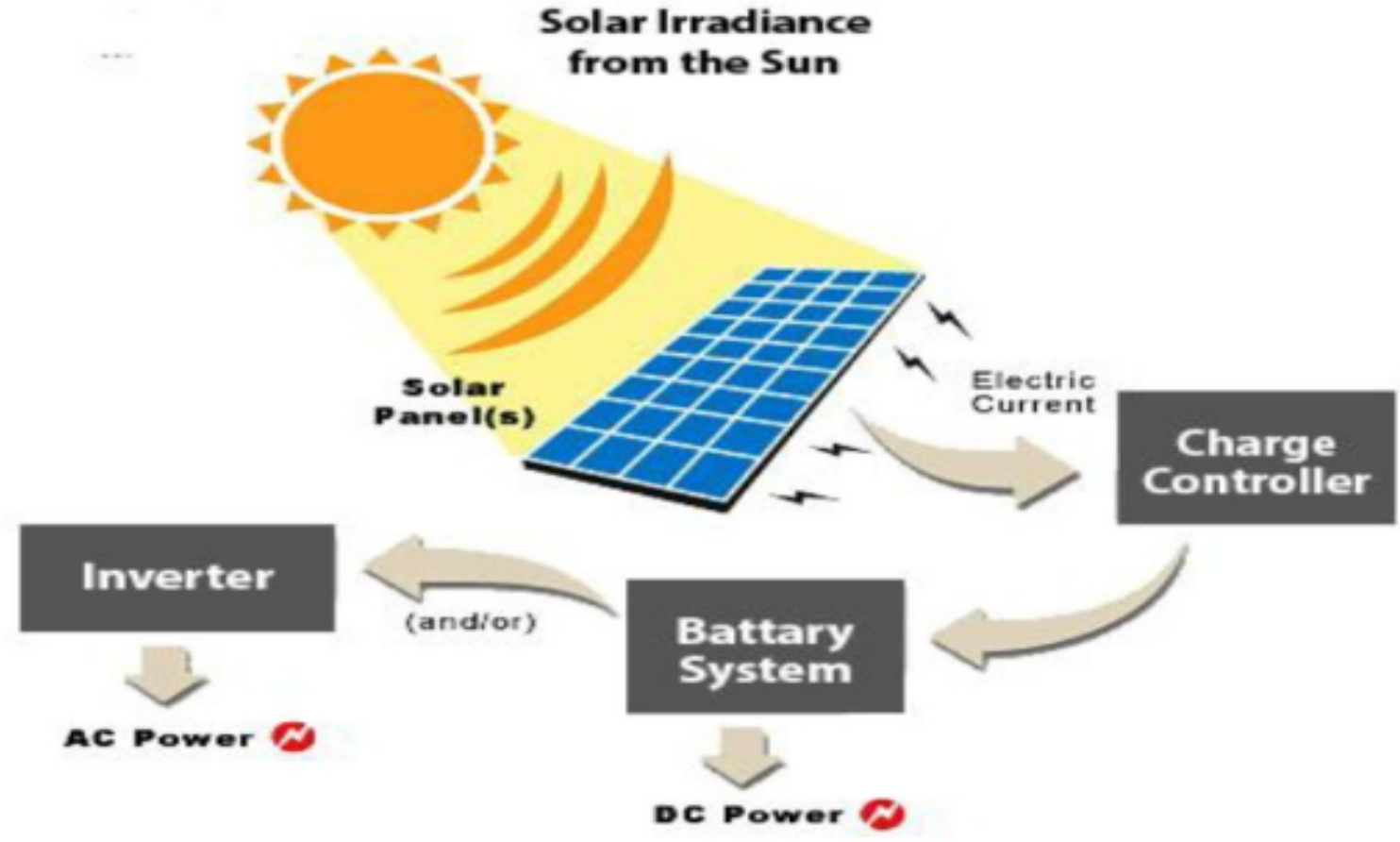
SOLAR ENERGY



SOLAR ENERGY
Out line

- Photovoltaic energy
- Solar thermal energy
- How does it work?

SOLAR ENERGY

- Solar radiation is the primary natural energy source of the Earth.
- Solar radiation mainly emanates as electromagnetic radiation from the surface of the sun (photosphere).
- It is originated by several nuclear fusion processes in the interior of the sun.
- The energy of solar radiation is directly utilized in mainly two forms by accumulation of heat in solar collectors (Solar thermal) and by direct conversion into electricity that takes place in semiconductor devices called solar cells (Solar PV systems).

Calculation of Global Solar Radiation(H)

1) Sunshine duration-based models($\Rightarrow$ Angstrom-Prescott)

It is given as;

$$\frac{H}{H_o} = a + b(\frac{n}{N})$$

Where

a and b are empirical regression coefficients (Angstrom constants)and given as

$$a = -0.11 + 0.235 * cos(\phi) + 0.323(\frac{n}{N})$$

$$b = 1.449 - 0.553 * cos(\phi) - 0.694(\frac{n}{N})$$

n is the sunshine duration.

N is the maximum possible sunshine duration(day length) and calculated as;

$$N = \frac{2}{15}\omega_s$$

Sunset hour ω_s is given as

$$\omega_s = cos^{-1}[-tan(\delta) * tan(\phi)]$$

δ is solar declination angle and is given as;

$$\delta = 23.45 * sin(\frac{360}{365}(284 + d))$$

d is the day number of the year counting from first January.
ϕ is latitude of specific place.
H_o is the extraterrestrial solar radiation on the horizontal surfