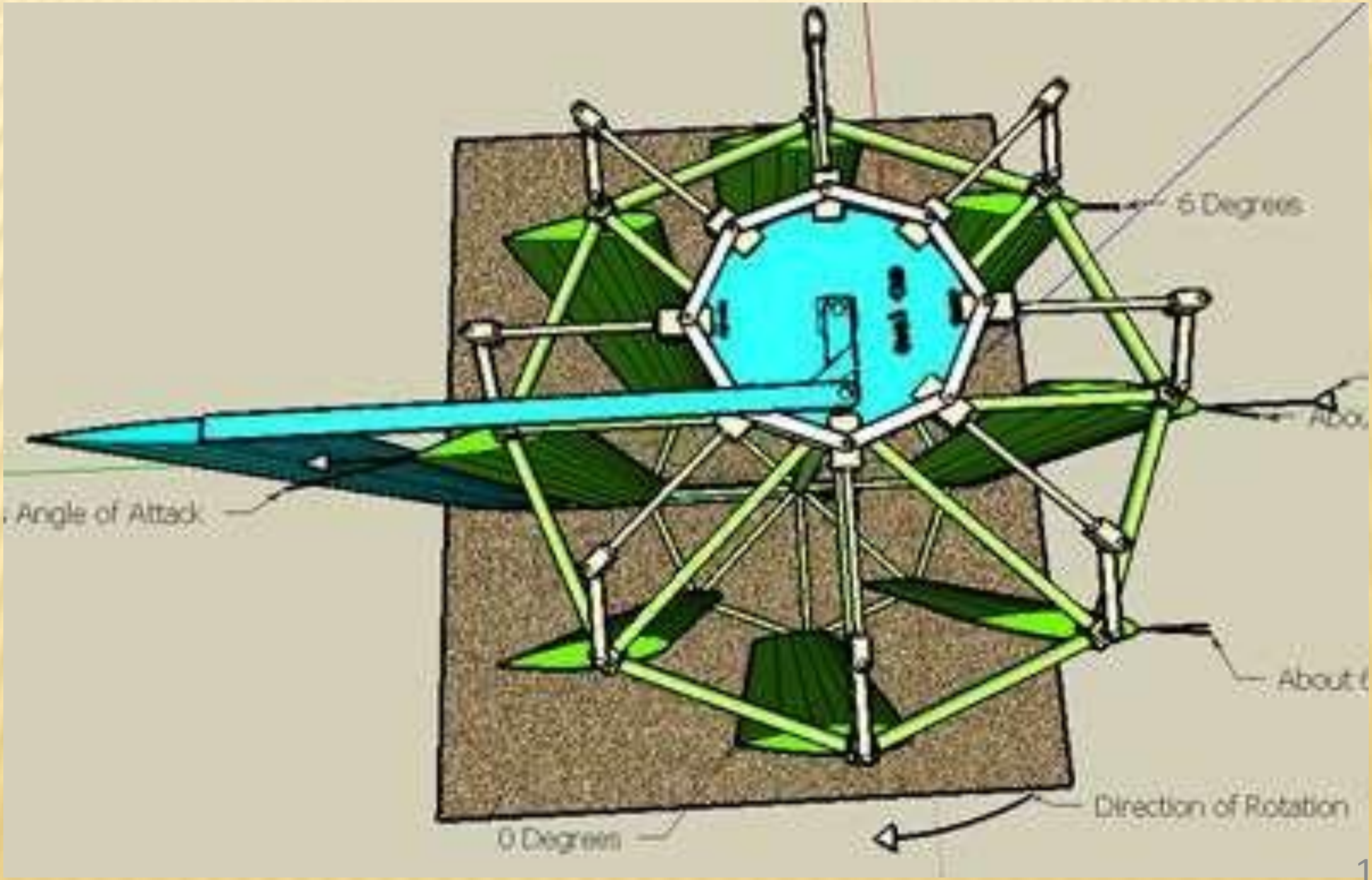
- Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind, like a **fan, wind turbines use wind to make** electricity. The wind turns the blades, which spin a shaft, which connects **to a generator and makes electricity.**

WIND TURBINE TYPES



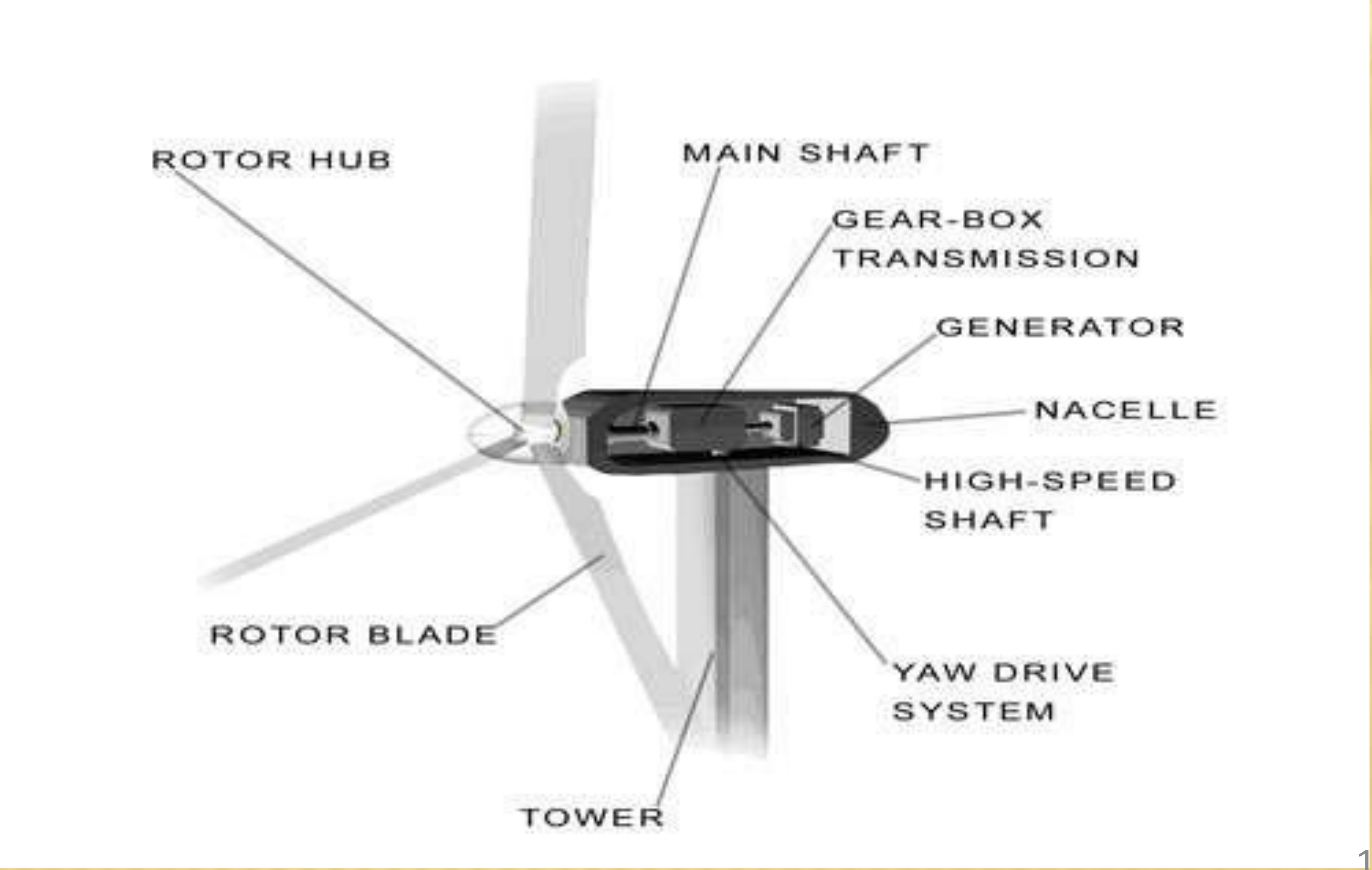
Wind Turbine Configurations

VERTICAL AXIS TURBINE

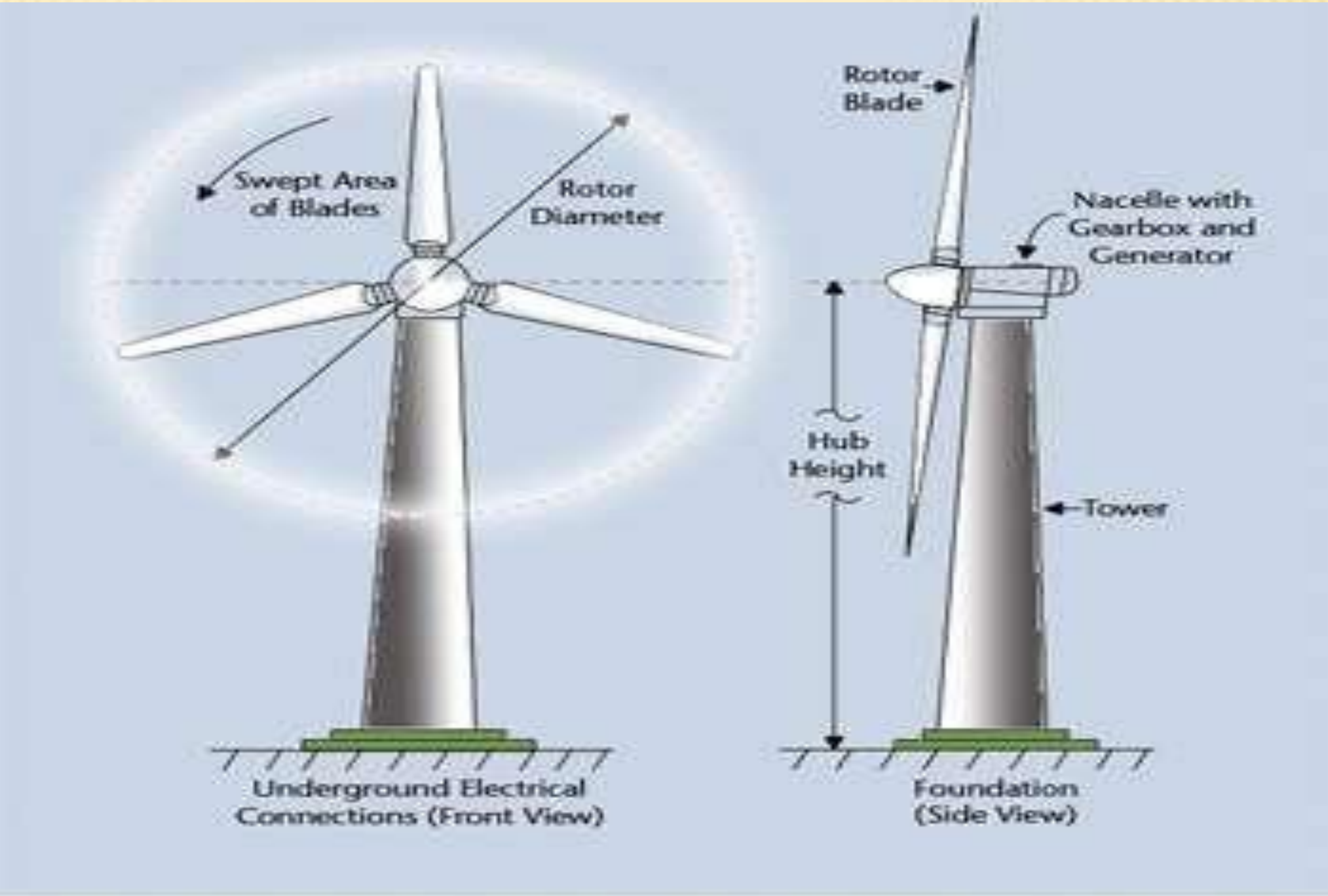


- Modern wind turbines fall into two basic groups; the **horizontal-axis** variety, like the traditional farm windmills used for pumping water, and the **vertical-axis** design, like the eggbeater-style Darrieus model, named after its French inventor. Most large modern wind turbines are horizontal-axis turbines.

TURBINE COMPONENTS



- **blade** or **rotor**, which converts the energy in the wind to rotational shaft energy;
- a **drive train**, usually including a gearbox and a generator; a **tower** that supports the rotor and drive train
- other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.



Drawing of the rotor and blades of a wind turbine, courtesy of ESN

TURBINE CONFIGURATIONS

Electricity from these turbines is fed into a utility Wind turbines are often grouped together into a single wind power plant, also known as a wind farm, and generate bulk electrical power.grid and distributed to customers, just as with conventional power plants.

WIND TURBINE SIZE AND POWER RATINGS

- **Wind turbines are available in a variety of sizes, and therefore power ratings. The largest machine has blades that span more than the length of a football field, stands 20 building stories high, and produces enough electricity to power 1,400 homes.**

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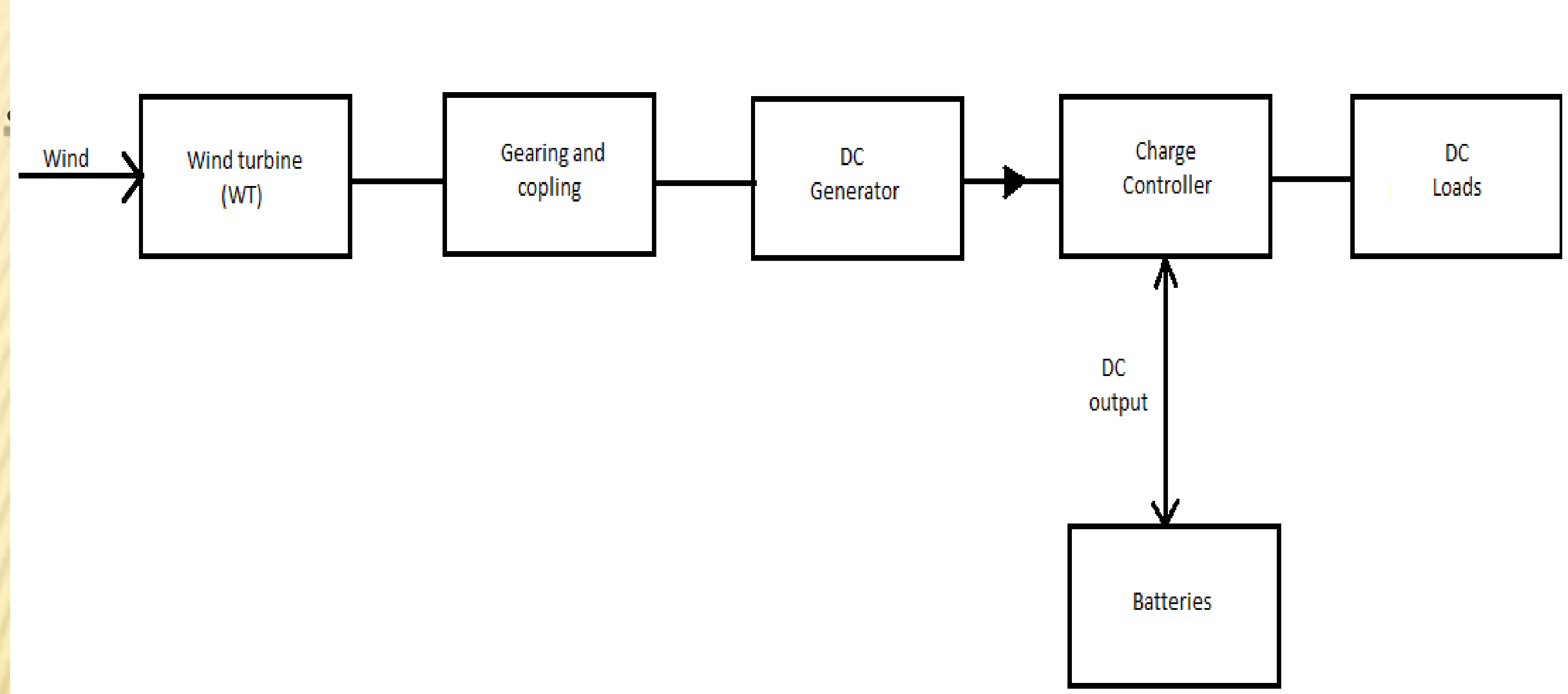
- ***A small home-sized wind machine has rotors between 8 and 25 feet in diameter and stands upwards of 30 feet and can supply the power needs of an all-electric home or small business. Utility-scale turbines range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications***



- **In this system the wind energy is converted to DC power by a DC generator & charges the batteries.**

- **Power is supplied to DC loads or by the batteries. The charge controller is used for controlling the charge/discharge of batteries. The systems can be used as standalone system for charging the batteries or for power supply in remote areas.**

TOTAL WIND POWER

- The total wind power is equal to the incomming kinetic energy of the wind stream.
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$$P=\tfrac{1}{8} \square \rho D^2 C^3$$

P=power

ρ=Density of air(kg/m^3)

D=Rotor diameter

C=Incomming wind velocity(m/s)

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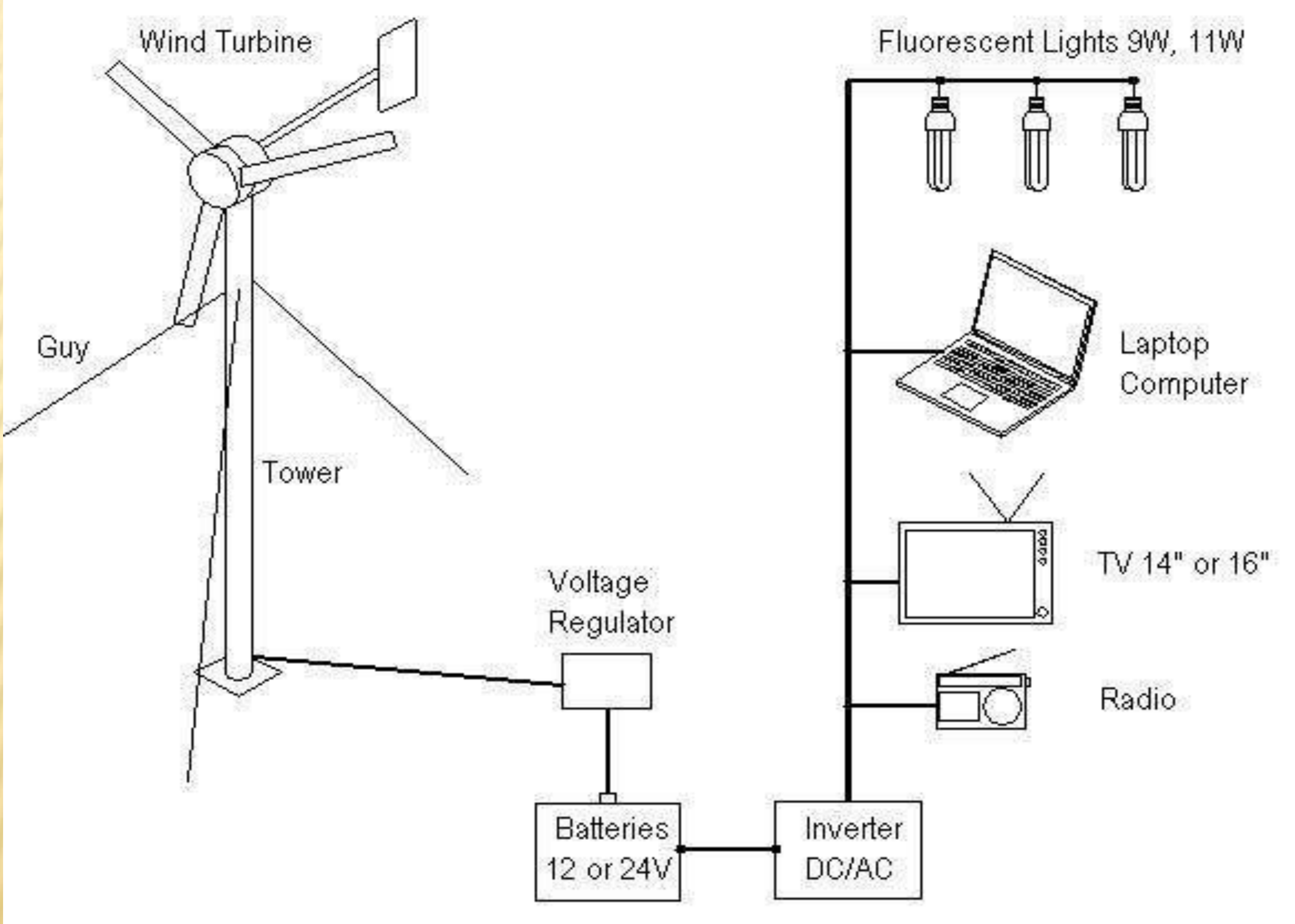
- **The wind power generation India was stared in 1994-95 with installed capacity of 230MW The installed power generator capacity up to September 2006 was 6018MW out of which 1080MW was installed in the year2006 itself there fore , we find that wind power generation in India is growing at rapid rate.**

WIND POWER GENERATION IN INDIA

STATE	POWER (MW)
Andra Pradesh	2000
Gujrat	3100
Karnatak	4120
Kerala	1380
Madhya Pradesh	1920
Orrisa	840
Rajasthan	1210
Tamil Nadu	1900
West Bengal	1180
Other State	2150
TOTAL	20000


Wind Turbine
Guy
Tower
Voltage Regulator
Batteries 12 or 24V
Inverter DC/AC
Fluorescent Lights 9W, 11W
Laptop Computer
TV 14" or 16"
Radio

ADVANTAGES AND DISADVANTAGES OF WIND-GENERATED ELECTRICITY

- **A Renewable Non-Polluting Resource :**
- **Wind energy is a free, renewable resource, so no matter how much is used today, there will still be the same supply in the future. Wind energy is also a source of clean, non-polluting, electricity. Unlike conventional power plants, wind plants emit no air pollutants or greenhouse gases**

- According to the U.S. Department of Energy, in 1990, California's wind power plants offset the emission of more than 2.5 billion pounds of carbon dioxide, and 15 million pounds of other pollutants that would have otherwise been produced. It would take a forest of 90 million to 175 million trees to provide the same air quality.

COST ISSUES

- Even though the cost of wind power has decreased dramatically in the past 10 years, the technology requires a higher initial investment than fossil-fueled generators. Roughly 80% of the cost is the machinery, with the balance being site preparation and installation.

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- If wind generating systems are compared with fossil-fueled systems on a "life-cycle" cost basis (counting fuel and operating expenses for the life of the generator), however, wind costs are much more competitive with other generating technologies because there is no fuel to purchase and minimal operating

ENVIRONMENTAL CONCERNS

- **Although wind power plants have relatively little impact on the environment compared to fossil fuel power plants, there is some concern over the noise produced by the rotor blades, aesthetic (visual) impacts, and birds and bats having been killed (avian/bat mortality) by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or**

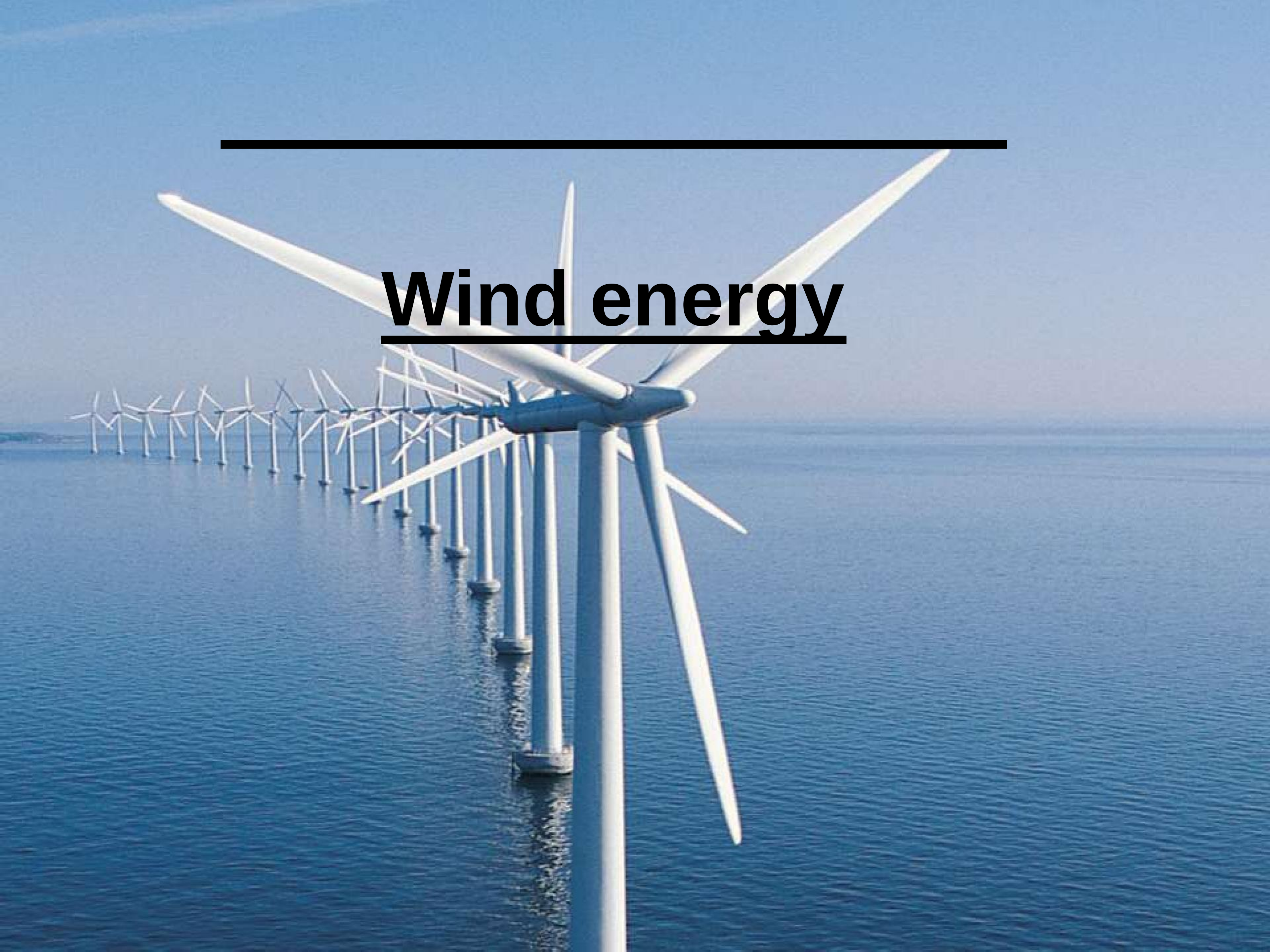
SUPPLY AND TRANSPORT ISSUES :

- **The major challenge to using wind as a source of power is that it is intermittent and does not always blow when electricity is needed. Wind cannot be stored (although wind-generated electricity can be stored, if batteries are used), and not all winds can be harnessed to meet the timing of electricity demands.**

- Further, good wind sites are often located in remote locations far from areas of electric power demand (such as cities). Finally, wind resource development may compete with other uses for the land, and those alternative uses may be more highly valued than electricity generation. However, wind turbines can be located on

Assignment :

Q 1. Wind is the form of solar energy. Eplain
Q 2. How wind is generated ? What are the types of wind.
Q 3. How wind power is generated ?
Q 4. What is a wind turbine ?What are its types ?
Q 5. Explain the wind turbine components, with the help of a neat diagram.
Q 6. What are advantages and disadvantages of wind generated electricity ?
Q 7. Explain the cost issues of energy produced by wind turbines.
Q 8. Explain the environment issue of wind turbines.
Q 9. Explain the supply and transport issues of wind energy.
Q 10. Draw a line diagram of production of wind energy by wind turbines.



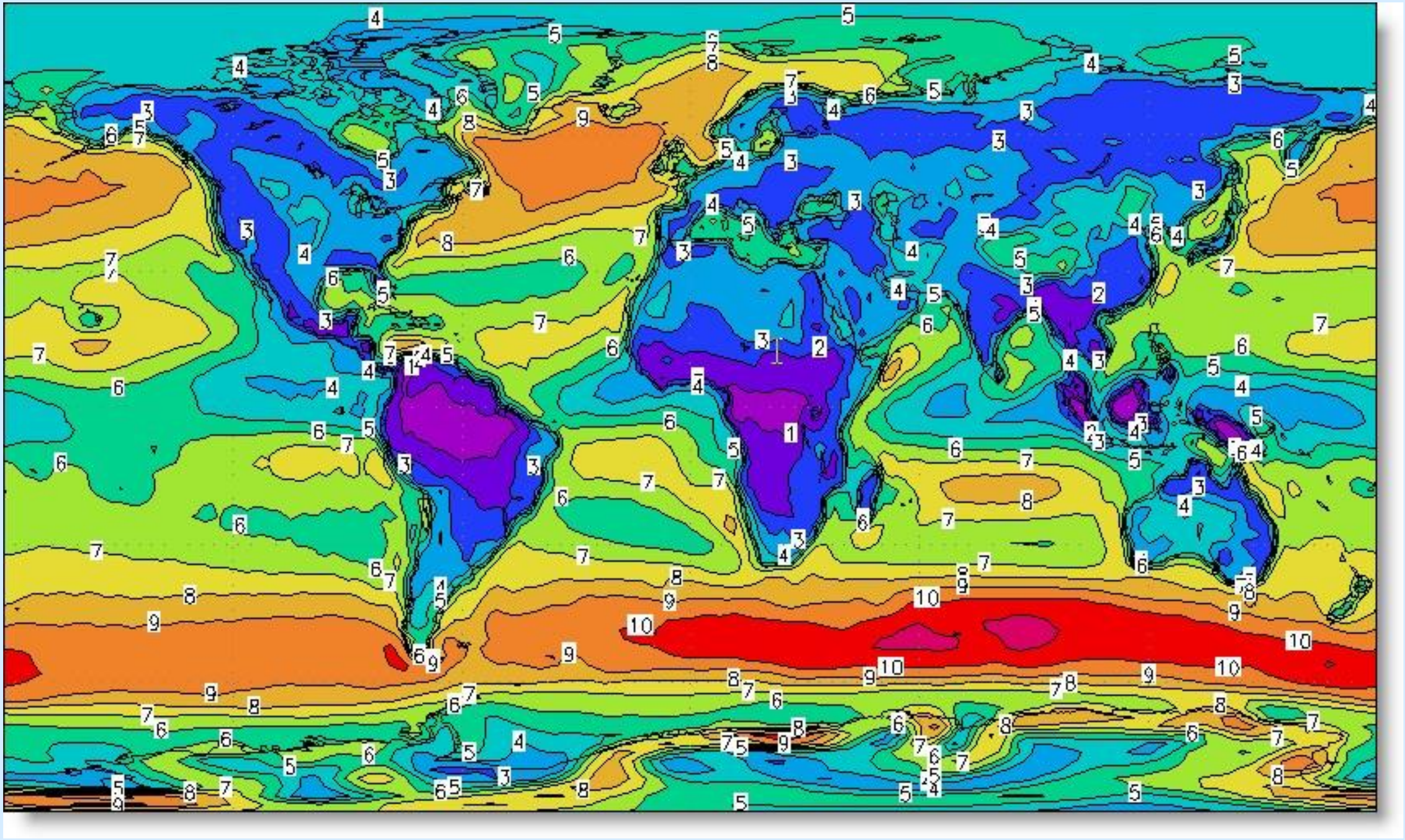
Wind energy

Energy in a moving object:

- Any moving object has energy. This type of energy is called kinetic energy. For example, a car, a bicycle, or a ball, when moving, all have kinetic energy.The amount of energy of a moving object depends on two factors, its mass and its speed.

- The same is true for moving air when wind strikes an object, it exerts a force in an attempt to move it out of the way. Some of the winds' energy is transferred to the object, in this case the windmill, causing it to move.

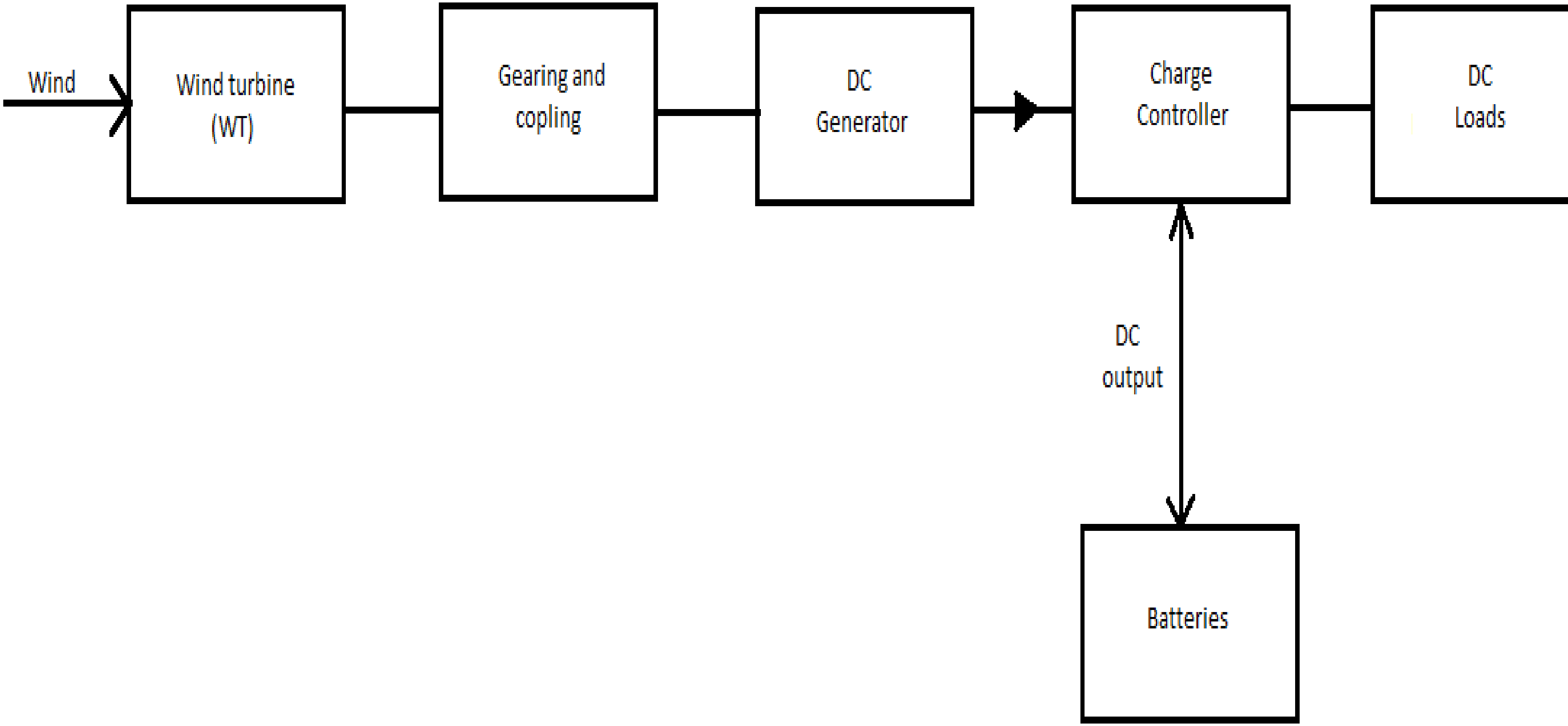
Average World Wind Energy Resources



History:

- One of the earliest energy resources.
- Used to power boats and grind grain, later to pump water,
- Windmills were mentioned at the beginning of Islamic civilization (7th century).
- Egyptians may have been the first to go up the Nile river around 4th century powered by wind.
- Chinese used vertical axis windmills to grind grain.
- Windmills used for pumping water.

How do you convert wind into electricity???



Wind

Wind turbine
(WT)

Gearing and
copling

DC
Generator

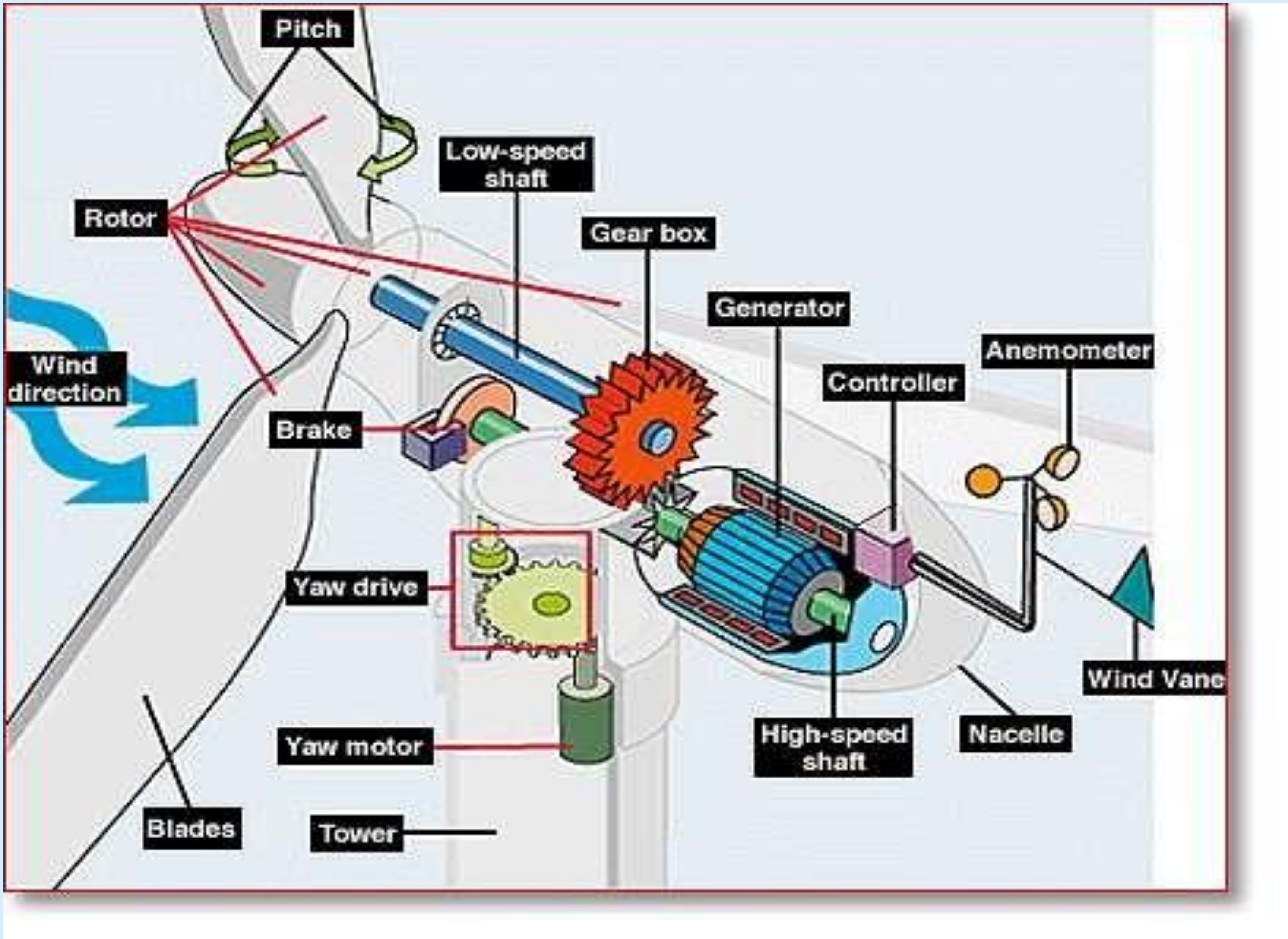
Charge
Controller

DC
Loads

DC
output

Batteries

Wind turbine:



Mechanical components

- Foundation
- Tower
- Blades
- Hub
- Nacelle
- Generator
- Turbine brake
- Gearbox
- Yaw motor and drive
- Wind vane & Anemometer
- Controller

Foundation:

Foundation:

Any turbine tower must be able to withstand all the various forces from the wind. A turbine is like a high-rise building, which is subject to heavy weight and large lateral forces from wind. For any heavy structure, the foundation must be strong enough to withstand the forces. Because soil is not strong, the foundations of large structures are mounted on a number of piles that are inserted in the ground by hammering action. Under each wind turbine, large concrete foundation with a sufficiently huge mass that holds the wholeTurbine.

Foundation:

The turbine size, weather conditions in the region, the type of soil, and the terrain topography. It can be a 50 ft 50 ft 30 ft deep block (15 m 15 m 9 m deep) of concrete. The tower is bolted to the foundation by a number of bolts These bolts are long and reach the bottom of the foundation .Only part of each bolt is out of the ground to install the tower. A plastic cover can be used for protection of bolts from rain and snow.

Tower:

Tubular tower

Lattice towers

Tower:

The tower supports the other parts and holds them in the air. Thus, the tower must be structurally strong to withstand the weights of the components it supports and the forces from wind that can easily bend or break the tower if it is not strong enough.

Tower:

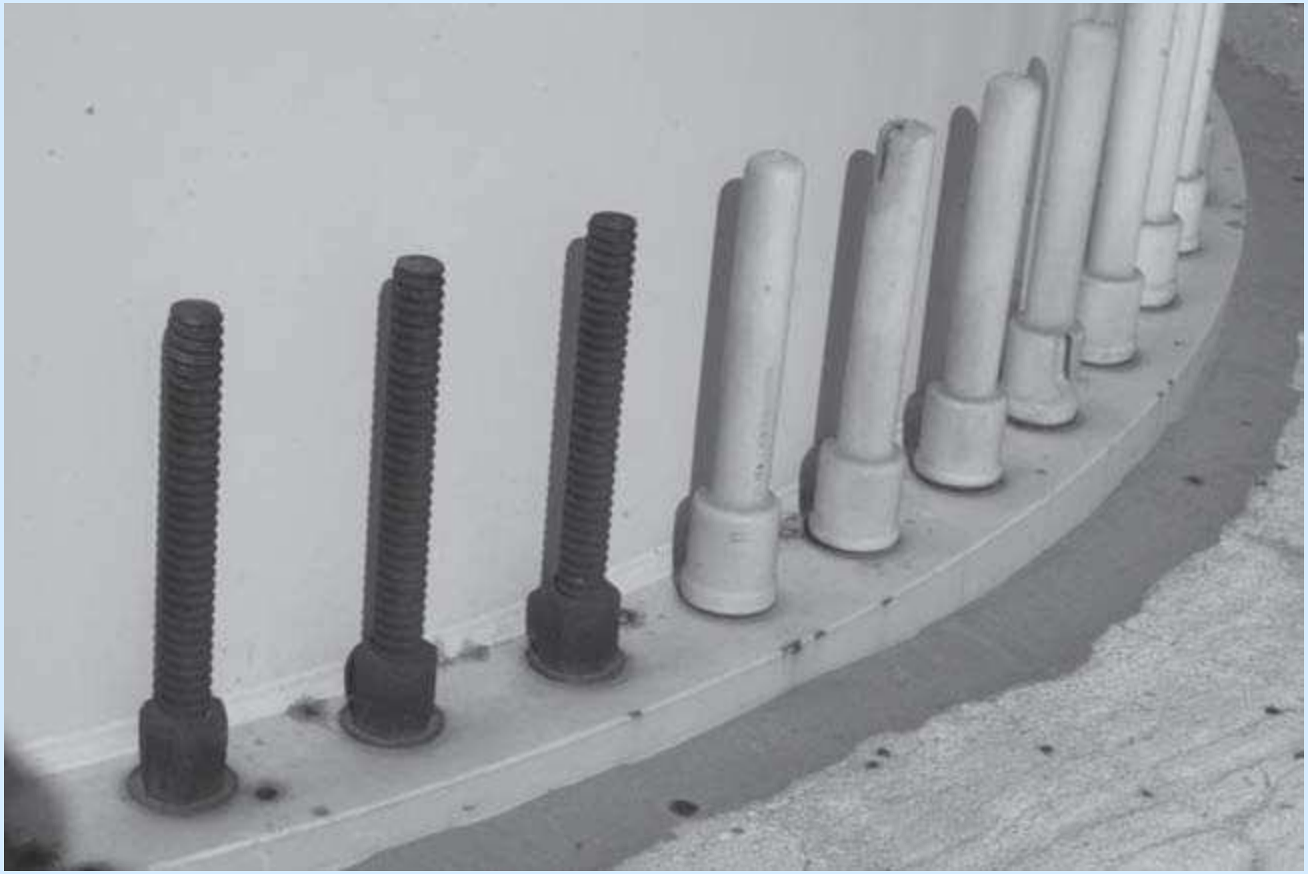
- **Lattice Towers:**

  In the earlier turbines lattice towers were used. These towers are like the ones used for overhead transmission lines, made up of a number of metallic bars that are bolted or welded together.

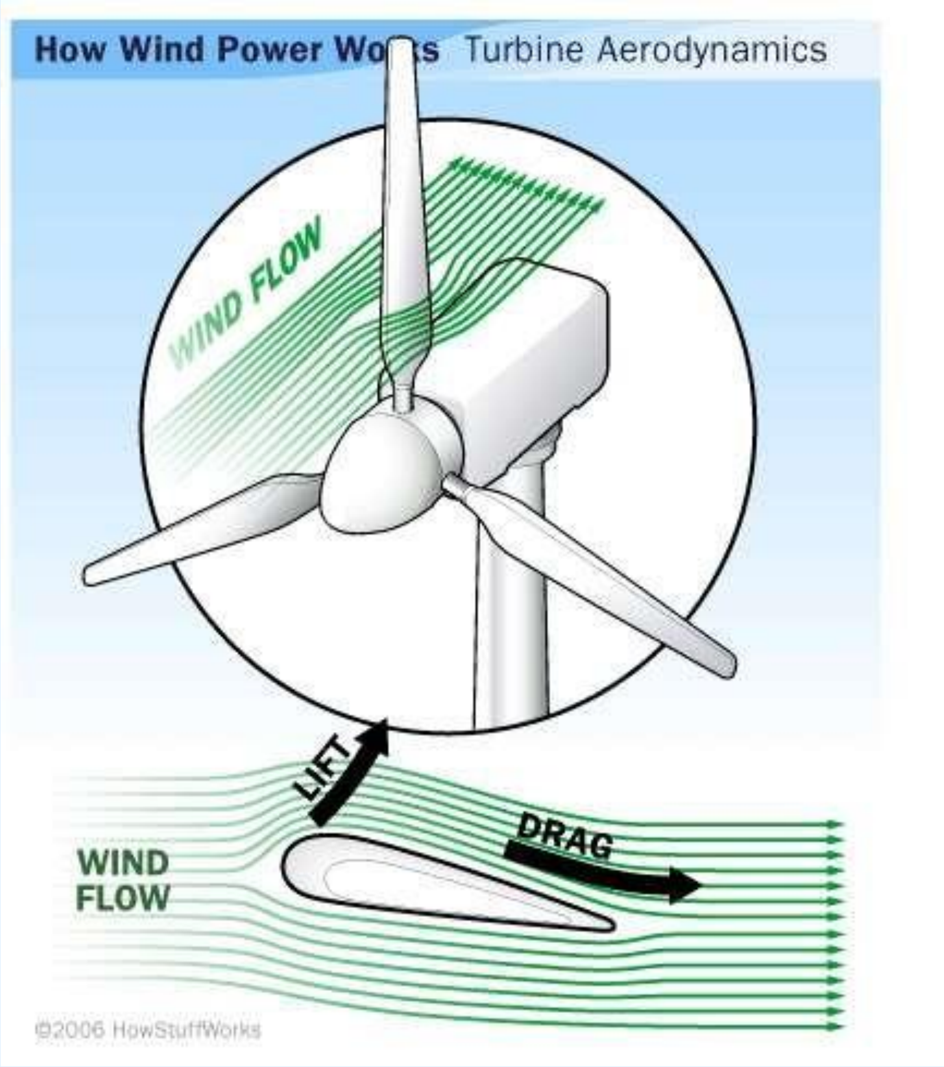
- **Tubular Tower:**

  These towers are usually made in a number of shorter segments that make both manufacturing and transportation easier. The segments are attached together by bolts. The diameter of a tubular tower can be 10–14 ft . It is usually tapered, it has a smaller diameter on the top.

Tower fitting with foundation:



Blades:


How Wind Power Works Turbine Aerodynamics
WIND FLOW
LIFT
DRAG
WIND
FLOW
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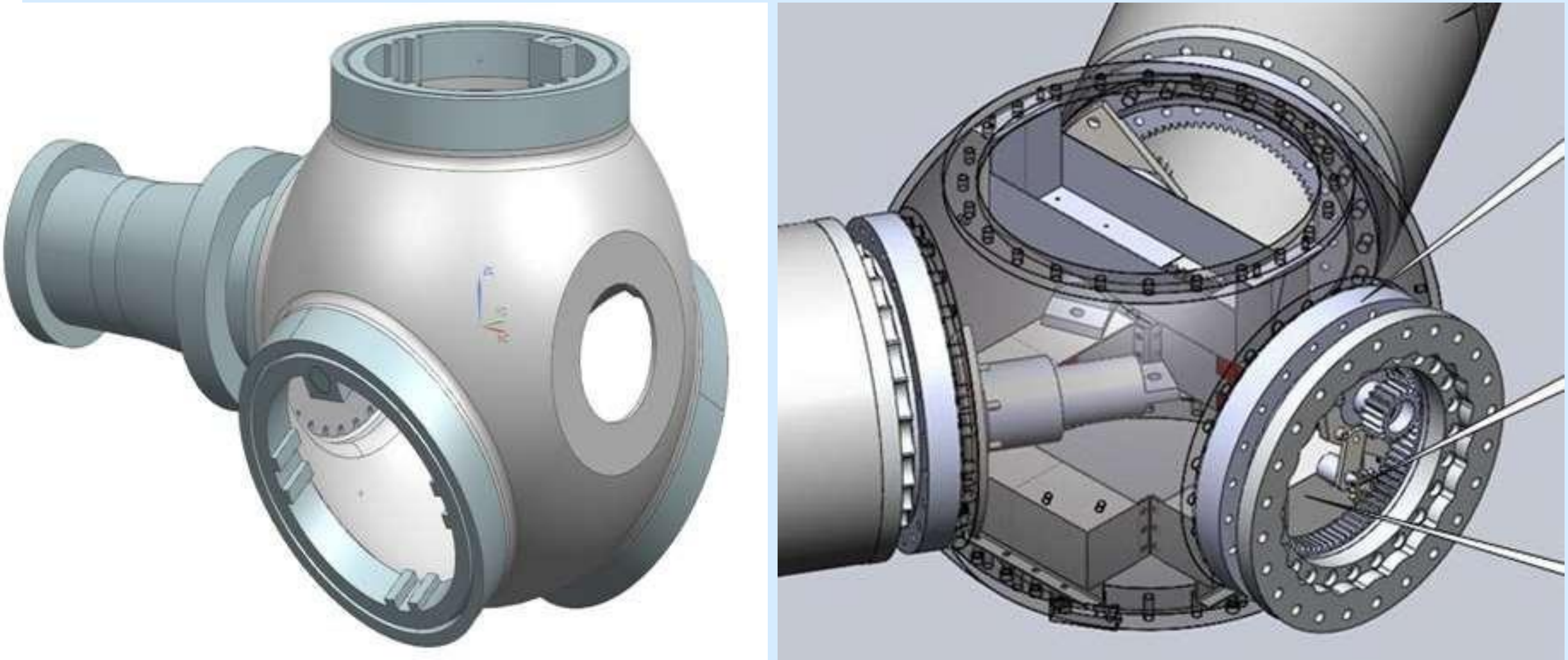
Blades:

- Blades are the parts of a wind turbine that catch the wind energy. lift forces in the three blades give rise to a torque on the hub of turbine and the hub start rotating due to this torque at the turbine shaft also start rotating which is coupled with the gear box.
- The angle of blades are changed according to the condition of air with the pitch adjustment mechanism installed on hub

Blades Material:

- Wide availability and easy processing to reduce cost and maintenance.
- Low weight or density to reduce gravitational forces.
- High strength to withstand strong loading of wind and gravitational force of the blade itself.
- High fatigue resistance to withstand cyclic loading.
- The ability to withstand environmental impacts such as lightning strikes, humidity, and temperature.

Hub:



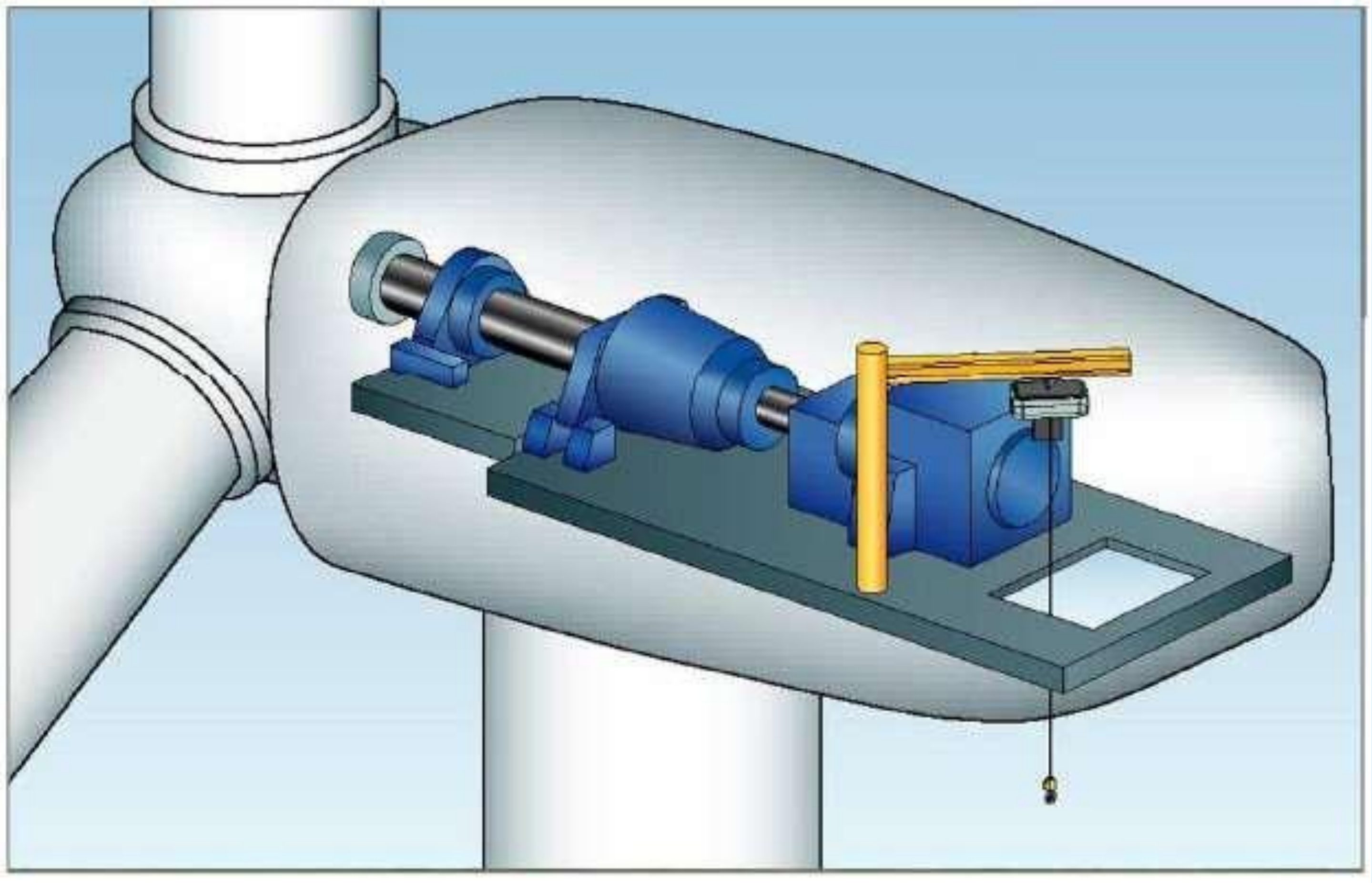
Hub:

- The hub is that part on which the blades are fitted and this hub is attached with the low speed shaft which is connected with gearbox.
- The hub and the blades always rotate together when a turbine is working. They drive the turbine shaft .All the energy grasped from wind is on the turbine shaft .

Hub:

- In the older turbines the blades were fixed to the hub with bolts and there was no relative motion between the hub and any of the blades. Newer turbines are equipped with **pitch control. The** blade is not fixed to the hub and can rotate with hub about its (blade’s) axis. In this way, the angle between a blade and the hub can be changed. The is angle, called **pitch angle,** can be changed up to 90° to 100°.

Nacelle:



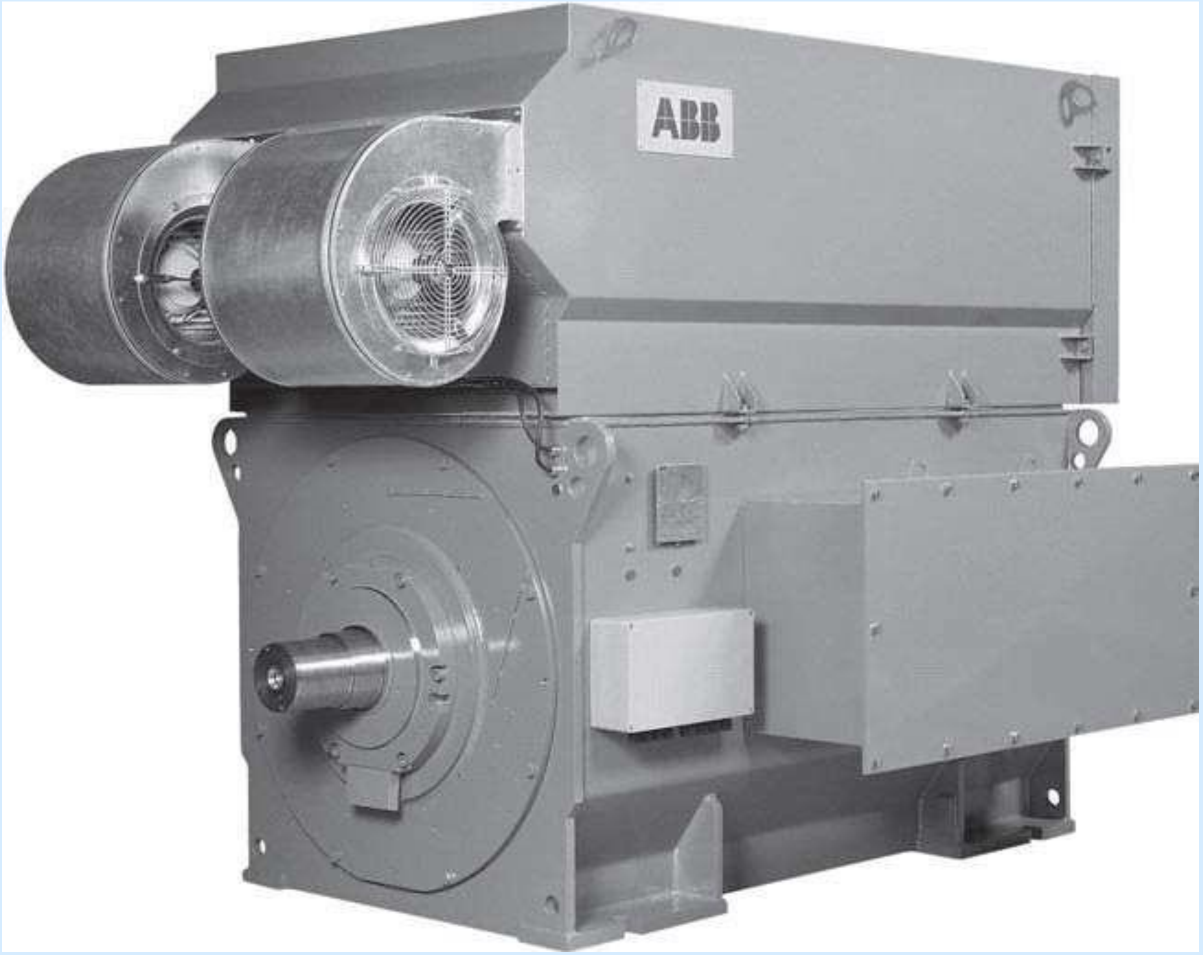
Nacelle:

- A nacelle is a cover housing that houses all of the generating components in a wind turbine, including the generator, gearbox, drive train, and brake assembly.
- The intermediate part between the rotor and the tower is the nacelle.
- The nacelle does not rotate with the rotor, but it must rotate with respect to the tower. It is not fixed with tower and the hub. It rotates about the tower axis.

Nacelle purposes:

- Houses the all equipments based on the turbine design.
- Allows yawing of the turbine; that is, adjusting the turbine orientation to the wind direction.
- Provides counterweight for the hub and blades' weight.

Generators :

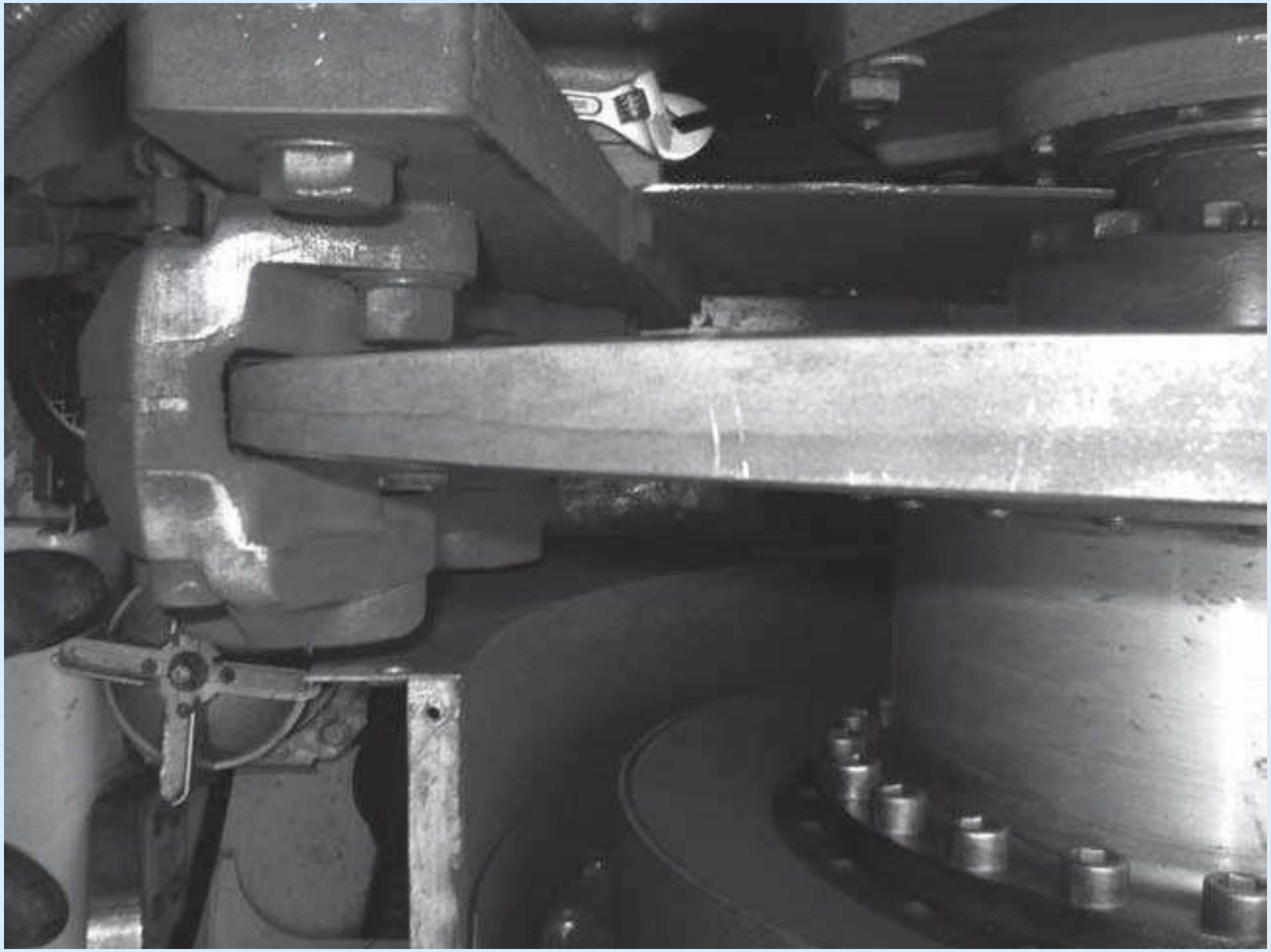


Generators :

- An electric generator converts mechanical energy to electrical energy. It comes in different sizes. The size is proportional to power.

- A generator, in fact, has the same construction as a motor. That is, it can be referred to as an electric machine; if it is fed with electricity, it behaves as a motor, and if it is turned (receives mechanical energy), it functions as a generator.

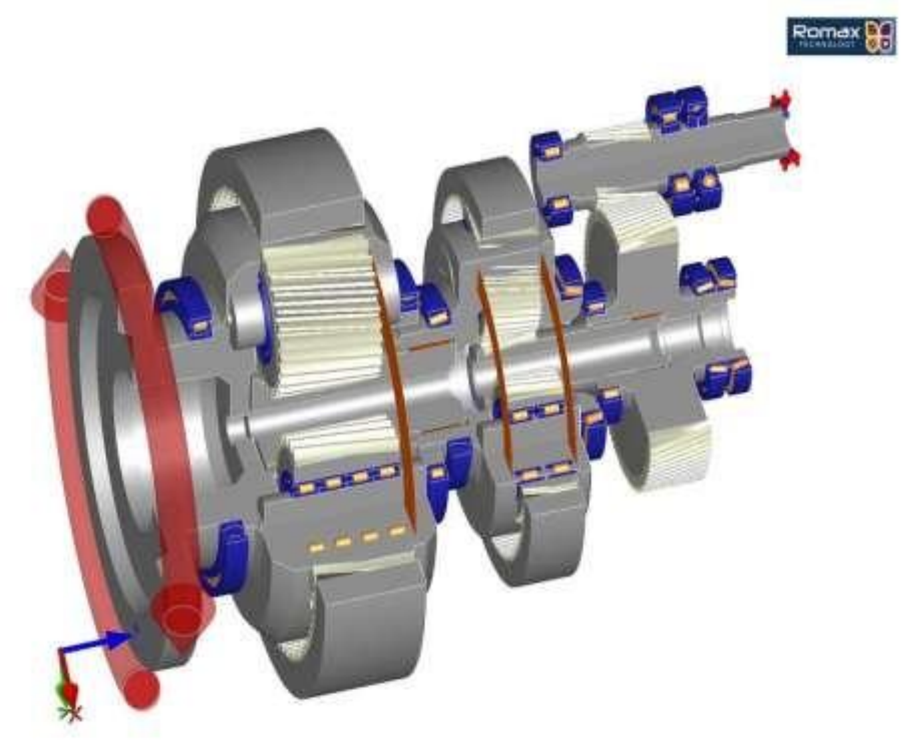
Turbine brake:



Turbine brake:

- Brake is used to stop turbine in emergency situation such as extreme gust events or over speed. This brake is a secondary means to hold the turbine at rest for maintenance.Mechanical brakes are driven by hydraulic systems and are connected to main control box

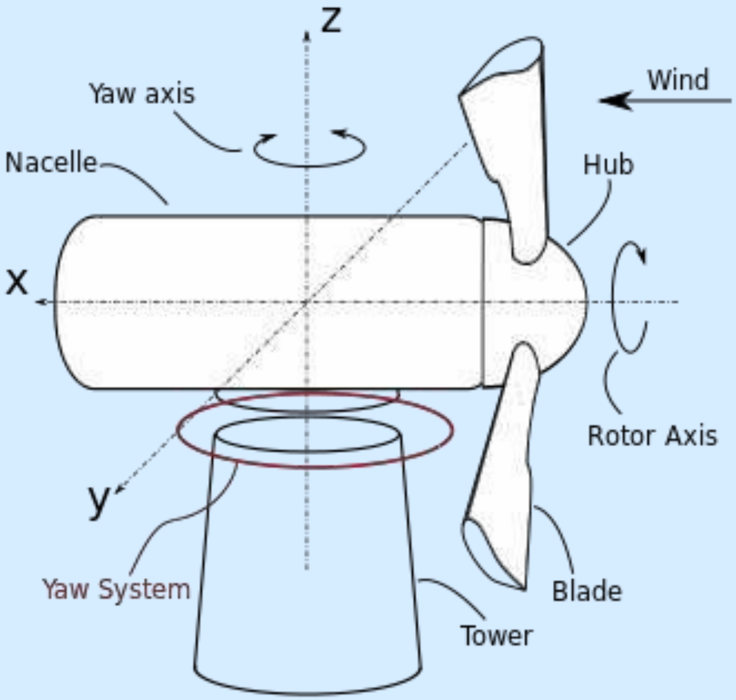
Gearbox:

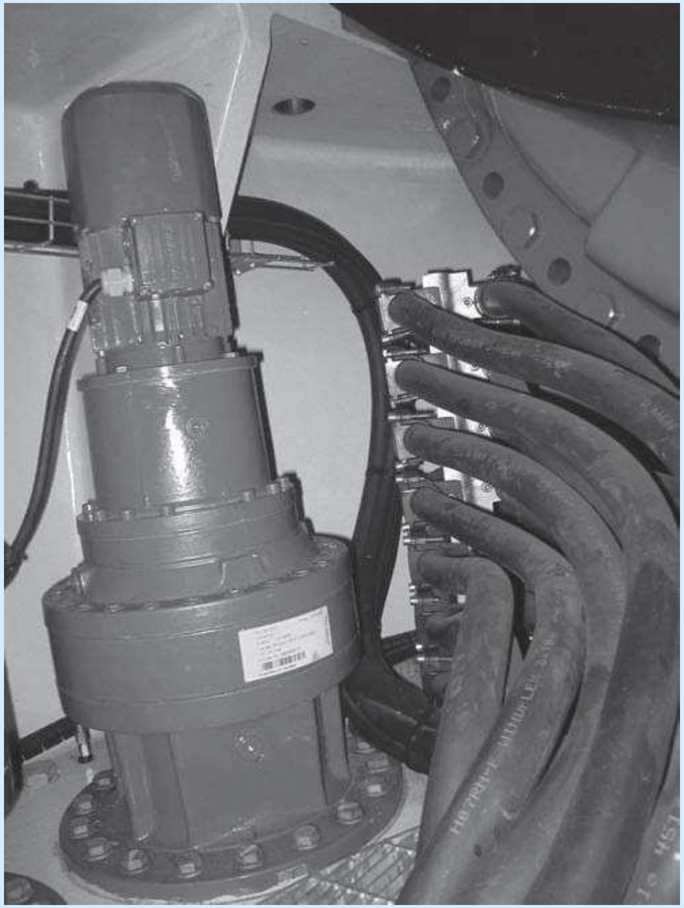


Gearbox:

- Wind turbines have a speed in the range of 24 rpm. Approximately
- A gearbox increase the rotor speed to become appropriate for the generator. The speeds for most generators are between 900 to 1800 rpm.
- A wind turbine gearbox, then, must increase the speed by a ratio of around1:75
- The more common type of gear in use is called a planetary gear.

Yaw motor and drive:





Yaw motor and drive:

- The yaw system of wind turbines is the component responsible for the orientation of the wind turbine rotor towards the wind.
- A horizontal-axis wind turbine must orient itself with the wind direction. This is the one of the automated functions of a turbine based on determining the direction of wind.
- The number of motors attached with this system and they rotate the nacelle when controller allow

Wind vane & Anemometer:

Wind vane & Anemometer:

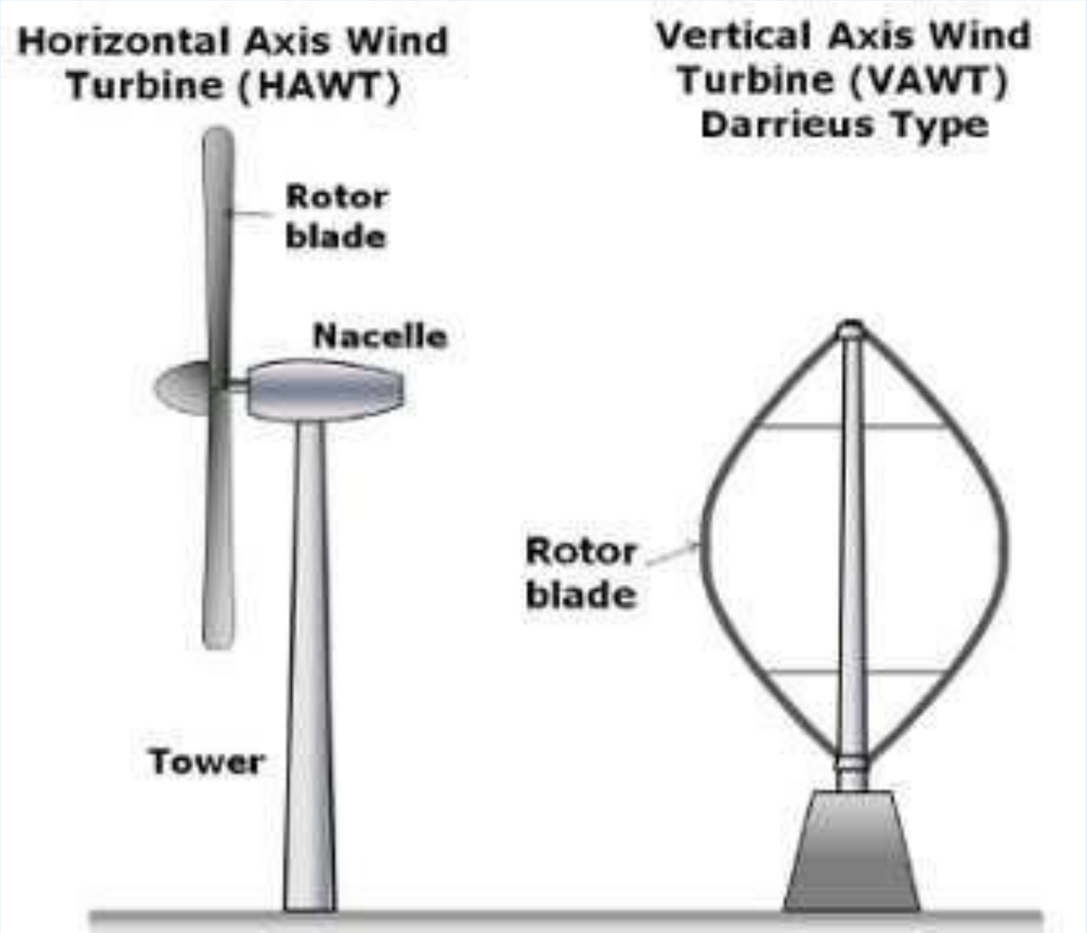
- The wind vane & anemometer is usually mounted on the top of the roof of the nacelle.
- An anemometer is used to measure the speed of wind. To control of a wind turbine it is necessary to know the speed of wind
- Wind vane is use to know the direction or air . it is essential to yaw a turbine to the wind direction, otherwise a turbine does not get the full energy from wind, and it may even stop.

Controller:

- It is a electronic device which take the signals from the anemometer and wind vane.

- On the base of these signals it give power to the yaw control motors and pitch control system

Types of wind turbine:



Horizontal axis:

- Horizontal-axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator

Vertical axis:

- Vertical-axis wind turbines have the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building because it is inherently less steerable. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance. However, these designs produce much less energy averaged over time, which is a major drawback

Total wind power:

- The total wind power is equal to the incoming kinetic energy of the wind stream

$$P=\tfrac{1}{8} * 3.14 * \rho D^2 C^3$$

P=power

ρ=Density of air(kg/m^3)

D=Rotor diameter

C=Incomming wind velocity(m/s

Onshore wind turbine:

- Onshore advantages:

1. Normally it takes about 2-3 months before the wind turbine has paid itself back.
2. This also includes the energy, which were used to produce, install, maintain and remove the wind turbine.
3. Cheaper foundation
4. Cheaper integration with electrical-grid network

Onshore wind turbine:

- Onshore disadvantages:

1. Wind turbines are noisyEach one can generate the same level of noise as a family car travelling 70 mph
2. Some people thinks that the large towers of wind turbines destroys the view of the landscape

Offshore wind turbine:

- Offshore advantages:

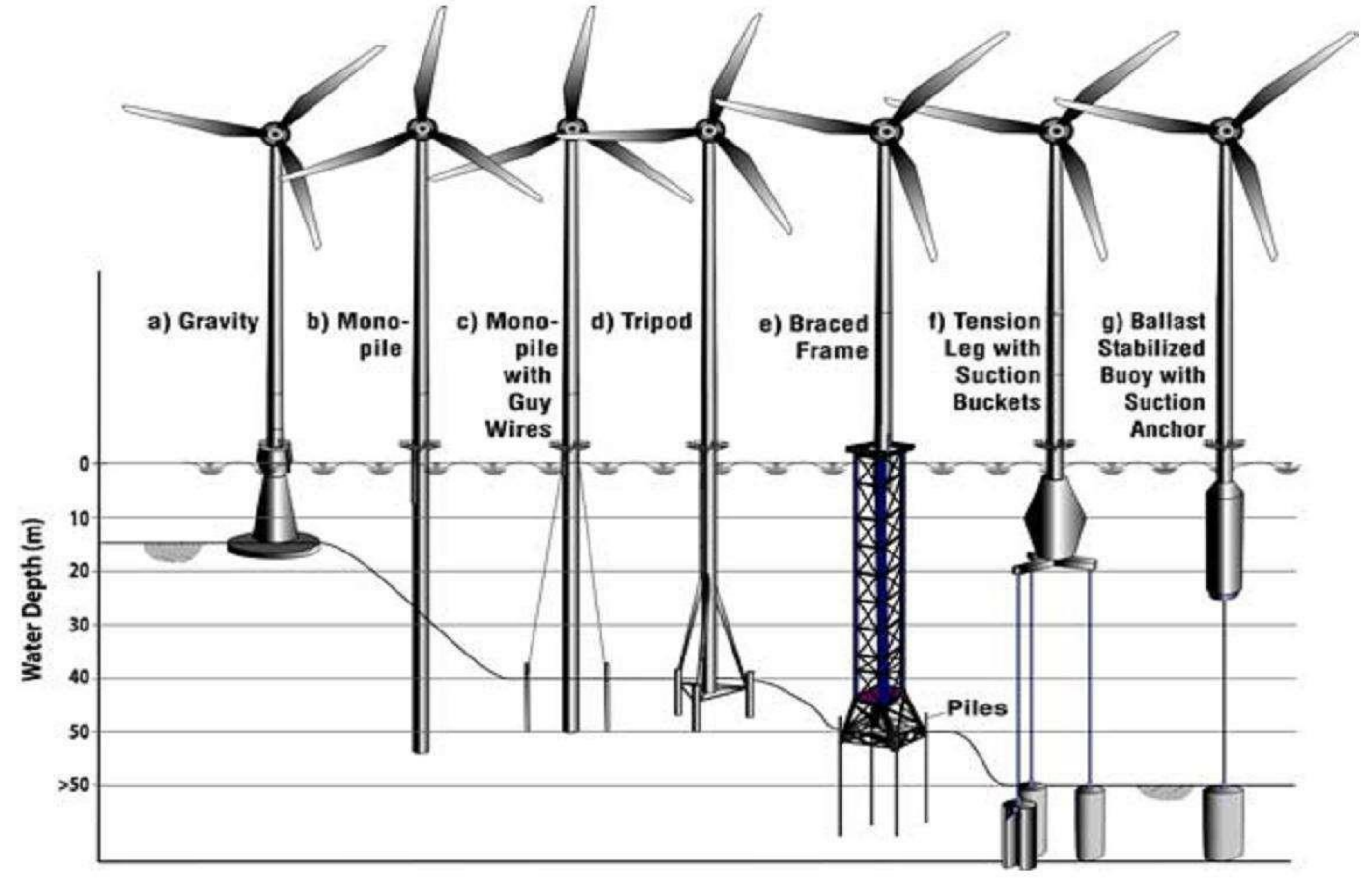
1. A offshore wind turbine is stronger than a onshore turbine. It lasts around 25-30 years, and produces about 50 % more energy than a onshore turbine.
2. When a strong wind blows, it produces around 3-5 MW per hour.
3. Higher and more constant wind speed

Offshore wind turbine:

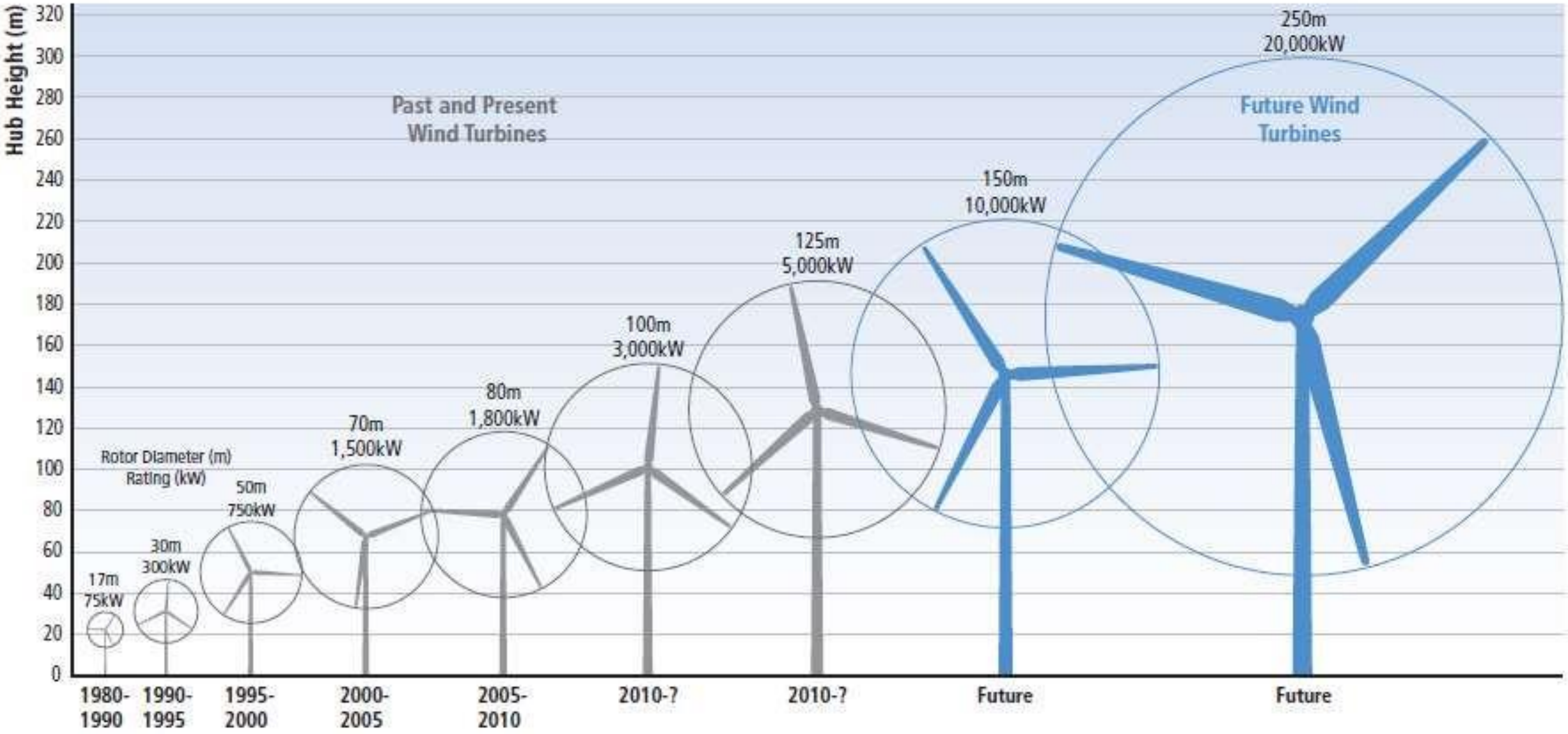
- Offshore disadvantages:

1. More expensive to built
2. More difficult to maintain and access

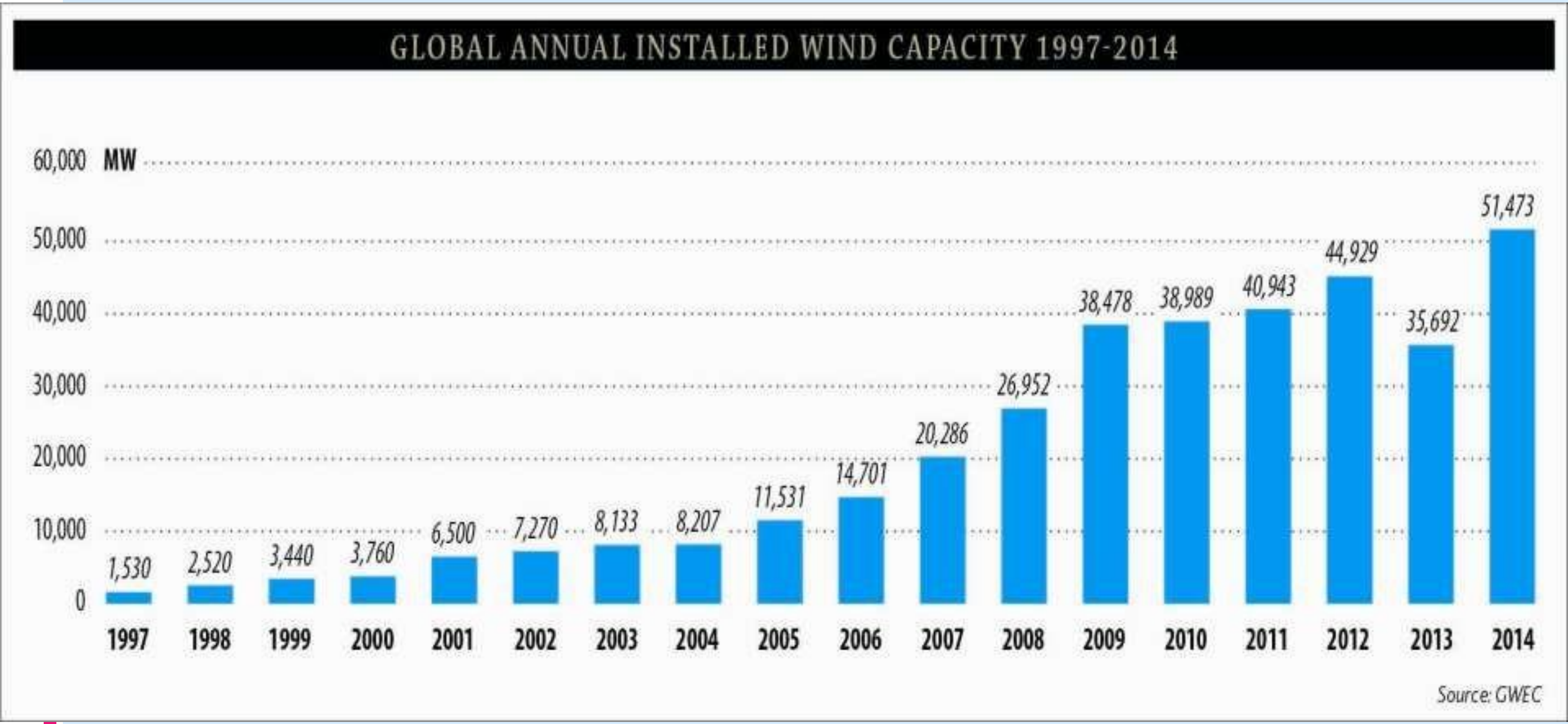
OFFSHORE FOUNDATION OPTIONS:



Growth in size of typical commercial wind turbines:



World Wind Power Installations:



Source: GWEC

General advantages

- Wind energy is friendly to the surrounding environment, as no fossil fuels are burnt to generate electricity from wind energy
- Wind turbines requires less space than average power stations.
- When combined with solar electricity, this energy source is great for developed and developing countries to provide a steady, reliable supply of electricity

General disadvantages

- The main disadvantage regarding wind power is down to the winds unreliability factor. In many areas, the winds strength is not enough to support a wind turbine
- Wind turbines generally produce allot less electricity than the average fossil fuelled power station, which means that multiple wind turbines are needed to make an impact.

POWER COEFFICIENT OF WIND MILL

By: Mudit M. Saxena,
Dept. of Mech. Engg.
Indus University

POWER COEFFICIENT

- Power Coefficient (Cp) is a measure of wind turbine efficiency often used by the wind power industry. Cp is the ratio of actual electric power produced by a wind turbine divided by the total wind power flowing into the turbine blades at specific wind speed. When defined in this way, the power coefficient represents the combined efficiency of the various wind power system components which include the turbine blades, the shaft bearings and gear train, the generator and power electronics.

- The Cp for a particular turbine is measured or calculated by the manufacturer, and usually provided at various wind speeds. If you know the Cp at a given wind speed for a specific turbine you can use it to estimate the electrical power output.

- The Cp of a particular wind turbine varies with operating conditions such as wind speed, turbine blade angle, turbine rotation speed, and other parameters. It is a measure of a particular wind turbine's overall system efficiency. It should not be confused with, or compared to, wind power Capacity Factor.

- The power coefficient should only be used to compare the performance of wind turbines. Cp has no relationship to the efficiencies of other electrical power sources, such as solar, gas-turbine, a coal-fired steam plant, or any other non-wind driven system.

POWER COEFFICIENT - IT'S AN EFFICIENCY

- I would like to call it (and some people do) overall turbine system efficiency. The wind power industry often calls it the **Power Coefficient**, and gives it the symbol **Cp**.
- **Power Coefficient - An Indicator of Total Wind Turbine System Efficiency**
- The term Power Coefficient is commonly used to designate the efficiency of the entire turbine power system. As shown in the expression below, it is generally defined as the ratio of the "electrical power produced by the wind turbine" (Pout in the formula below) divided by the "wind power into the turbine" (Pin). Pin is sometimes also called "available wind power". But I don't really like that expression because the total power in the wind is never really totally "available".
-

TOTAL WIND POWER

- As shown in the formula to the right, we can write this expression with Cp as the coefficient multiplied by Pin. If we know the Cp at a specific wind speed, we can multiply it by Pin as calculated in the formula described below. This will tell us what the electrical power actually produced by the turbine system will be at that wind speed (see the plot below).

- **Total Wind Power - A Function of Wind Speed Cubed**

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

- *Power in the wind, Pin,*
  is a function of air density, rho
  (funny greek letter above);
  the blade swept area, A;
  and the cube of the wind velocity, V.

TOTAL WIND POWER

- The total wind power flowing into the turbine is defined by the fairly simple wind power formula, shown to the right. The power into the turbine blads is a function of the wind speed to the 3rd power (V times V times V), air density, and swept area of the turbine blades. A simple version of the wind power formula is shown to the right.
- The symbol that looks like a backwards 9, is the greek letter, rho. Rho is often used to symbolize the density of a liquid or a gas. In this case, rho stands for air density.
- The capital letter **A** represents the blade swept area. Note that for the most common horizontal axis turbines the swept area can be determined by the formula for the area of a circle which is Pi times the blade diameter squared (D^2 or D times D), divided by 4. Thus you may also see the formula written with D squared, as I show it on some other pages. (In that case you would also have the number Pi in the numerator and 8 in the denominator).
- For a given turbine, the swept area is a constant, but the air density will vary with elevation and with barometric changes at a given site and, of course, both wind speed and direction will vary over time.

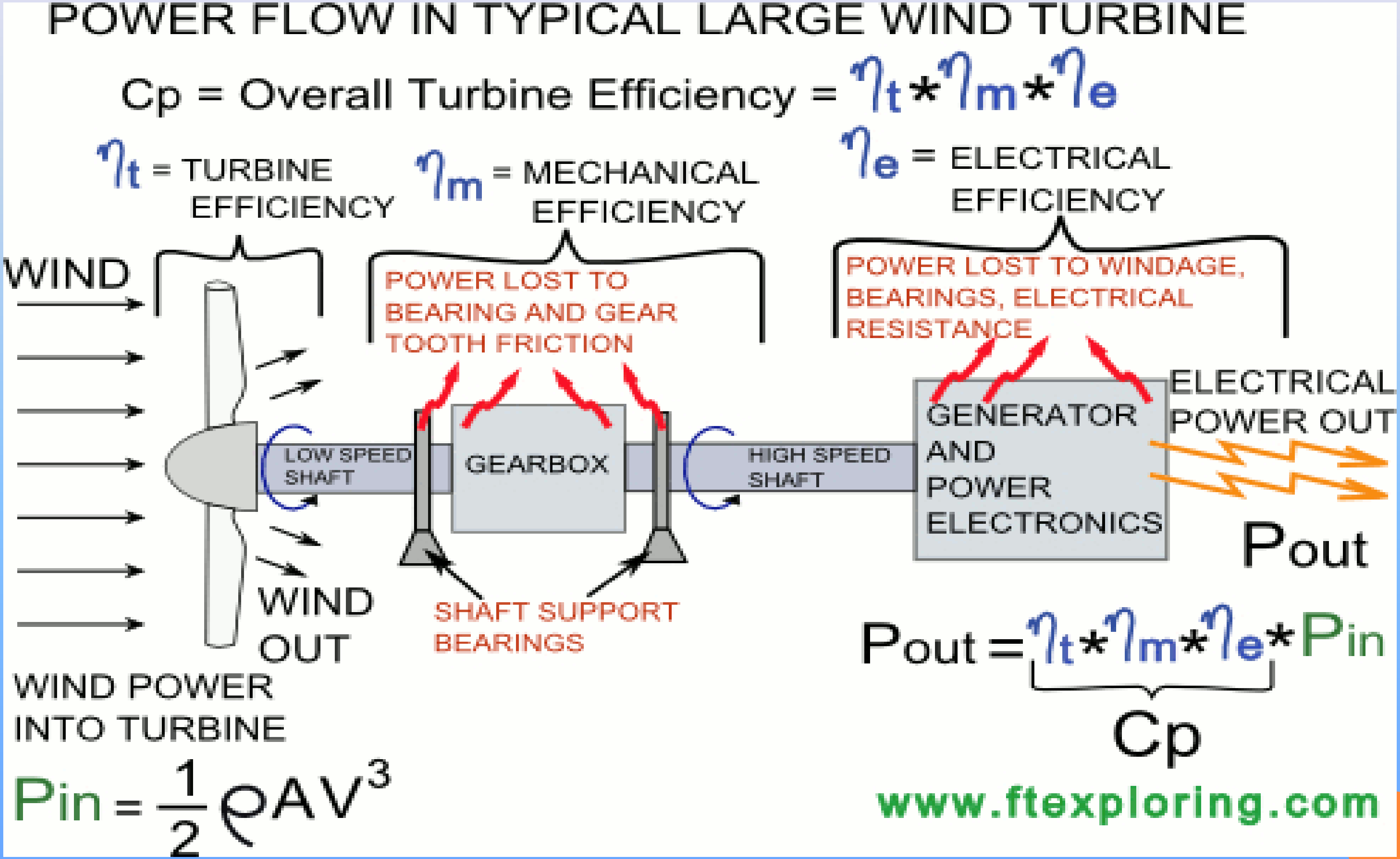
ELECTRICAL POWER PRODUCED

- **Electrical Power Produced - The End Result of Aerodynamic, Mechanical, & Electrical Efficiencies**
- Some wind turbines do things like pump water and grind grain. But most, and virtually all the big ones, are used to make electricity. If you are buying a wind turbine to make electricity then you are interested in the actual useful electric power your turbine will generate at a given wind speed.
- The energy conversion process that turns wind power into electric power goes through 3 major conversion steps which I will label here as the aerodynamic, mechanical, and electrical conversion steps. At each step, some energy is lost (yup, it's the 2nd Law), and the final electric power is less than the total wind power we started with. (This is not unique to wind. All power systems have losses.)

ELECTRICAL POWER PRODUCED

- ***Aerodynamic Efficiency*** - The wind power rotates the turbine blades, converting the wind's kinetic energy into the rotating mechanical energy of the turbine shaft. This is the first and largest "loss". The efficiency with which the blades convert available wind power to rotating shaft energy is sometimes referred to as **aerodynamic efficiency.**
- You may have heard of the Betz limit which says the best a wind turbine can do is convert a little more than 59% of the incoming wind power into mechanical shaft power. In reality it is lower than that, and at most wind speeds, much lower (see graph below).
- ***Mechanical Efficiency*** - In most of the large turbines, the turbine shaft drives a gear box which changes the blade's rotating speed to a speed that better suits the generator (usually faster for a big turbine). Even the best gear trains have friction and some energy is lost here. In addition there are large bearings supporting the shaft which also will introduce a little friction. Let's cleverly call the efficiency of all these mechanical components the **mechanical efficiency**.

POWER FLOW


POWER FLOW IN TYPICAL LARGE WIND TURBINE
Cp = Overall Turbine Efficiency = $\eta_t * \eta_m * \eta_e$
η_t = TURBINE EFFICIENCY
η_m = MECHANICAL EFFICIENCY
η_e = ELECTRICAL EFFICIENCY
WIND
POWER LOST TO BEARING AND GEAR TOOTH FRICTION
POWER LOST TO WINDAGE, BEARINGS, ELECTRICAL RESISTANCE
LOW SPEED SHAFT
GEARBOX
HIGH SPEED SHAFT
GENERATOR AND POWER ELECTRONICS
ELECTRICAL POWER OUT
Pout
WIND OUT
SHAFT SUPPORT BEARINGS
WIND POWER INTO TURBINE
$Pin = \frac{1}{2} \rho A V^3$
$Pout = \underbrace{\eta_t * \eta_m * \eta_e}_{Cp} * Pin$
www.ftexploring.com

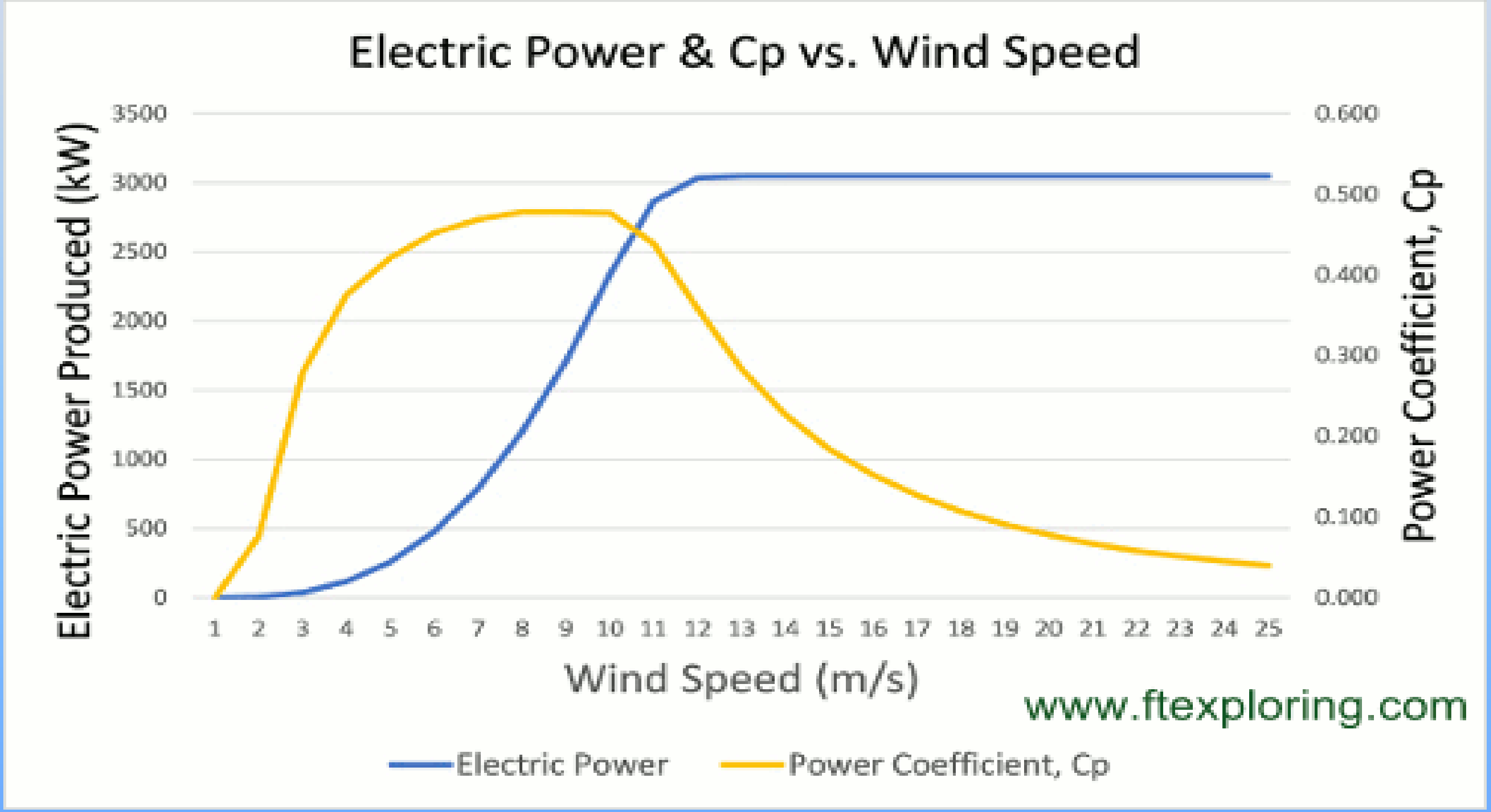
ELECTRIC EFFICIENCY

- ***Electric Efficiency*** - The shaft out of the gear box turns an alternator or generator which converts the mechanical energy into electrical energy. At this point, the electricity can either be direct or alternating current, depending on whether it is a dc generator or an alternator. But even if it is an alternator, the frequency of the current is unsteady and will not match the exact 60 Hz (or 50 Hz in some countries) of the electric power grid.
- Some complicated power electronics are needed to convert the much less-than-perfect electriciy into the clean & precise 60 Hz power needed for the grid. Both the generator and power electronics have losses also. Let's combine these two systems and refer to their combined performance as the **electric efficiency**.
- As shown in the drawing above, Cp is a measure of the *overall system efficiency* of a specific wind turbine, combining the efficiencies of the blade rotors, the mechanical, and the electrical systems.

POWER COEFFICIENT VARIES WITH WIND SPEED AND OTHER VARIABLES

- It should be obvious that a Cp of 1 (or 100%) is impossible. It would mean that all of the power (kinetic energy converted per unit of time) would be converted to electrical power. No wind coming out of the downwind side of the turbine and no mechanical or electrical losses in the system.
- The sample calculation above represents a well designed turbine running at or near its most efficient operating point. So it should be clear that real turbines operate at a Cp of considerably less than 1.
- Look now at my little chart below. It is a plot for a specific actual wind turbine of the Cp and Pout (actual electric power produced in kilowatts) versus wind speed (in meters per second).

ELECTRICAL POWER V/S WIND SPEED



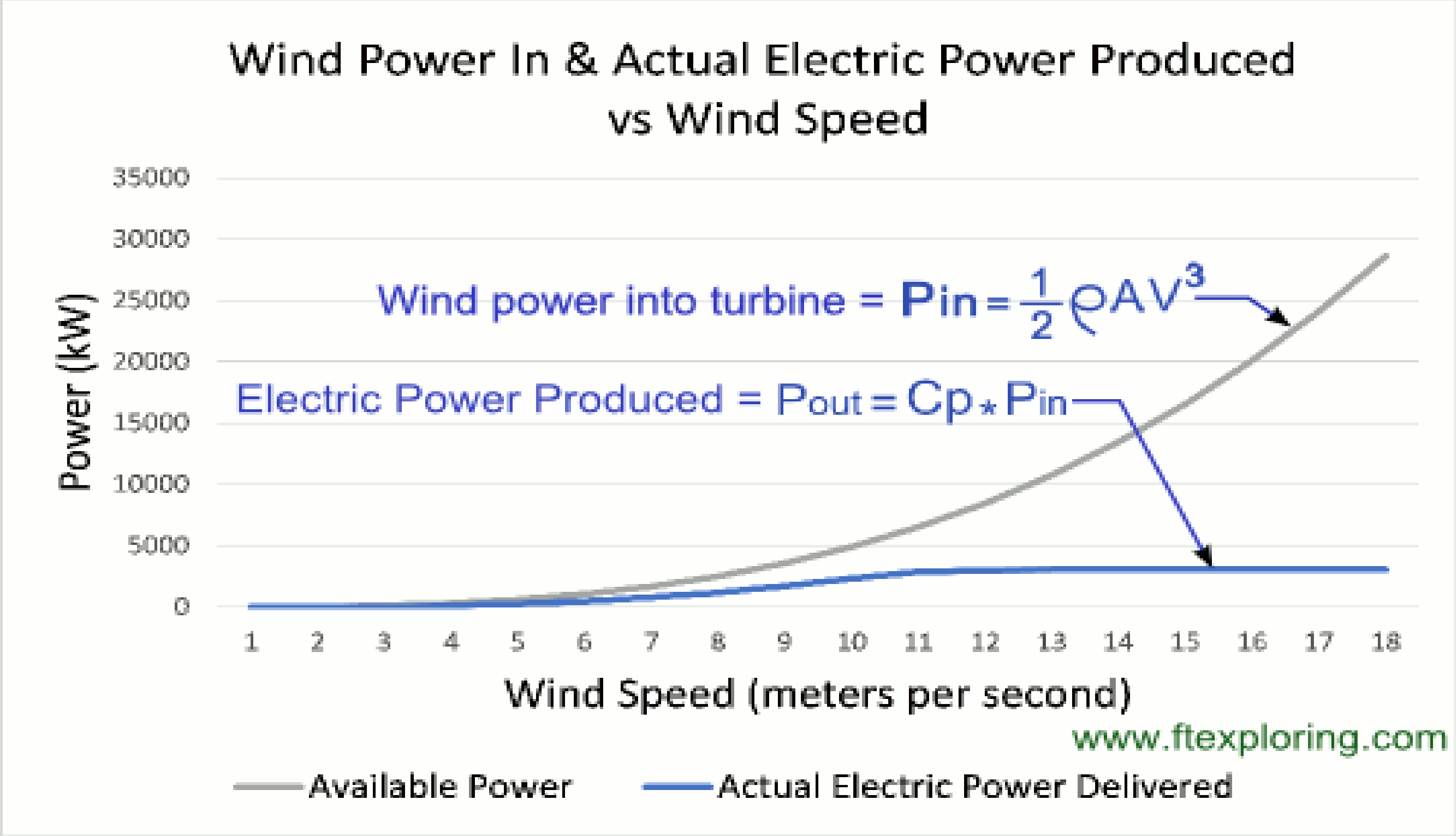
ELECTRICAL POWER V/S WIND SPEED

- It's a useful plot with some interesting information (Remember, turbines vary, this is just one example. Each specific model will have it's own data):
- First, notice that Cp (yellowish line in chart) varies significantly with wind speed. For this particular turbine, maximum efficiency occurs around the wind speed range of 8 to 10 meters per second (18 to 22 miles per hour). Other turbines may attain maximum efficiency at other speeds.
- The blue line shows the electric power produced as a function of wind speed. When the turbine reaches maximum power, which in this case is 3030 kW, it levels off. This is because the turbine blades are turned, or feathered, to keep them from spinning too fast, or breaking from too much force. The turbine control system will keep the blades spinning at or near a constant value. *Though it is not shown in the curve above, at some point the blades are stopped for safety, and power rapidly goes to zero.*

MAXIMUM EFFICIENCY

- For this particular turbine, the maximum efficiency starts to fall a little before maximum power. Once the system reaches maximum power the power coefficient starts to fall off rapidly. This is because the power is kept constant while the wind power into the turbine is increasing rapidly. Remember the power is a function of the wind speed cubed. Pout stays constant while Pin is increasing very fast. Cp has to get smaller.
- Look at the plot below. The wind power into the turbine blades is shown by the gray line. Because it increases with the cube of the wind velocity, it is increasing so fast with increasing wind speed that it's hard to show the blue power produced line which levels off at 3030 kilowatts. To capture power above the maximum limit would just put too much stress on the blades and/or drivetrain components.

WIND POWER IN AND ACTUAL ELECTRIC POWER PRODUCED V/S WIND SPEED



SUMMARY

- It also should be noted that manufacturers tend to specify Cp numbers that are based on certain ideal or standardized conditions. This is reasonable, since the numbers are helpful for comaparing to other turbines. However, in the real world, turbine blades get dirty, ice forms on them, and their surfaces wear or get otherwised damaged. The almighty wind, though freely available, can be capricious and gusty, changing direction and speed randomly and frequently.
- All this means that turbines rarely operate at the exact Cp quoted by the manufacturer.
- **Summary**
- The term power coefficient is used by much of the wind power industry to represent the overall efficiency of the turbine. It combines the efficiencies of the blades, mechanical, and electrical components. Knowing the Cp at a given wind speed provides a simple approximation of what the actual electrical power produced by the wind turbine will be.

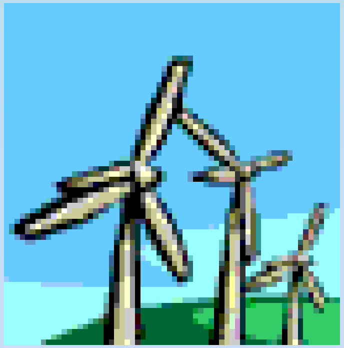
ASSIGNMENT

Q 1. Explain power coefficient of wind turbine.

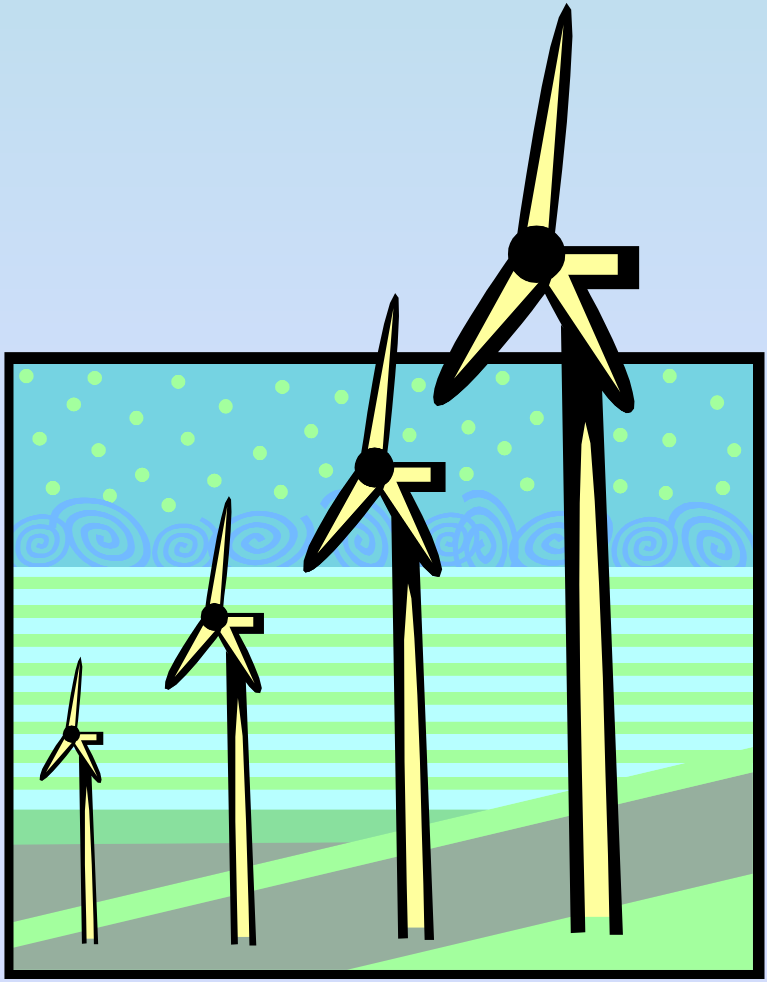
Q 2. Power Coefficient - An Indicator of Total Wind Turbine System Efficiency. Explain

Q 3. Explain Aerodynamic, mechanical and electrical efficiencies of wind turbine.

Q 4. Explain electrical power v/s wind speed .



Wind Energy



WINDMILL DESIGN

- A Windmill captures wind energy and then uses a generator to convert it to electrical energy.
- The design of a windmill is an integral part of how efficient it will be.
- When designing a windmill, one must decide on the size of the turbine, and the size of the generator.

WIND TURBINES

LARGE TURBINES:

- Able to deliver electricity at lower cost than smaller turbines, because foundation costs, planning costs, etc. are independent of size.
- Well-suited for offshore wind plants.
- In areas where it is difficult to find sites, one large turbine on a tall tower uses the wind extremely efficiently.

SMALL TURBINES:

- Local electrical grids may not be able to handle the large electrical output from a large turbine, so smaller turbines may be more suitable.
- High costs for foundations for large turbines may not be economical in some areas.
- Landscape considerations

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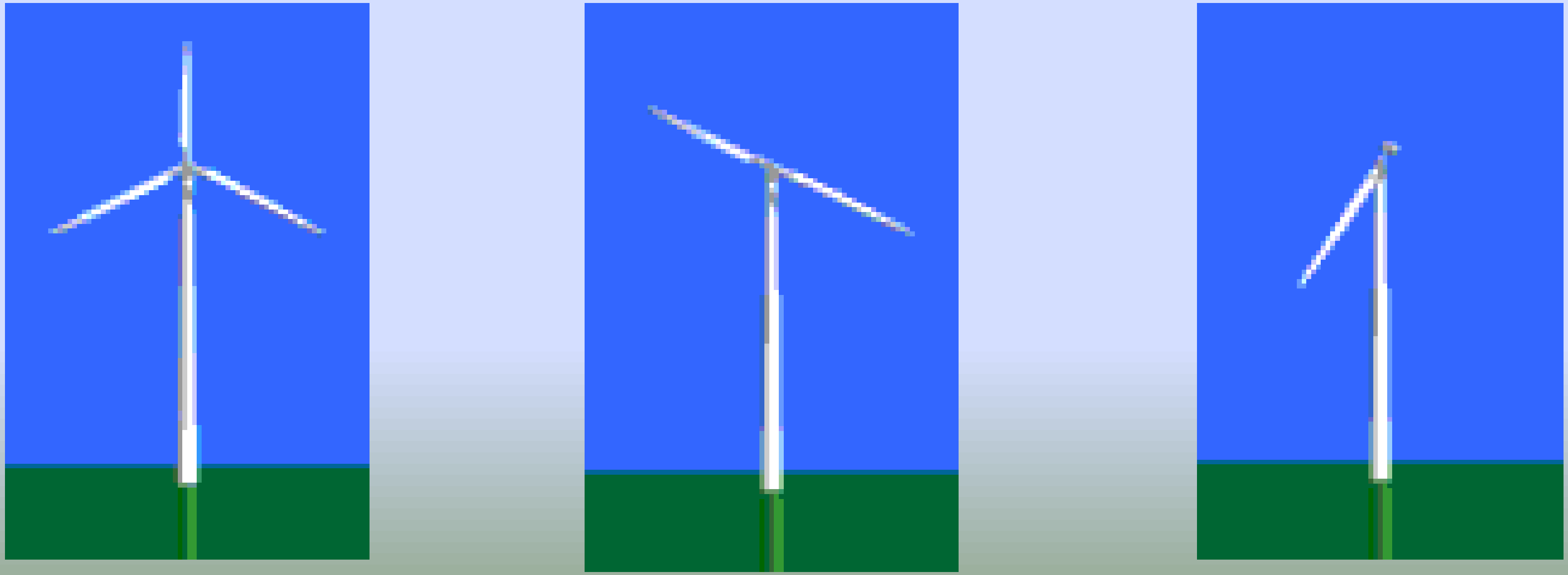
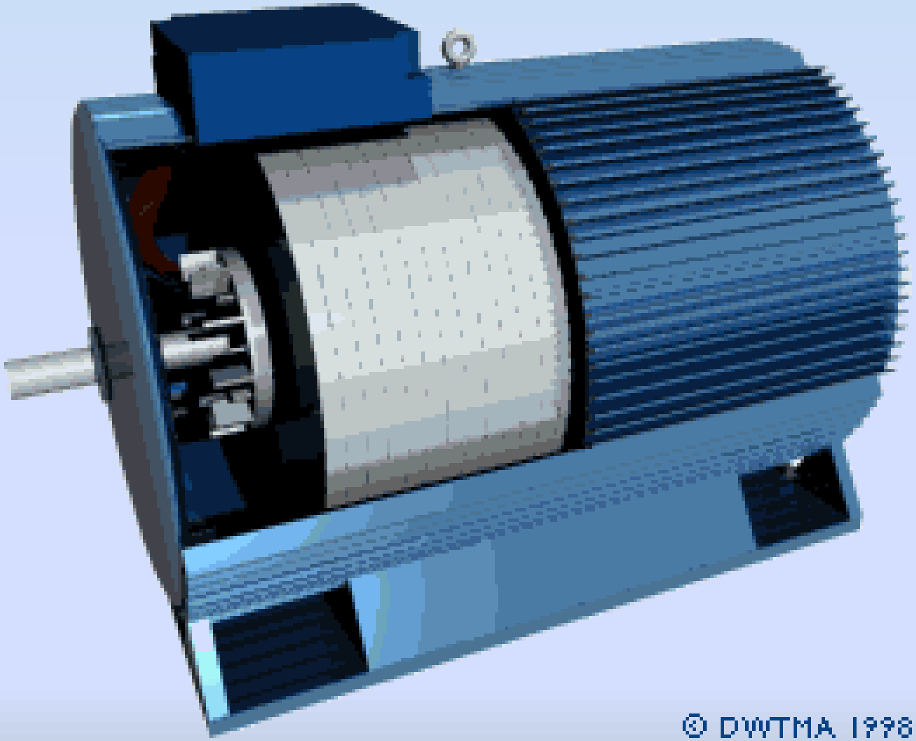
Wind Turbines: Number of Blades

- Most common design is the three-bladed turbine. The most important reason is the **stability** of the turbine. A rotor with an odd number of rotor blades (and at least three blades) can be considered.

- A rotor with an even number of blades will give stability problems for a machine with a stiff structure. The reason is that at the very moment when the uppermost blade bends backwards, because it gets the maximum power from the wind, the lowermost blade passes into the wind shade in front of the tower.



WIND TURBINE GENERATORS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- Wind power generators convert wind energy (mechanical energy) to electrical energy.
- The generator is attached at one end to the wind turbine, which provides the mechanical energy.
- At the other end, the generator is connected to the electrical grid.
- The generator needs to have a cooling system to make sure there is no overheating.

SMALL GENERATORS:

- Require less force to turn than a larger ones, but give much lower power output.
- Less efficient

i.e.. If you fit a large wind turbine rotor with a small generator it will be producing electricity during many hours of the year, but it will capture only a small part of the energy content of the wind at high wind speeds.

LARGE GENERATORS:

- Very efficient at high wind speeds, but unable to turn at low wind speeds.

i.e.. If the generator has larger coils, and/or a stronger internal magnet, it will require more force (mechanical) to start in motion.

OTHER DESIGN CONSIDERATIONS

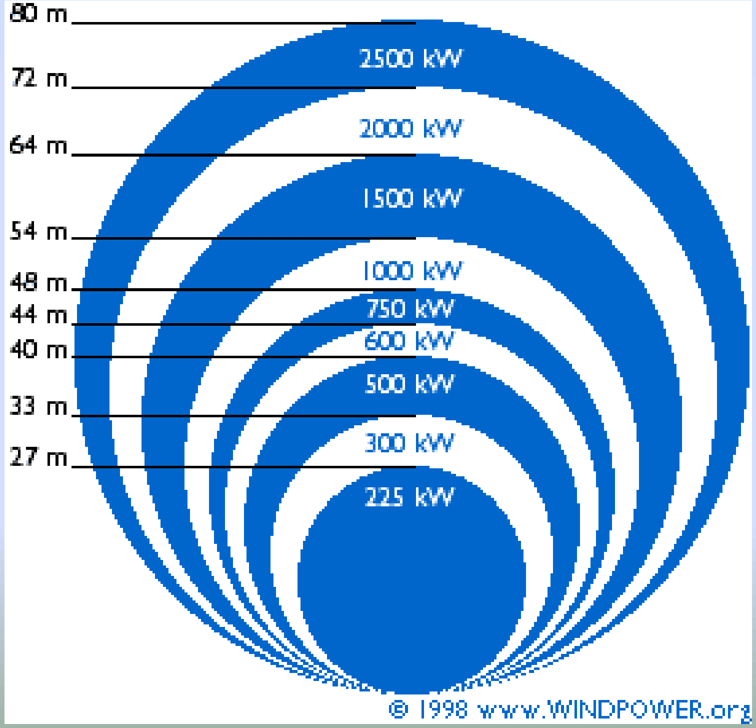
- Winds are influenced by the ground surface at altitudes up to 100 meters.
- Wind is slowed by the surface roughness and obstacles.
- When dealing with wind energy, we are concerned with surface winds.
- A wind turbine obtains its power input by converting the force of the wind into a torque (turning 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.
- The kinetic energy of a moving body is proportional to its mass (or weight). The kinetic energy in the wind thus depends on the density of the air, i.e. its mass per unit of volume.
 In other words, the "heavier" the air, the more energy is received by the turbine.

- at 15° Celsius air weighs about 1.225 kg per cubic meter, but the density decreases slightly with increasing humidity.

OTHER DESIGN CONSIDERATION

- ➢ A typical 600 kW wind turbine has a rotor diameter of 43-44 meters, i.e. a rotor area of some 1,500 square meters.
- ➢ The rotor area determines how much energy a wind turbine is able to harvest from the wind.

- ➢ To be considered a good location for wind energy, an area needs to have average annual wind speeds of at least 12 miles per hour.



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OTHER DESIGN CONSIDERATION

- **A windmill built so that it too severely interrupts the airflow through its cross section will reduce the effective wind velocity at its location and divert much of the airflow around itself, thus not extracting the maximum power from the wind.**

- **At the other extreme, a windmill that intercepts a small fraction of the wind passing through its cross section will reduce the wind's velocity by only a small amount, thus extracting only a small fraction of the power from the wind traversing the windmill disk.**

- **Modern Windmills can attain an efficiency of about 60 % of the theoretical maximum.**

POWER OF WIND

*The power in wind is proportional to the cubic wind speed ($\mathbf{v^3}$).

WHY?

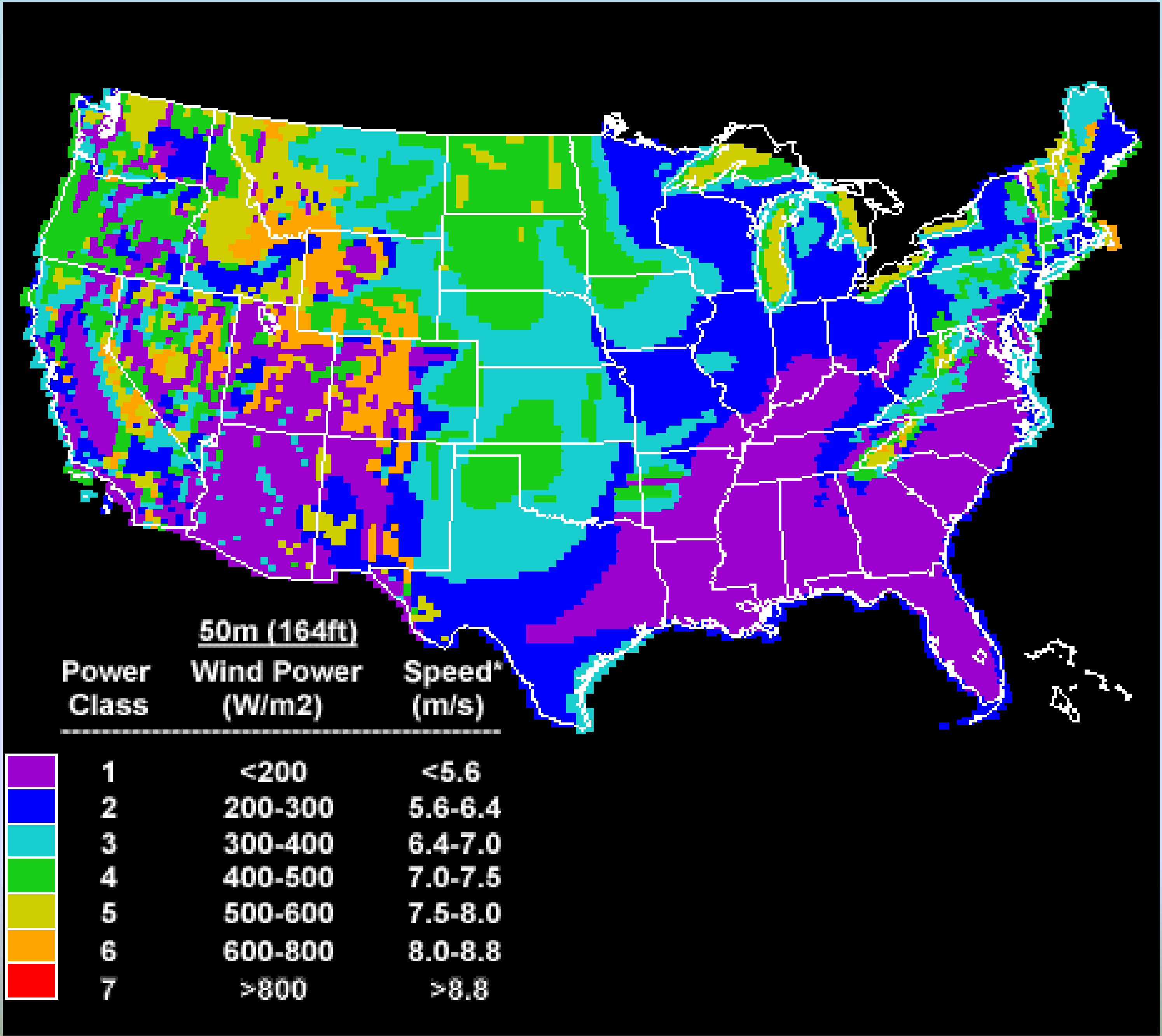
~ Kinetic energy of an air mass is proportional to $\mathbf{v^2}$

~ Amount of air mass moving past a given point is proportional to wind velocity (v)

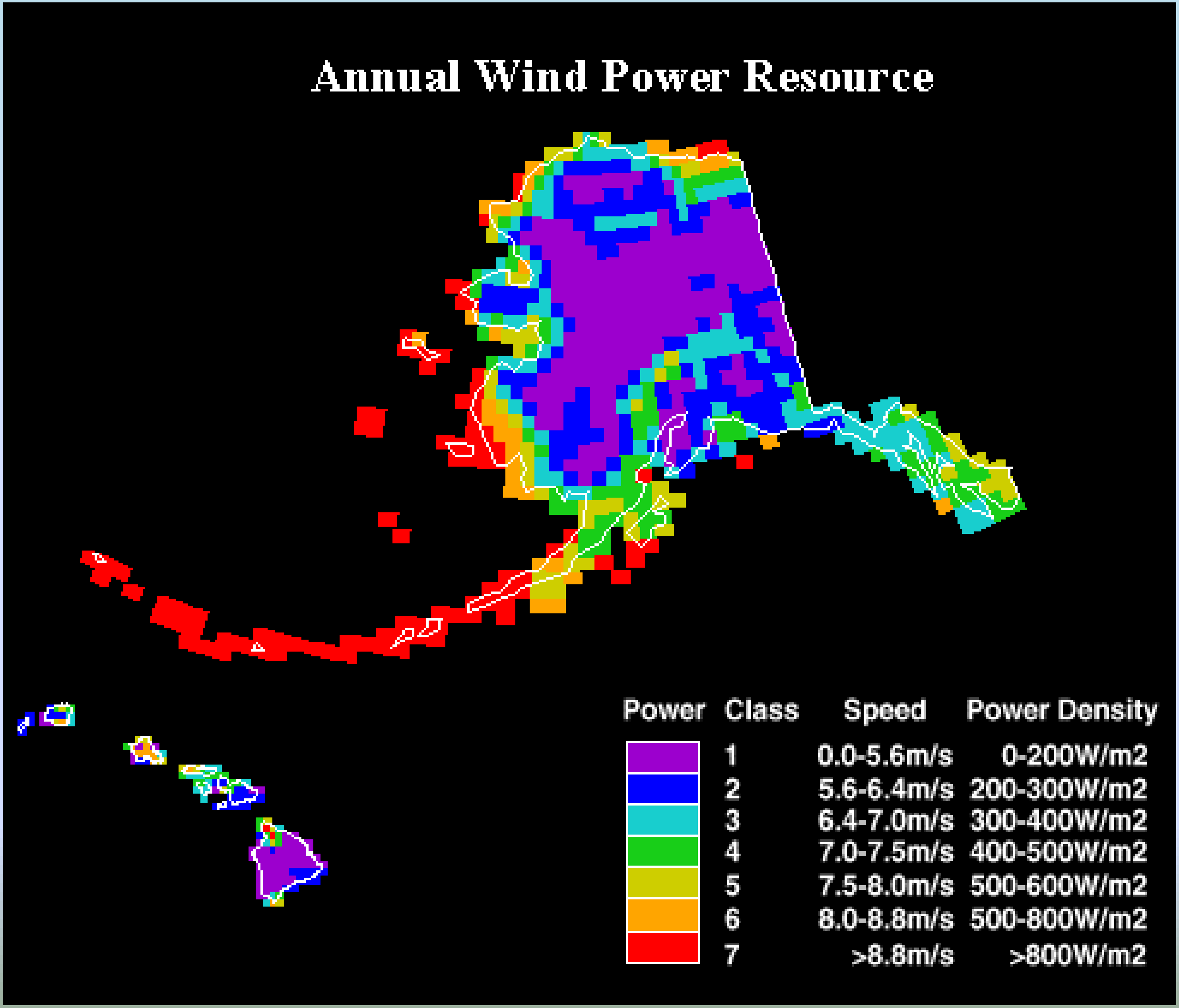
COST CALCULATIONS

- **A typical 600 kW turbine costs about $450,000.**
- **Installation costs are typically $125,000.**
- **Therefore, the total costs will be about $575,000.**
- **The average price for large, modern wind farms is around $1,000 per kilowatt electrical power installed.**
- **Modern wind turbines are designed to work for some 120,000 hours of operation throughout their design lifetime of 20 years. (13.7 years non-stop)**
- **Maintenance costs are about 1.5-2.0 percent of the original cost, per year.**

WIND POWER RESOURCE AREAS-US



WIND POWER RESOURCE AREAS-ALASKA & HAWAII



Annual Wind Power Resource

Power	Class	Speed	Power Density
🟪	1	0.0-5.6m/s	0-200W/m2
🟦	2	5.6-6.4m/s	200-300W/m2
🟦	3	6.4-7.0m/s	300-400W/m2
🟩	4	7.0-7.5m/s	400-500W/m2
🟨	5	7.5-8.0m/s	500-600W/m2
🟧	6	8.0-8.8m/s	500-800W/m2
🟥	7	>8.8m/s	>800W/m2

Advantages of Wind Power

- The wind blows day and night, which allows windmills to produce electricity throughout the day. (Faster during the day)

- Energy output from a wind turbine will vary as the wind varies, although the most rapid variations will to some extent be compensated for by the inertia of the wind turbine rotor.

- Wind energy is a domestic, renewable source of energy that generates no pollution and has little environmental impact. Up to 95 percent of land used for wind farms can also be used for other profitable activities including ranching, farming and forestry.

- The decreasing cost of wind power and the growing interest in renewable energy sources should ensure that wind power will become a viable energy source in the United States and worldwide.

Advantages

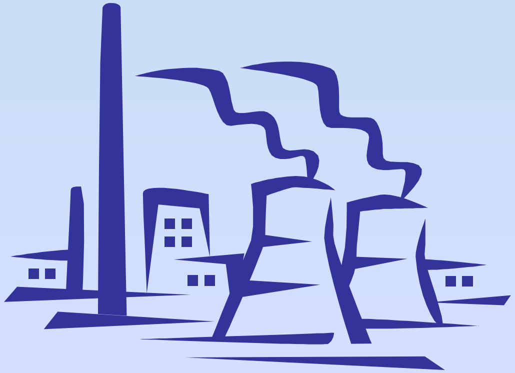
- Wind is free, wind farms need no fuel.
- Produces no waste or greenhouse gases.
- The land beneath can usually still be used for farming.
- Wind farms can be tourist attractions.
- A good method of supplying energy to remote areas.

Disadvantages

- The wind is not always predictable - some days have no wind.
- Suitable areas for wind farms are often near the coast, where land is expensive.
- Some people feel that covering the landscape with these towers is unsightly.
- Can kill birds - migrating flocks tend to like strong winds. However, this is rare, and we tend not to build wind farms on migratory routes anyway.
- Can affect television reception if you live nearby.
- Can be noisy. Wind generators have a reputation for making a constant, low, "swooshing" noise day and night, which can drive you nuts.

When the wind doesn’t blow…

- **Do fossil-fired generating units have to be kept running on a standby basis in case the wind dies down?**

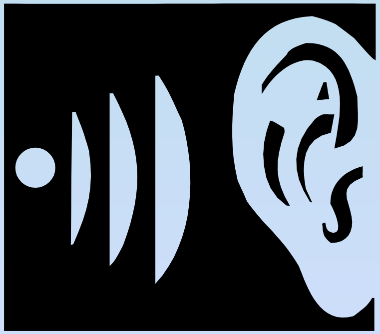


- No. Wind speeds rise and fall gradually and the system operator has time to move other plants on and off line as needed.
- A 100-MW wind plant requires about 2 MW of conventional capacity to compensate for changes in wind.
- Wind can reliably provide 20% or more of our electricity.

Lifetime environmental impact

- Manufacturing wind turbines and building wind plants does not create large emissions of carbon dioxide.
- When these operations are included, wind energy's CO_2 emissions are quite small:
  - about 1% of coal, or
  - about 2% of natural gas (per unit of electricity generated).

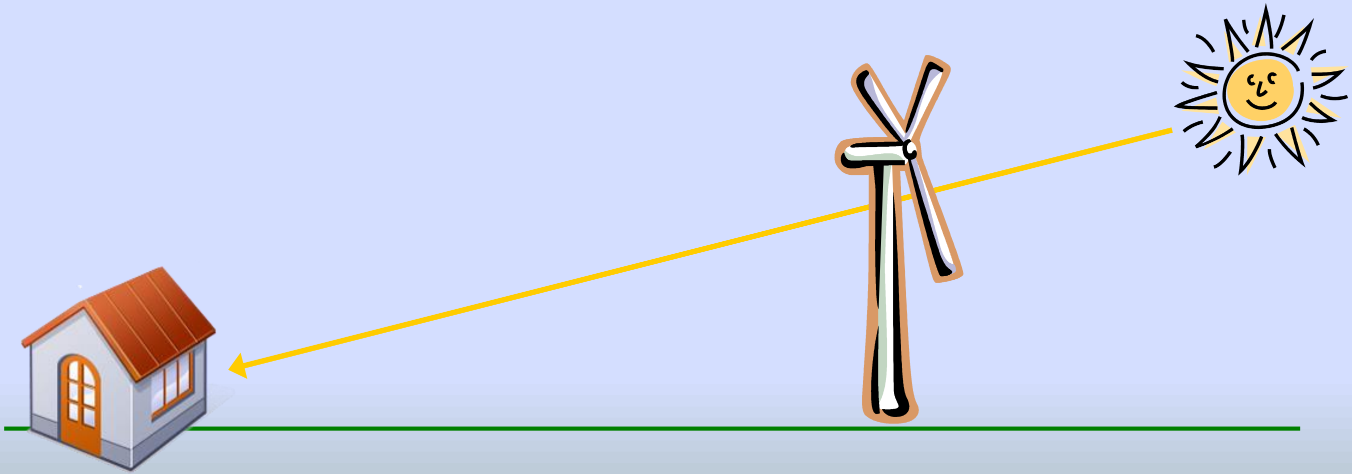
Noise



- Noise used to be a very serious problem for the wind energy industry.
  - annoying from as much as a mile away
- Aerodynamics and soundproofing have been improved significantly.
- Wind turbines operate when the wind is blowing, which tends to be louder than turbine noise.
- A modern operating wind farm at a distance of 750 to 1,000 feet is no noisier than a kitchen refrigerator or a moderately quiet room.

Shadow flicker

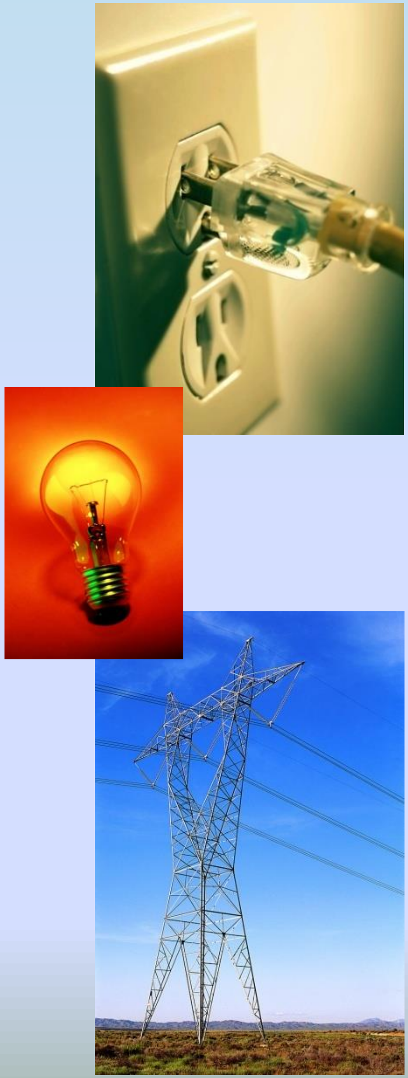
- A wind turbine's moving blades can cast a moving shadow on a nearby residence, depending on the time of the year and time of day.
- Normally, it should not be a problem in the U.S., because at U.S. latitudes (except in Alaska) the sun's angle is not very low in the sky.



Electrical power quality

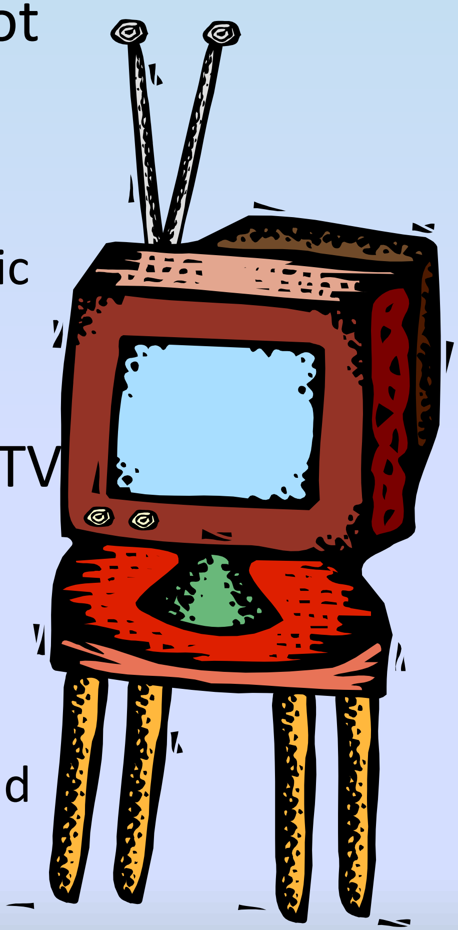
- Generally not a concern for low “penetration”
- Weak grids and grid reinforcement
  - Problems may occur if a turbine is connected to a weak electrical grid, which can be reinforced.
  - Power quality problems caused by wind farms are the exact mirror-image of connecting a large electricity user, (e.g. a factory with large electrical motors) to the grid.

- Electrical flicker
  - Flicker = short lived voltage variations in the electrical grid which may cause light bulbs to flicker.
  - Flicker may occur if a wind turbine is connected to a weak grid.
  - Flicker can be reduced with proper turbine design.



TV and radio reception

- Modern small (residential) wind turbines will not interfere with communication signals.
  - The materials used to make such machines are non-metallic (composites, plastic, wood).
  - Small turbines are too small to create electromagnetic interference (EMI) by "chopping up" a signal.
- Large wind turbines can interfere with radio or TV signals if a turbine is in the "line of sight" between a receiver and the signal source. Alleviate the problem by:
  - improving the receiver's antenna
  - installing relays to transmit the signal around the wind farm



Saint Paul Island, Alaska

- Turbine Size: 225 kW
- Turbine Manufacturer: Vestas
- Developer/owner: Northern Power Systems
- Capacity: .225 MW

Moorhead, Minnesota

- Turbine Size: 750 kW
- Turbine Manufacturer: NEG Micon
- Developer: Moorhead Public Service
- Capacity: .75 MW

Sizes and Applications

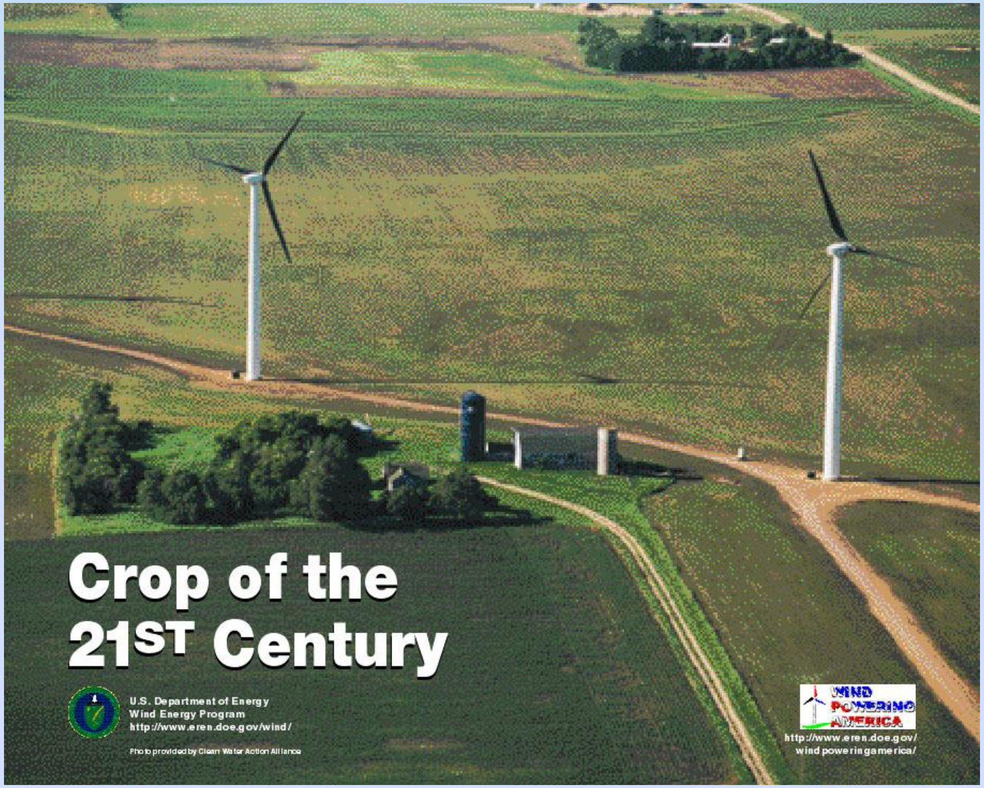
Small (≤10 kW)
- Homes
- Farms
- Remote Application

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

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

Drivers for Wind Power

- Declining Wind Costs
- Fuel Price Uncertainty
- Federal and State Policies
- Economic Development
- Green Power
- Energy Security



Assignment

Q 1. Explain the design consideration for small, medium and large soize wind turbines.

OTEC (OCEAN THERMAL ENERGY CONVERSION)

By: Mudit M. Saxena
Dept. of mechanical engineering
Indus University

OTEC (OCEAN THERMAL ENERGY CONVERSION)

- Ocean thermal energy conversion (OTEC) generates electricity indirectly from solar energy by harnessing the temperature difference between the sun-warmed surface of tropical oceans and the colder deep waters.

- A significant fraction of solar radiation incident on the ocean is retained by seawater in tropical regions, resulting in average year-round surface temperatures of about 28 C.

- Deep, cold water, meanwhile, forms at higher latitudes and descends to flow along the seafloor toward the equator. The warm surface layer, which extends to depths of about 100-200m, is separated from the deep cold water by a thermocline. The temperature difference, ΔT, *between the surface and thousand-meter depth* ranges from 10 to 25 C, with larger differences occurring in equatorial and tropical waters.

OTEC (OCEAN THERMAL ENERGY CONVERSION)

- ***ΔT establishes the limits of the*** performance of OTEC power cycles; the rule-of thumb is that a differential of about 20 C is necessary to sustain viable operation of an OTEC facility.

- Since OTEC exploits renewable solar energy, recurring costs to generate electrical power are minimal. However, the fixed or capital costs of OTEC systems per kilowatt of generating capacity are very high because large pipelines and heat exchangers are needed to produce relatively modest amounts of electricity.

- These high fixed costs dominate the economics of OTEC to the extent that it currently cannot compete with conventional power systems, except in limited niche markets.

STATE OF THE TECHNOLOGY

- OTEC power systems operate as cyclic heat engines.

- They receive thermal energy through heat transfer from surface sea water warmed by the sun, and transform a portion of this energy to electrical power.

- The Second Law of Thermodynamics precludes the complete conversion of thermal energy in to electricity. A portion of the heat extracted from the warm sea water must be rejected to a colder thermal sink. The thermal sink employed by OTEC systems is sea water drawn from the ocean depths by means of a submerged pipeline.

- A steady-state control volume energy analysis yields the result that net electrical power produced by the engine must equal the difference between the rates of heat transfer from the warm surface water and to the cold deep water. The limiting (i.e., maximum) theoretical Carnot energy conversion efficiency of a cyclic heat engine scales with the difference between the temperatures at which these heat transfers occur.

STATE OF THE TECHNOLOGY

- For OTEC, this difference is determined by ΔT *and is* very small; hence, OTEC efficiency is low. Although viable OTEC systems are characterized by Carnot efficiencies in the range of 6-8%, state-of-the-art combustion steam power cycles, which tap much higher temperature energy sources, are theoretically capable of converting more than 60% of the extracted thermal energy into electricity.

- The low energy conversion efficiency of OTEC means that more than 90% of the thermal energy extracted from the ocean's surface is 'wasted' and must be rejected to the cold, deep sea water.

- This necessitates large heat exchangers and seawater flow rates to produce relatively small amounts of electricity. In spite of its inherent inefficiency, OTEC, unlike conventional fossil energy systems, utilizes a renewable resource and poses minimal threat to the environment

STATE OF THE TECHNOLOGY

- In fact, it has been suggested that widespread adoption of OTEC could yield tangible environmental benefits through avenues such as reduction of greenhouse gas CO_2 emissions; enhanced uptake of atmospheric CO_2 by marine organism populations sustained by the nutrient-rich, deep OTEC sea water; and preservation of corals and hurricane amelioration by limiting temperature rise in the surface ocean through energy extraction and artificial upwelling of deep water.

- Carnot efficiency applies only to an ideal heat engine. In real power generation systems, irreversibilities will further degrade performance. Given its low theoretical effciency, successful implementation of OTEC power generation demands careful engineering to minimize irreversibilities. Although OTEC consumes what is essentially a free resource, poor thermodynamic performance will reduce the quantity of electricity available for sale and, hence, negatively affect the economic feasibility of an OTEC facility

CLOSED CYCLE OTEC

- D’Arsonval’s original concept employed a pure working fluid that would evaporate at the temperature of warm sea water. The vapor would subsequently expand and do work before being condensed by the cold sea water. This series of steps would be repeated continuously with the same working fluid, whose flow path and thermodynamic process representation constituted closed loops } hence, the name ‘closed cycle.’

- The specific process adopted for closed cycle OTEC is the Rankine, or vapor power, cycle. The principal components are the heat exchangers, turbogenerator, and seawater supply system, which, although not shown, accounts for most of the parasitic power consumption and a significant fraction of the capital expense. Also not included are ancillary devices such as separators to remove residual liquid downstream of the evaporator and subsystems to hold and supply working fluid lost through leaks or contamination.

CLOSED CYCLE OTEC

- In this system, heat transfer from warm surface sea water occurs in the evaporator, producing a saturated vapor from the working fluid.
- Electricity is generated when this gas expands to lower pressure through the turbine. Latent heat is transferred from the vapor to the cold sea water in the condenser and the resulting liquid is pressurized with a pump to repeat the cycle.
- The success of the Rankine cycle is a consequence of more energy being recovered when the vapor expands through the turbine than is consumed in re-pressurizing the liquid. In conventional (e.g.,combustion) Rankine systems, this yields net electrical power.
- For OTEC, however, the remaining balance may be reduced substantially by an amount needed to pump large volumes of sea water through the heat exchangers. (One misconception about OTEC is that tremendous energy must be expended to bring cold sea water up from depths approaching 1000 meters. In reality, the natural hydrostatic pressure gradient provides for most of the increase inthe gravitational potential energy of a fluid particle moving with the gradient from the ocean depths to the surface.)

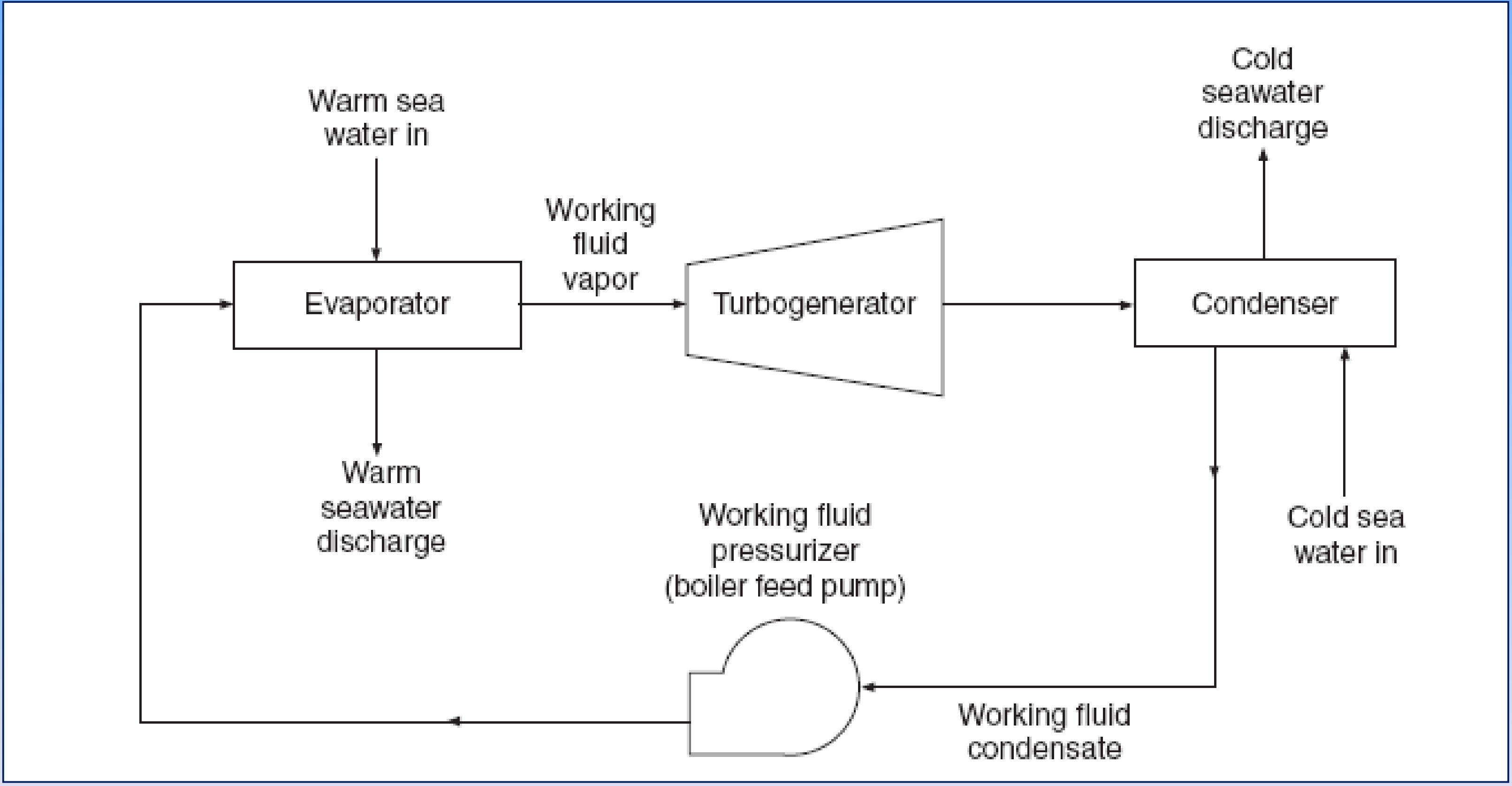
Closed Cycle OTEC

- Irreversibilities in the turbomachinery and heat exchangers reduce cycle efficiency below the Carnot value. Irreversibilities in the heat exchangers occur when energy is transferred over a large temperature difference. It is important, therefore, to select a working fluid that will undergo the desired phase changes at temperatures established by the surface and deep sea water. Insofar as a large number of substances can meet this requirement (because pressures and the pressure ratio across the turbine variations are viable alternatives. and pump are design parameters), other factors must be considered in the selection of a working fluid including: cost and availability, compatibility with system materials, toxicity, and environmental hazard. Leading candidate working fluids for closed cycle OTEC applications are ammonia and various fluorocarbon refrigerants. Their primary disadvantage is the environmental hazard posed by leakage;

CLOSED CYCLE OTEC

- ammonia is toxic in moderate concentrations and certain fluorocarbons have been banned by the Montreal Protocol because they deplete stratospheric ozone. The Kalina, or adjustable proportion fluid mixture (APFM), cycle is a variant of the OTEC closed cycle. Whereas simple closed cycle OTEC systems use a pure working fluid, the Kalina cycle proposes
- to employ a mixture of ammonia and water with varying proportions at different points in the system. The advantage of a binary mixture is that, at a given pressure, evaporation or condensation occurs
- over a range of temperatures; a pure fluid, on the other hand, changes phase at constant temperature This additional degree of freedom allows heat transfer-related irreversibilities in the evaporator and condenser to be reduced Although it improves efficiency, the Kalina cycle needs additional capital equipment and may impose severe demands on the evaporator and condenser. The efficiency improvement will require some combination
- of higher heat transfer coefficients, more heat transfer surface area, and increased seawater
- flow rates. Each has an associated cost or power penalty. Additional analysis and testing are required to confirm whether the Kalina cycle and assorted

CLOSED CYCLE OTEC



By: Mudit M. Saxena, Dept. of Mechanical engineering

OPEN CYCLE OTEC

- **Open Cycle OTEC** Claude's concern about the cost and potential biofoulingof closed cycle heat exchangers led him to propose using steam generated directly from the
- warm sea water as the OTEC working Suid. The steps of the Claude, or open, cycle are: (1) Sash evaporation of warm sea water in a partial vacuum;
- (2) expansion of the steam through a turbine to generate power; (3) condensation of the vapor by direct contact heat transfer to cold sea water; and (4) compression and discharge of the condensate and any residual noncondensable gases. Unless fresh water is a desired by-product, open cycle OTEC eliminates the need for surface heat exchangers. The
- name 'open cycle' comes from the fact that the working Suid (steam) is discharged after a single pass and has different initial and final thermodynamic
- states; hence, the Sow path and process are 'open.' The entire system, from evaporator to condenser, operates at partial vacuum, typically at pressures of 1}3% of atmospheric.

By: Mudit M. Saxena, Dept. of Mechanical engineering

OPEN CYCLE OTEC

- Initial evacuation of the system and removal of non-condensable gases during operation are performed by the vacuum compressor, which, along with the sea water and discharge pumps, accounts for the bulk of the open cycle OTEC parasitic power consumption.

- The low system pressures of open cycle OTEC are necessary to induce boiling of the warm sea water. Flash evaporation is accomplished by exposing the sea water to pressures below the saturation pressure corresponding to its temperature. This is usually accomplished by pumping it into an evacuated chamber through spouts designed to maximize heat and mass transfer surface area. Removal of gases dissolved in the sea water, which will come out of solution in the low-pressure evaporator and compromise operation, may be performed at an intermediate pressure prior to evaporation.Vapor produced in the Sash evaporator is relativelypure steam. The heat of vaporization is extracted from the liquid phase, lowering its temperature and preventing any further boiling. Flash evaporation may be perceived, then, as a transfer of thermal energy from the bulk of the warm sea water of the small fraction of mass that is vaporized. Less than 0.5% of the mass of warm sea water entering the evaporator is converted into steam.

OPEN CYCLE OTEC

- The pressure drop across the turbine is established by the cold seawater temperature. At 43C, steam condenses at 813 Pa. The turbine (or turbine diffuser) exit pressure cannot fall below this value. Hence, the maximum turbine pressure drop is only about 3000Pa, corresponding to about a 3:1 pressure ratio. This will be further reduced to account for other pressure drops along the steam path and differences in the temperatures of the steam and seawater streams needed to facilitate heat transfer in the evaporator and condenser.

OPEN CYCLE OTEC

- Condensation of the low-pressure steam leaving the turbine may employ a direct contact condenser (DCC), in which cold sea water is sprayed over the vapor, or a conventional surface condenser that physically separates the coolant and the condensate. DCCs are inexpensive and have good heat transfer characteristics because they lack a solid thermal boundary between the warm and cool fluids. Surface condensers are expensive and more difficult to maintain than DCCs; however, they produce a marketable freshwater by-product. Effluent from the condenser must be discharged to the environment. Liquids are pressurized to ambient levels at the point of release by means of a pump, or, if the elevation of the condenser is suitably high,

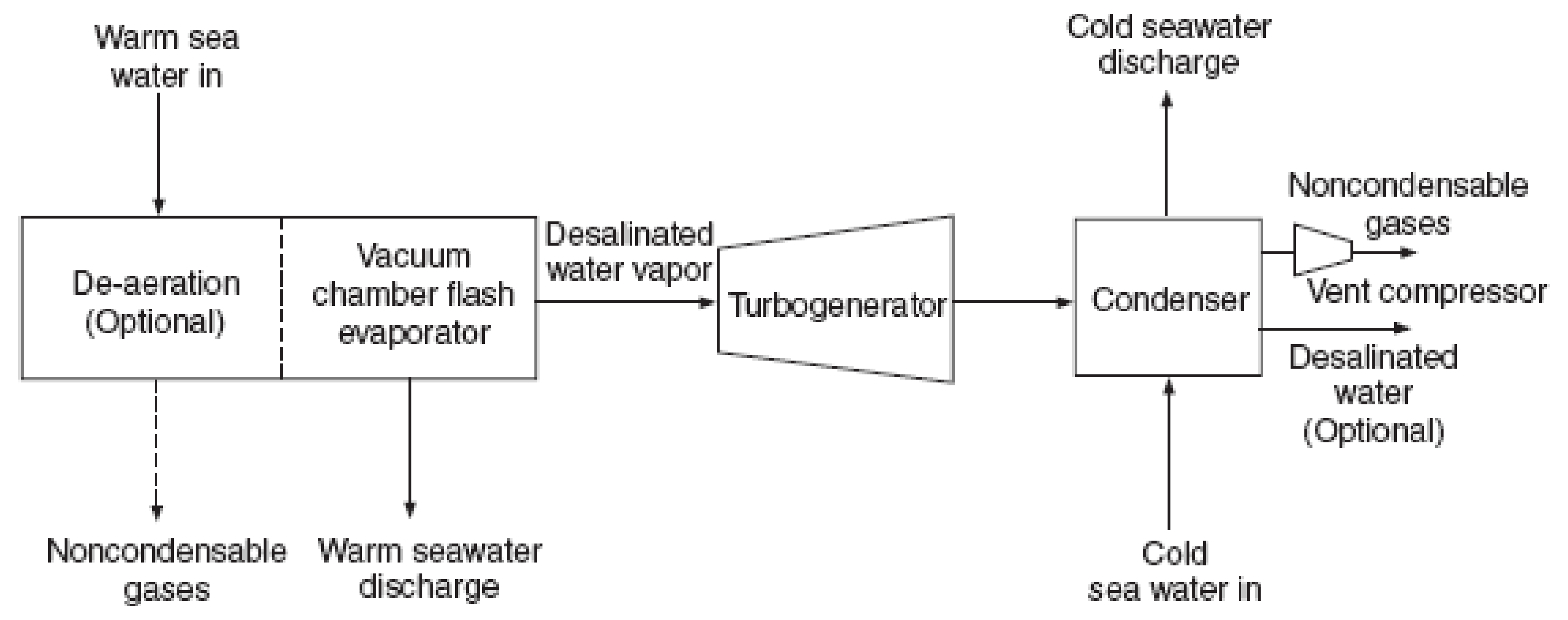
OPEN CYCLE OTEC

- can be compressed hydrostatically. As noted previously, noncondensable gases, which include any residual water vapor, dissolved gases that have come out of solution, and air that may have leaked into the system, are removed by the vacuum compressor. Open cycle OTEC eliminates expensive heat exchangers at the cost of low system pressures. Partial vacuum operation has the disadvantage of making the system vulnerable to air in-leakage and promotes the evolution of noncondensable gases dissolved in sea water. Power must ultimately be expended to pressurize and remove these gases. Furthermore, as a consequence of the low steam density, volumetric Sow rates are very high per unit of electricity generated. Large components are needed to accommodate these Sow rates. In particular, only the largest conventional steam turbine stages have the potential for integration into open cycle OTEC systems of a few megawatts gross generating capacity.

OPEN CYCLE OTEC

- It is generally acknowledged that higher capacity plants will require a major turbine development effort. The mist lift and foam lift OTEC systems are variants of the OTEC open cycle. Both employ the sea water directly to produce power. Unlike Claude's open cycle, lift cycles generate electricity with a hydraulic turbine. The energy expended by the liquid to drive the turbine is recovered from the warm sea water. In the lift process, warm seawater is Sash evaporated to produce a two-phase, liquid}vapor mixture } either a mist consisting of liquid droplets suspended in a vapor, or a foam, where vapor bubbles are contained in a continuous liquid phase. The mixture rises, doing work against gravity. Here, the thermal energy of the vapor is expended to increase the potential energy of the Suid. The vapor is then condensed with cold sea water and discharged back into the ocean. Flow of the liquid through the hydraulic turbine may occur before or after the lift process. Advocates of the mist and foam lift cycles contend that they are cheaper to implement than closed cycle OTEC because they require no expensive heat exchangers, and are superior to the Claude cycle because they utilize a hydraulic turbine rather than a low pressure steam turbine. These claims await verification.

OPEN CYCLE OTEC



Hybrid Cycle OTEC

- Some marketing studies have suggested that OTEC systems that can provide both electricity and water may be able to penetrate the marketplace more readily than plants dedicated solely to power generation. Hybrid cycle OTEC was conceived as a response to these studies. Hybrid cycles combine the potable water production capabilities of open cycle OTEC with the potential for large electricity generation capacities offered by the closed cycle Several hybrid cycle variants have been proposed. Typically, as in the Claude cycle, warm surface seawater is flash evaporated in a partial vacuum. This low pressure steam flows into a heat exchanger where it is employed to vaporize a pressurized, low-boiling-point fluid such as ammonia. During this process, most of the steam condenses, yielding desalinated potable water

HYBRID CYCLE OTEC

- The ammonia vapor flows through a simple closed-cycle power loop and is condensed using cold sea water. The uncondensed steam and other gases exiting the ammonia evaporator may be further cooled by heat transfer to either the liquid ammonia leaving the ammonia condenser or cold sea water. The non-condensables are then compressed and discharged to the atmosphere. Steam is used as an intermediary heat transfer medium between the warm sea water and the ammonia; consequently, the potential for biofouling in the ammonia evaporator is reduced significantly. Another advantage of the hybrid cycle related to freshwater production is that condensation occurs at significantly higher pressures than in an open cycle OTEC condenser, due to the elimination of the turbine from the steam Sow path.

HYBRID CYCLE OTEC

- This may, in turn, yield some savings in the amount of power consumed to compress and discharge the non-condensable gases from the system. These savings (relative to a simple Claude cycle producing electricity and water), however, are offset by the additional back work of the closed-cycle ammonia pump. One drawback of the hybrid cycle is that water production and power generation are closely coupled. Changes or problems in either the water or power subsystem will compromise performance of the other. Furthermore, there is a risk that the potable water may be contaminated by an ammonia leak. In response to these concerns, an alternative hybrid cycle has been proposed, comprising decoupled power and water production components.

HYBRID CYCLE OTEC

- The basis for this concept lies in the fact that warm sea water leaving a closed cycle evaporator is still sufficiently warm, and cold seawater exiting the condenser is sufficiently cold, to sustain an independent freshwater production process. The alternative hybrid cycle consists of a conventional closed-cycle OTEC system that produces electricity and a downstream Sash-evaporation-based desalination system. Water production and electricity generation can be adjusted independently, and either can operate should a subsystem fail or require servicing. The primary drawbacks are that the ammonia evaporator uses warm seawater directly and is subject to biofouling; and additional equipment, such as the potable water surface condenser, is required, thus increasing capital expenses.

ASSIGNMENT

Q 1. Explain with a neat diagram close cycle OTEC power plant.

Q 2. Explain with a neat diagram closed cycle OTEC power plant.

Q 3. Explain Hybrid OTEC power plant.

Q 4. Write a short note on OTEC.

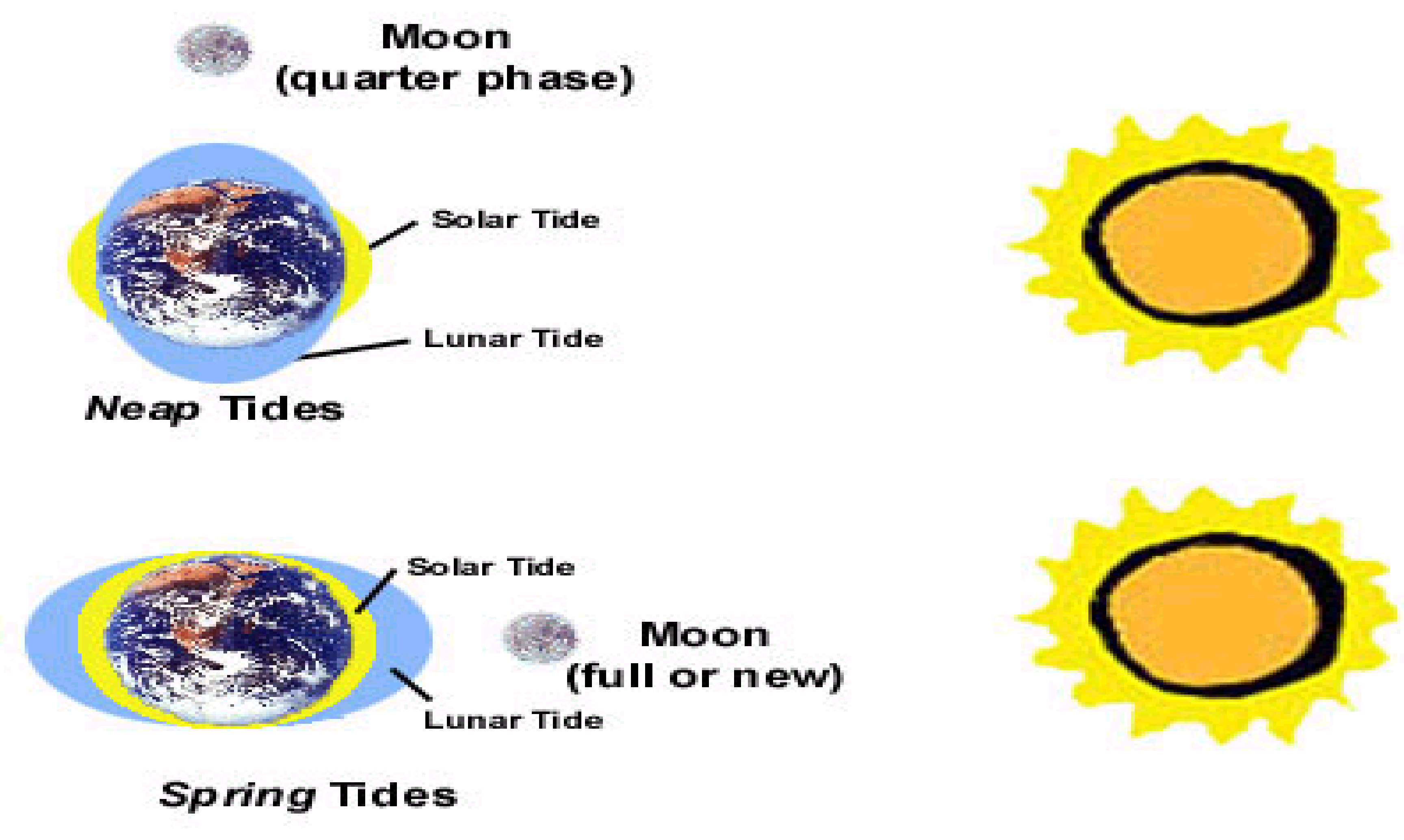
TIDAL ENERGY & WAVE POWER

By: Mudit M. Saxena,
Dept. of Mech. Engineering,
Indus University

ENERGY FROM THE MOON

- Tides generated by the combination of the moon and sun's gravitational forces
- Greatest affect in spring when moon and sun combine forces
- Bays and inlets amplify the height of the tide
- In order to be practical for energy production, the height difference needs to be at least 5 meters
- Only 40 sites around the world of this magnitude
- Overall potential of 3000 gigawatts from movement of tides

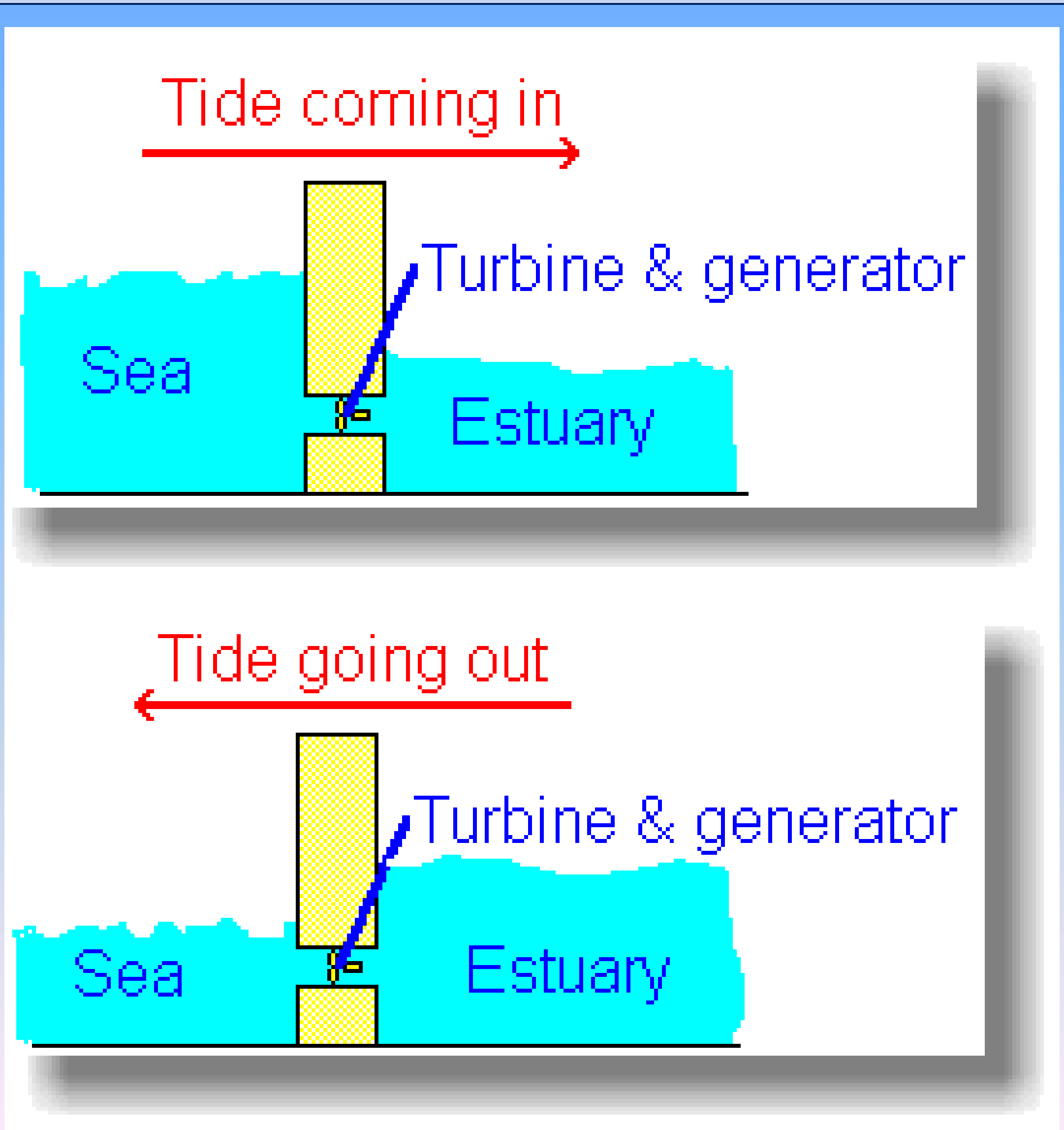
TIDE


Moon
(quarter phase)
Solar Tide
Lunar Tide
Neap Tides
Solar Tide
Moon
(full or new)
Lunar Tide
Spring Tides

HOW IT WORKS

- First generation, barrage-style tidal power plants
- Works by building Barrage to contain water after high tide, then water has to pass through a turbine to return to low tide

TIDAL ENERGY



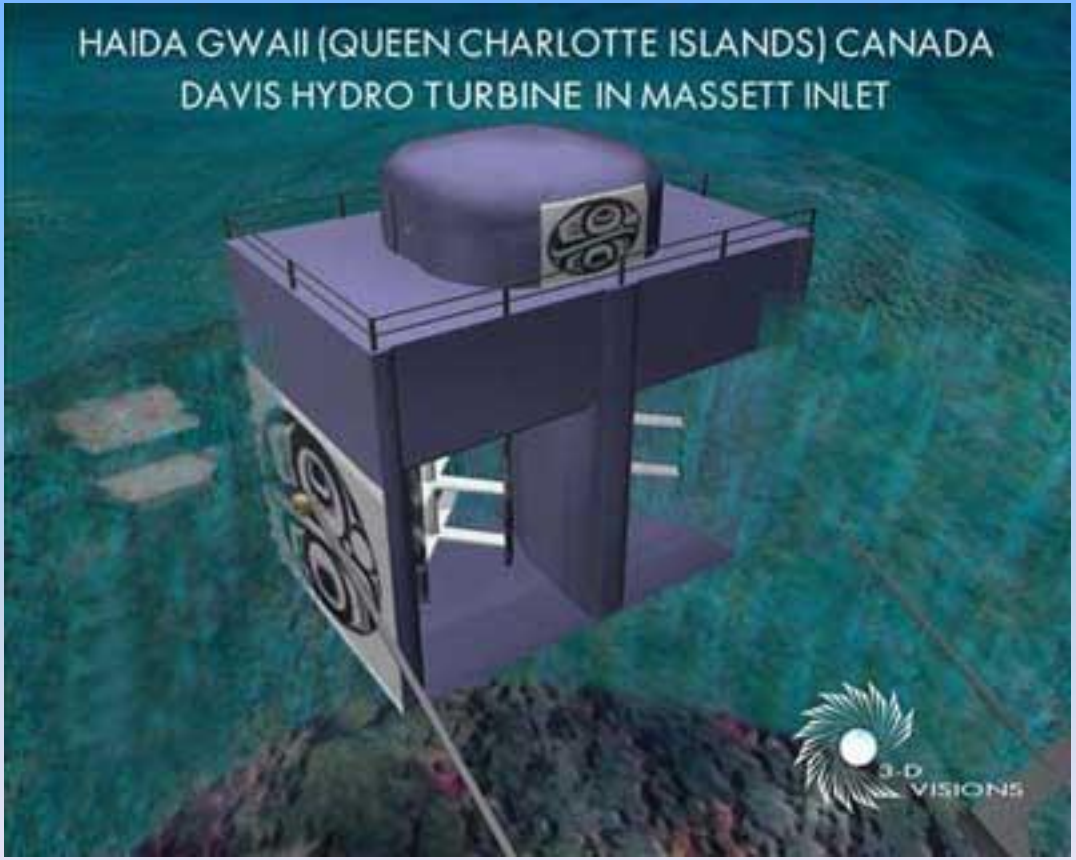
TIDAL ENERGY

SECOND-GENERATION TIDAL POWER PLANTS

- Barrage not need, limiting total costs
- Two types- vertical axis and horizontal axis
- Davis Hydro turbine….. Successfully tested in St. Lawrence Seaway

- Harness the energy of tidal streams
- More efficient because they allow for energy production on both the ebbing and surging tides
- One site has potential to equal the generating power of 3 nuclear power plants

TURBINE


HAIDA GWAII (QUEEN CHARLOTTE ISLANDS) CANADA
DAVIS HYDRO TURBINE IN MASSETT INLET
3-D VISIONS

DISADVANTAGES

- Presently costly
  - Expensive to build and maintain
  - A 1085MW facility could cost as much as 1.2 billion dollars to construct and run
- Connection to the grid
- Technology is not fully developed
- Barrage style only produces energy for about 10 hours out of the day
- Barrage style has environmental affects
  - Such as fish and plant migration
  - Silt deposits
  - Local tides change- affects still under study

ADVANTAGES

- No pollution
- Renewable resource
- More efficient than wind because of the density of water
- Predictable source of energy vs. wind and solar
- Second generation has very few disadvantages
  - Does not affect wildlife
  - Does not affect silt deposits
  - Less costly – both in building and maintenance

WAVE POWER

WAVE FACTS:

- Waves are caused by a number of forces, i.e. wind, gravitational pull from the sun and moon, changes in atmospheric pressure, earthquakes etc. Waves created by wind are the most common waves. Unequal heating of the Earth's surface generates wind, and wind blowing over water generates waves.
- This energy transfer results in a concentration of the energy involved: the initial solar power level of about 1 kW/m2 is concentrated to an average wave power level of 70kW/m of crest length. This figure rises to an average of 170 kW/m of crest length during the winter, and to more than 1 MW/m during storms.
- Wave energy performance measures are characterized by diffuse energy, enormous forces during storms, and variation over wide range in wave size, length, period, and direction.
- Wave energy is an irregular and oscillating low-frequency energy source that must be converted to a 60-Hertz frequency before it can be added to the electric utility grid.

WORLD WAVE POWER RESOURCES

- World Energy Council 2001 Survey stated the "potential exploitable wave energy" resources worldwide to be 2 TW. For European waters the resource was estimated to be able to cover more than 50% of the total power consumption.
- The wave market is estimated at $32 billion in the United Kingdom and $800 billion worldwide.
- The United States has exhibited weak effort compared to overseas projects in Norway, Denmark, Japan and the United Kingdom.
- As of 1995, 685 kilowatts (kW) of grid-connected wave generating capacity was operating worldwide. This capacity comes from eight demonstration plants ranging in size from 350 kW to 20 kW.
- Until recently the commercial use of wave power has been limited to small systems of tens to hundreds of watts aboard generate power

By; Mudit M. Saxena, Dept. of Mech. Engineering

WAVE POWER DESIGNS

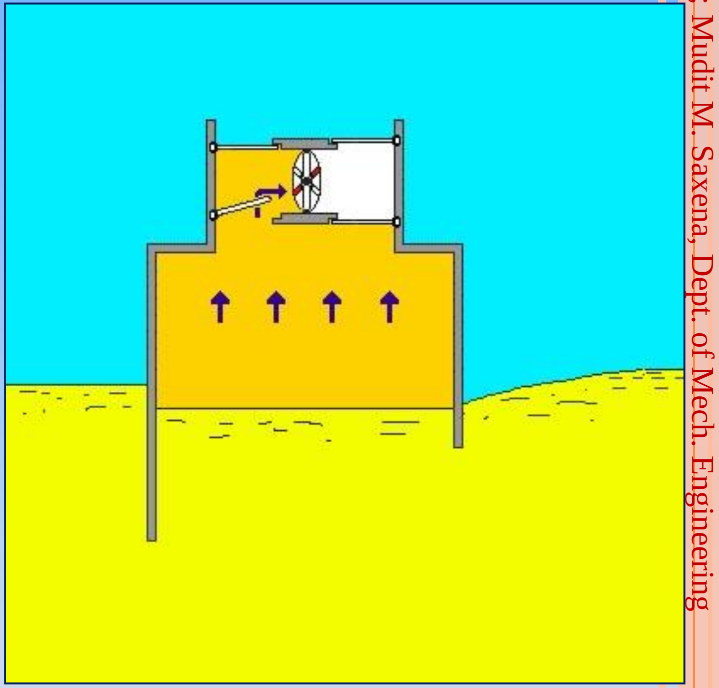
Although many wave energy devices have been invented, only a small proportion have been tested and evaluated. Only a few of these have been tested at sea, in ocean waves, rather than in artificial wave tanks. Large scale offshore devices and small scale shoreline devices have been ocean tested.

The total power of waves breaking on the world's coastlines is estimated at 2 to 3 million megawatts. In favorable locations, wave energy density can average 65 megawatts per mile of coastline.

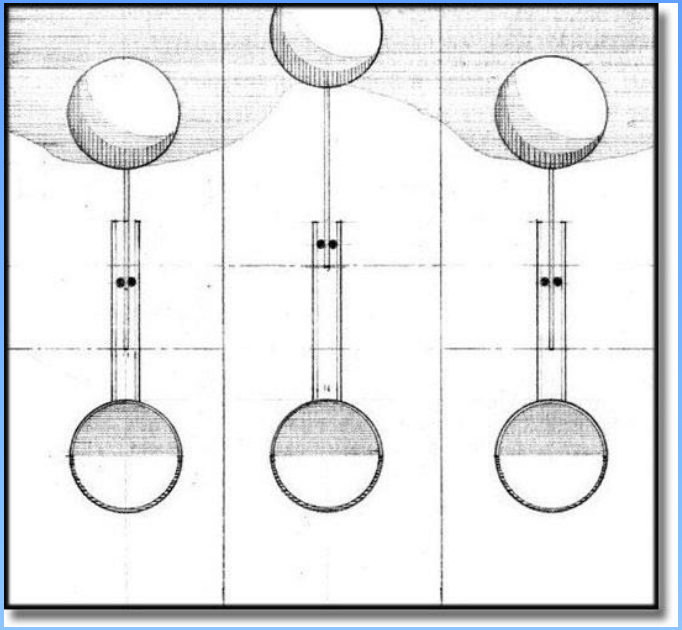
- **Oscillating Water Columns (OWC)**
  These devices generate electricity from the wave-driven rise and fall of water in a cylindrical shaft. The rising and falling water column drives air into and out of the top of the shaft, powering an air-driven turbine.
- **Floats or Pitching Devices**
  These devices generate electricity from the bobbing or pitching action of a floating object. The object can be mounted to a floating raft or to a device fixed on the ocean floor.
- Wave Surge or Focusing Devices
  These shoreline devices, also called "tapered channel" systems, rely on a shore-mounted structure to channel and concentrate the waves, driving them into an elevated reservoir. These focusing surge devices are sizable barriers that channel large waves to increase wave height for redirection into elevated reservoirs.

OSCILLATING WATER COLUMNS

- The Nearshore OWC rests directly on the seabed and is designed to operate in the near-shore environment in a nominal mean water depth of 15m.
- Nearshore OWC units also act like artificial reefs, improving environments for fishing while calming the water for a harbor.
- OWC designs typically require high maintenance, costly, taut moorings or foundations for operation while only using the extreme upper strata of an ocean site for energy conversion. While focusing devices are less susceptible to storm damage, massive structuring renders them most costly among wave power plant types.
- Since 1965, Japan has installed hundreds of OWC-powered navigational buoys and is currently operating two small demonstration OWC power plants. China constructed a 3 kW OWC and India has a 150 kW OWC caisson breakwater device.
- A 75 kW shore-based demonstration plant by Queens University, Belfast, using the OWC process described above has operated on the Scottish island of Islay for 10 years

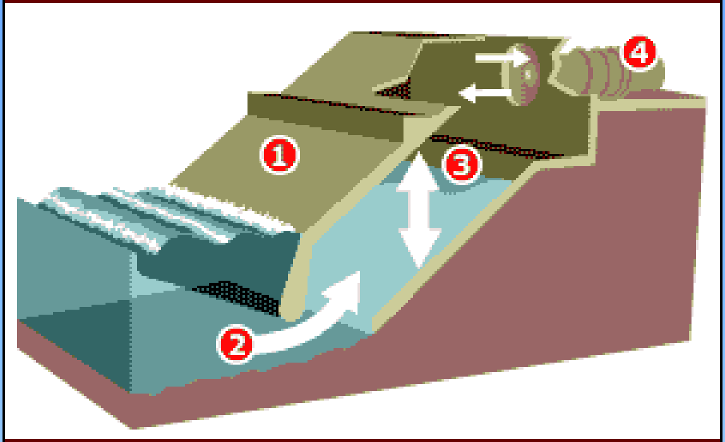


FLOATING DEVICES



- The Salter Duck, Clam, Archimedes wave swing, and other floating wave energy devices generate electricity through the harmonic motion of the floating part of the device. In these systems, the devices rise and fall according to the motion of the wave and electricity is generated through their motion.
- The Salter Duck is able to produce energy very efficiently, however its development was stalled during the 1980s due to a miscalculation in the cost of energy production by a factor of 10 and it has only been in recent years when the technology was reassessed and the error identified.

TAPERED CHANNEL WAVE POWER



ISLAY WAVE POWER STATION

① Wave capture chamber set into rock face

② Tidal power forces water into chamber

③ Air alternately compresssed and decompressed by "oscillating water column"

④ Rushes of air drive the Wells Turbine, creating power

These shoreline systems consist of a tapered channel which feeds into a reservoir constructed on a cliff. The narrowing of the channel causes the waves to increase their amplitude (wave height) as they move towards the cliff face which eventually spills over the walls of the channel and into the reservoir which is positioned several meters above mean sea level. The kinetic energy of the moving wave is converted into potential energy as the water is stored in the reservoir. The water then passes through hydroelectric turbines on the way back to sea level thus generating electricity.

THIS VS. THAT

- **Advantages**
- The energy is free - no fuel needed, no waste produced.
- Most designs are inexpensive to operate and maintain.
- Waves can produce a great deal of energy.
- There are minimal environmental impacts.

- **Disadvantages**
- Depends on the waves - sometimes you'll get loads of energy, sometimes nothing.
- Needs a suitable site, where waves are consistently strong.
- Must be able to withstand very rough weather.
- Disturbance or destruction of marine life
- Possible threat to navigation from collisions because the wave energy devices rise only a few feet above the water.
- Degradation of scenic ocean front views from wave energy devices located near or on the shore, and from onshore overhead electric transmission lines.

- Conclusion: Waves harness a lot of the sun's power,
  but they are better for surfing than generating electricity.

ASSIGNMENT

Q 1. How tidal power is generated in first generation and second generation power plant ?

Q 2. What are the advantages and disadvantages of tidal power plant.

Q 3. How wave power is generated ?

Q4. What are advantages and disadvantages of wave energy.

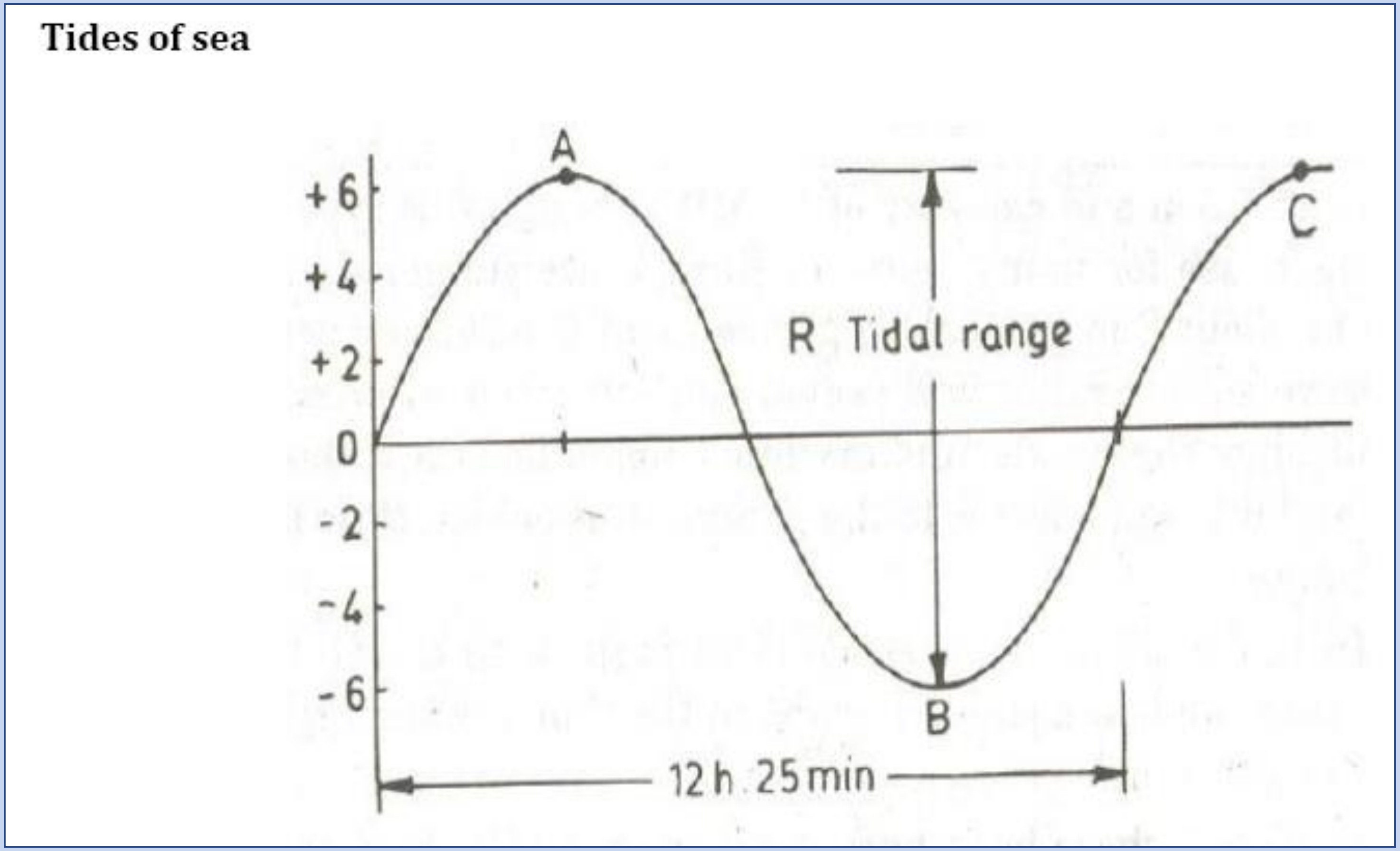
SINGLE BASIN AND DOUBLE BASIN TIDAL POWER PLANT

By: Mudit M. Saxena
Dept. of Mechanical Engineering
Indus University

TIDAL ENERGY

- Tides are periodic rise and fall of water level of sea which are caused by the action of sun and moon on the water on the earth. They are mainly caused by the gravitational attraction of the moon & Sun on the water of solid earth & Oceans. 70% of tides are produced by the force due to moon. Moon is the major factor in the tide.
- Two tidal cycles occurs during a lunar day of 24Hrs 50 Minutes. They are two high tides and two low tides. Time between high tides & Low tides at any given location is a little over 6 Hrs.
- A High tide will be experienced at a point which is directly under the moon. At the Same time, a diametrically opposite point on the earth's surface also experience a high tide due to dynamic balancing. Hence the Full moon as well as a No moon produce a high tide. The Rise & Fall of water level follows a Sinusoidal curve. Tides are periodical phenomenon. No two tides are alike, since the relative positions of sun & moon and their distances are continuously changing.
- When the water is above the mean sea level, it is called flood tide and when the level is below the mean level, it is called ebb tide. These tides can be used to produce electrical power which is known as tidal power.

TIDES OF SEA



Tides of sea

TIDAL POWER PLANT

- **Basic principle of tidal power plant**
- A dam is constructed in such a way that a basin gets separated from the sea and a difference in the water level is obtained between the basin and sea. The constructed basin is filled during high tide and emptied during low tide passing through sluices and turbine respectively. The Potential energy of the water stored in the basin is used to drive the turbine which in turn generates electricity as it is directly coupled to an alternator.

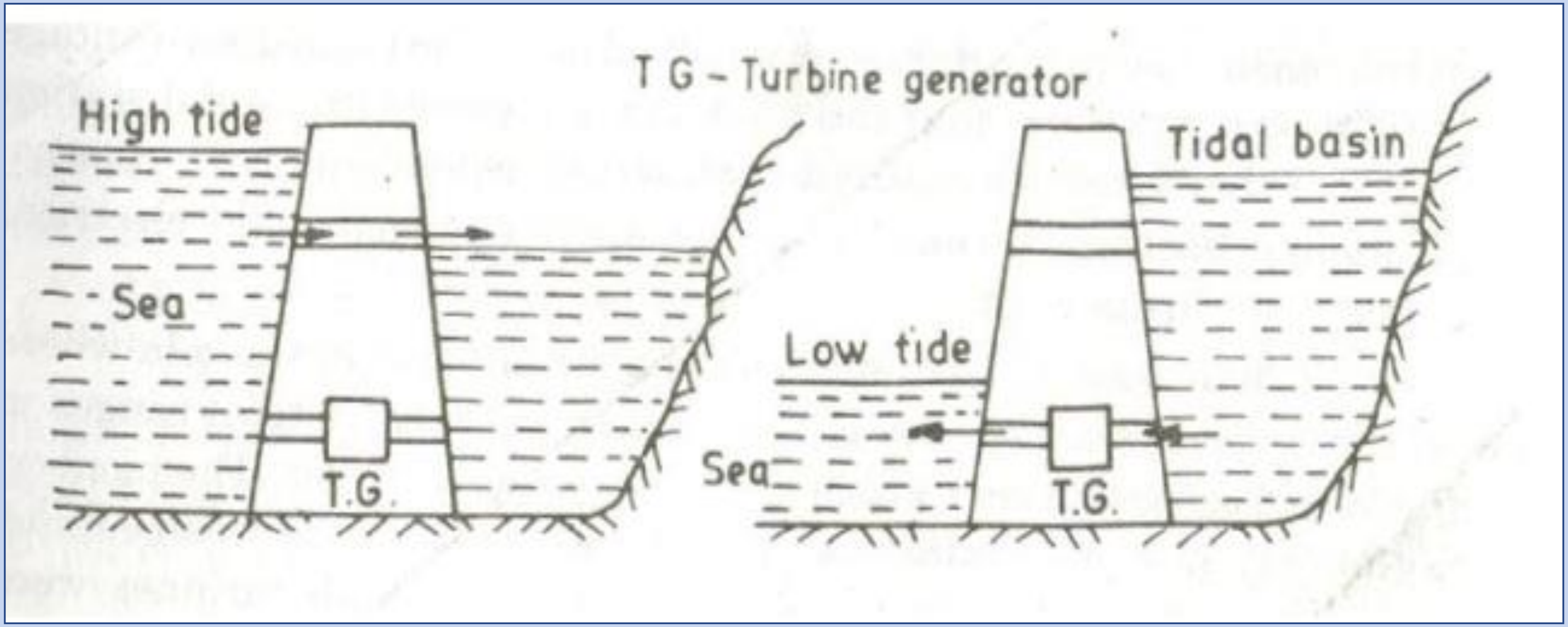
- **Components of tidal Power plants**
- There are three main Components of a tidal Power plant.

- Dam or barrage

- □ Sluice-ways from the basins to the sea and vice versa.

- □ Power house

BASIC PRINCIPLES OF TIDAL POWER PLANT



COMPONENTS OF TIDAL POWER PLANTS

- There are three main Components of a tidal Power plant.
- Dam or barrage
- Sluice-ways from the basins to the sea and vice versa.
- Power house
- **Barrage**
- Dam and barrage are synonymous terms. The function of dam is to form a barrier between the sea and the basin or between one basin and the other in case of multiple basins. Tidal power barrages have to resist waves whose shock can be severe and where pressure changes sides continuously. The barrage needs to provide channels for the turbines in reinforced concrete.
- The location of the barrage is important, because the energy available is related to the size of trapped basin and to the square of the tidal range. The nearer it is built to the mouth of bay, the larger the basin, but the smaller the tidal range. A balance must also be struck between increased output and increased material requirements and construction costs. Tidal barrages require sites where there is a sufficiently high tidal range to give a good head of water – the minimum useful range is around three meters.

COMPONENTS OF TIDAL POWER PLANTS

- **Gates and Locks**
- The sluice ways are used either to fill the basin during the high tide or empty the basin during the low tide, as per operational requirement. Gate structures can be floated as modular units. Though, in existing plants, vertical lift gates have been used. The technology is about ready to substitute a series of flap gates. Flap gates are gates operated by water pressure that are positioned so as to allow water in to the holding basin and require no mechanical means of operation. The flap gates allow only in the direction of the sea to basin. Hence, the basin level rises well above to sea level as ebb flow area is far less than flood flow area.
- **Power house**
- The turbines, electric generators and other auxiliary equipment's are the main components of a power house. For small head, large size turbines are needed; hence, the power house is also a large structure. Both the French and Soviet operating plants use the bulb type of turbine of the propeller type, with revisable blades, bulbs have horizontal shafts coupled to a single generator.

SCHEMATIC LAYOUT OF TIDAL POWER PLANT

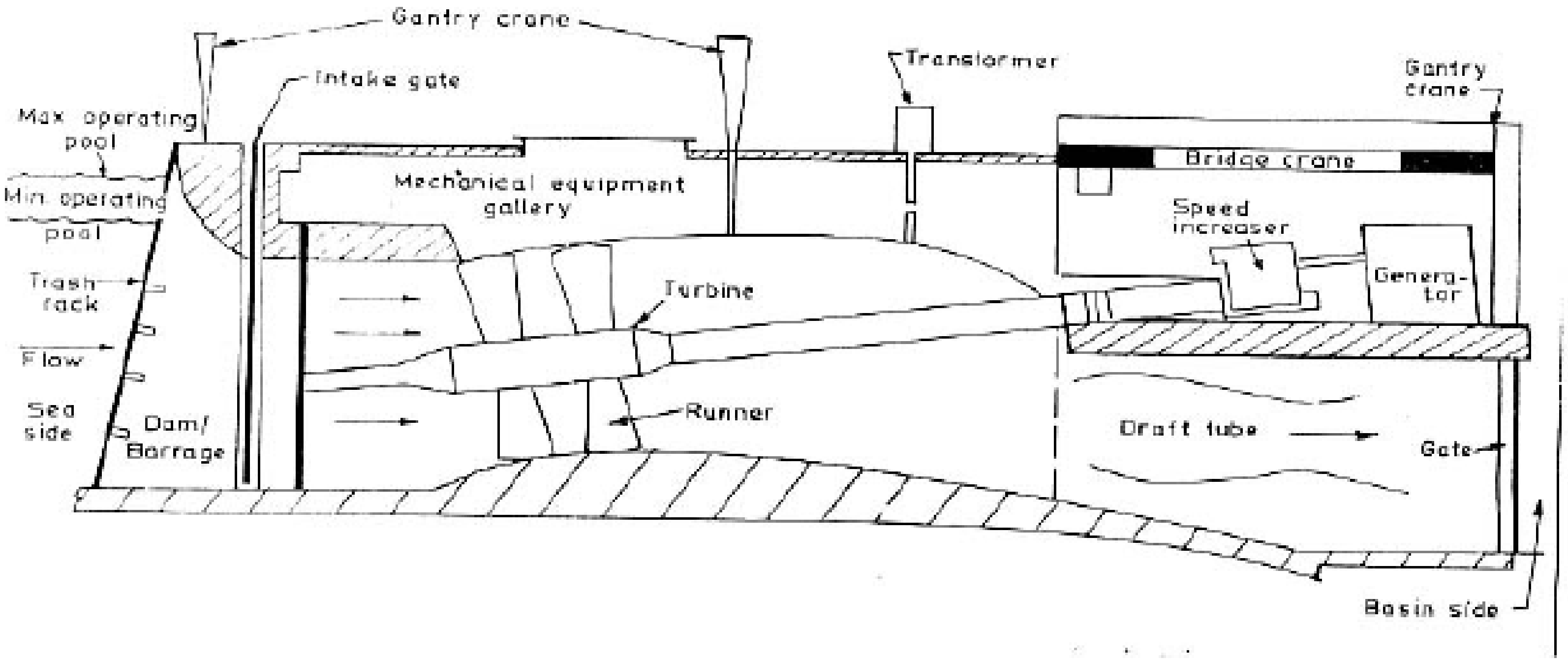


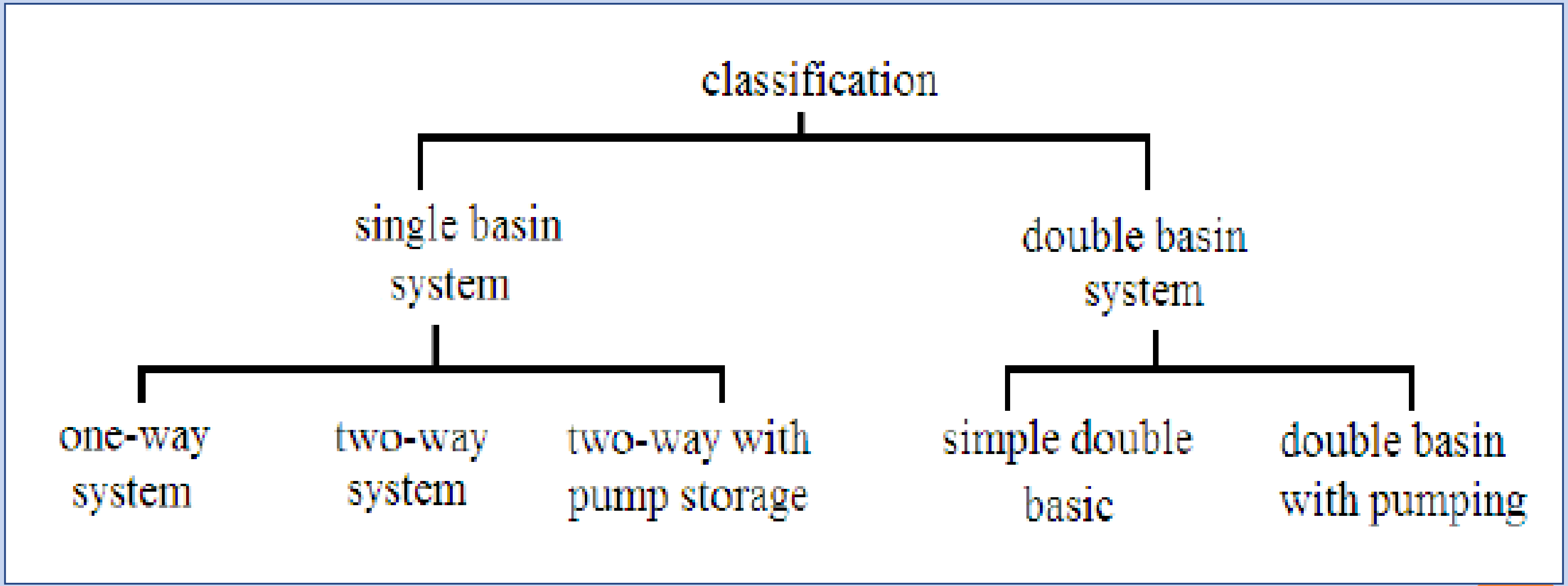
Fig 5.6 Schematic Lay out of Tidal Power House

SCHEMATIC LAYOUT OF TIDAL POWER PLANT

- The design cycle may also provide for pumping between the basin and the sea in either direction. If reversible pump turbines are provided, the pumping operation can be taken over at any time by the same machine. The modern tubular turbines are so versatile that they can be used either as turbines or as pumps in either direction of flow. In addition, the tubular passages can also be used as sluice-ways by locking the machine in to a standstill. As compared to conventional plants, this, however, imposes a great number of operations in tidal power plants.

CLASSIFICATION OF TIDAL POWER PLANTS

- The tidal power plants are generally classified on the basis of the number of basins used for the power generation. They are further subdivided as one-way or two-way system as per the cycle of operation for power generation.



WORKING OF DIFFERENT TIDAL POWER PLANTS

- **Single basin-One-way cycle**
- This is the simplest form of tidal power plant. In this system, a basin is allowed to get filled during flood tide and during the ebb tide. The water flows from the basin to the sea passing through the turbine and generates power. The power is available for a short duration during ebb tide.

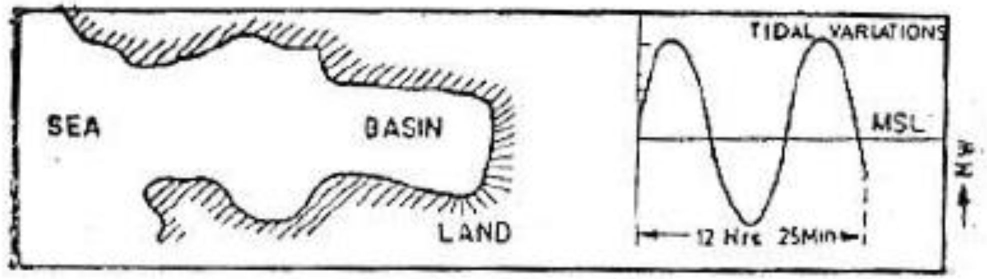
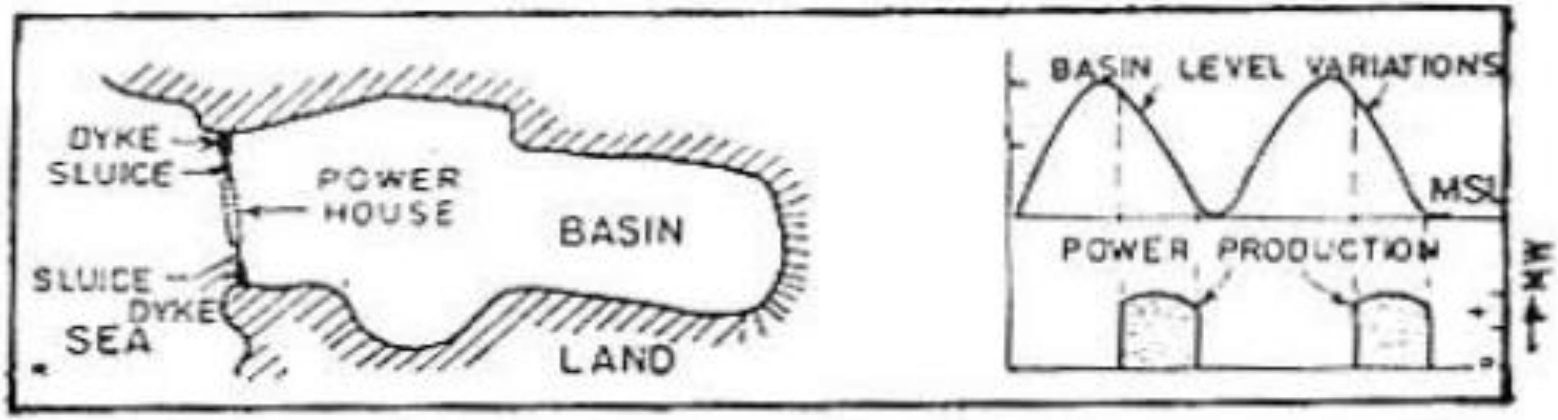


Fig1. Single basin Tidal Power Plant

BY. Mudit M. Saxena, Dept. of. Mech. Engg.

WORKING OF DIFFERENT TIDAL POWER

- Fig1. Shows a single tide basin before the construction of dam and Fig.2 shows the diagrammatic representation of a dam at the mouth of the basin and power generation during the falling tide.



(b) Single basin, one-way tidal power plant.

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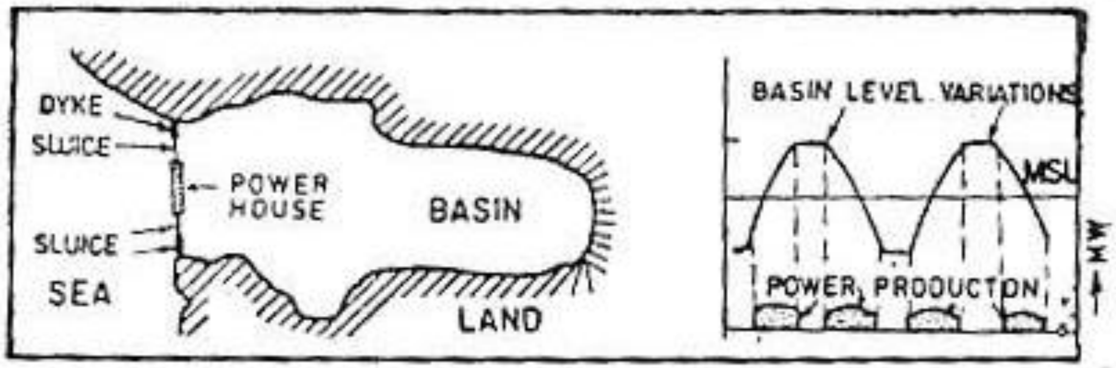
WORKING OF DIFFERENT TIDAL POWER PLANTS

- **Single-basin two-way cycle**
- In this arrangement power is generated both during flood tide as well as ebb tide also. The power generation is also intermittent but generation period is increased compared with one-way cycle. However the peak power obtained is less than the one-way cycle. The arrangement of the basin and the power cycle is shown in Fig.3.
- The main difficulty with this arrangement, the same turbine must be used as Prime mover as ebb and tide flows pass through the turbine in opposite directions. Variable pitch turbine and dual rotation generator are used for such schemes.



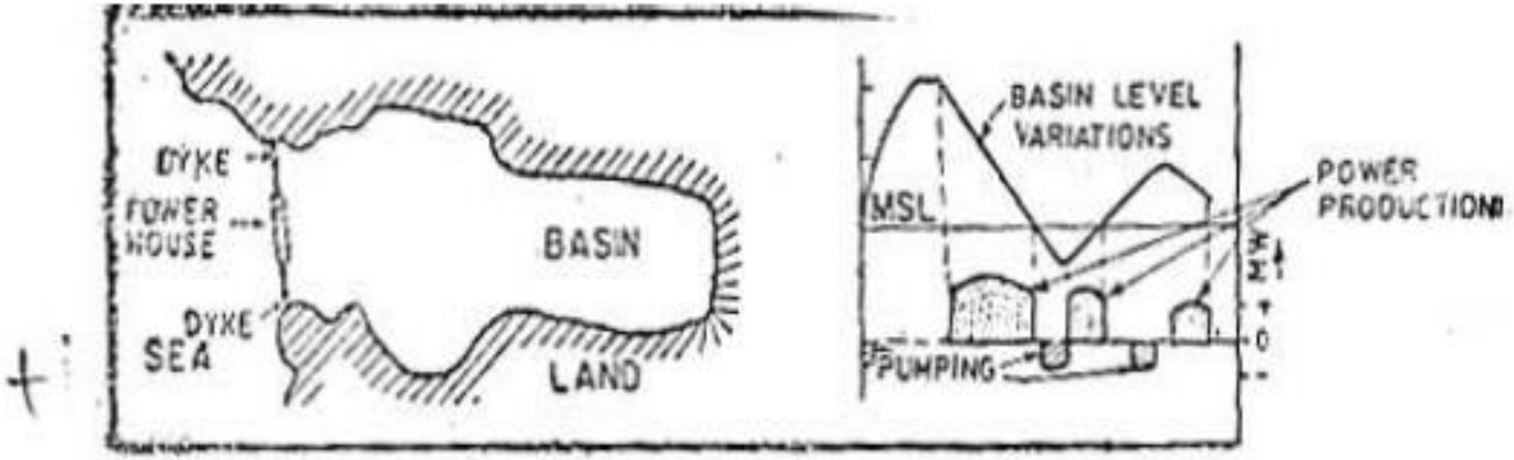
Single-basin two-way tidal power plant.

BY. Mudit M. Saxena, Dept. of. Mech. Engg.

SINGLE-BASIN TWO-WAY CYCLE WITH PUMP STORAGE

- **Single-basin two-way cycle with pump storage**
- The Rance tidal power plant in France uses this type of arrangement. In this system, power is generated both during flood and ebb tides. Complex machines capable of generation Power and Pumping the water in either direction are used. A part of the energy produced is used for introducing the difference in the water levels between the basin and the sea at any time of the tide and this is done by pumping water into the basin up or down. The period of power production with this system is much longer than the other two described earlier. The cycle of operation is shown in Fig 5.4.

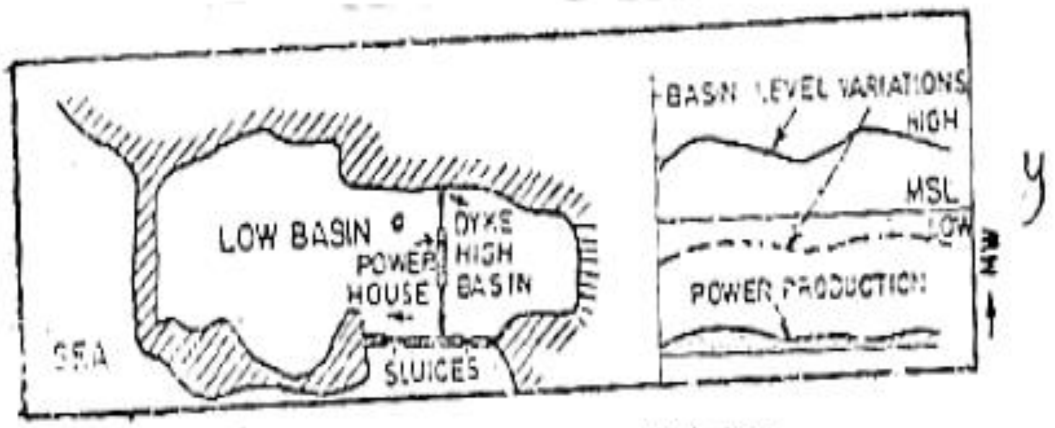
SINGLE-BASIN TWO-WAY CYCLE WITH PUMP STORAGE



Single-basin, two-way tidal plant coupled with pump storage system.

DOUBLE BASIN TYPE

- In this arrangement, the turbine is set up between the two basins as shown in Fig 5.5. one basin is intermittently filled by the flood tide and other is intermittently drained by the ebb tide. Therefore a small capacity but continues power is made available with this system as shown in Fig5.5. The main disadvantage of this system is that 50% of the Potential energy is sacrificed in introducing the variation in the water levels of the two basins.



Double basin, one-way tidal plant.

DOUBLE BASIN WITH PUMPING

- In this case, off peak power from the base load plant in a interconnected transmission system is used either to pump the water up the high basin. Net energy gain is possible with such a system if the pumping head is lower than the basin-to-basin turbine generating head.

ADVANTAGES OF TIDAL POWER PLANT

- **Advantages**
- - It is free from pollution as it does not use any fuel.
- - The tides are totally independent on nature's cycle of rainfall.
- - This will also not produce any unhealthy waste like gases, ash, atomic refuse which entails heavy removal costs.
- - Another notable advantage of tidal power is that it has a unique capacity to meet the peak power demand effectively when it works in combination with thermal or hydroelectric system.

DISADVANTAGES OF TIDAL POWER PLANT

- **Disadvantages**
- - These Power plants can be developed only if natural sites are available.
- - These Power plants will be always located far away from the load centers. The power generated must be transported to long distances. This increases the transportation cost.
- - The capital cost of the plant (Rs.5000/kw) is considerably large compared with conventional-power plants (hydro, thermal).
- - The supply of power is not continuous as it depends upon the timing of tides. Therefore some arrangements (double basin or double basin with pump storage) must be made to supply the continuous power. This also further increase the capital cost of the plant.
- - It is interesting to note that the output of power from tidal power plant varies with lunar cycle, because the moon largely influences the tidal rhythm, where as our daily power requirement is directly related to solar cycle.

ASSIGNMENT

Q 1. What is Tidal energy ? How it is harnessed ?

Q 2. Explain basic principle of Tidal power plant. Draw a line diagram to explain.

Q 3. What are the components of tidal power plant ? Explain.

Q 4. Explain single basin one way tidal power plant.

Q 5. Explain double basin type power plant.

Q 6. Make schematic layout of a Tidal power plant.

Q 7. Give classification of Tidal power plant.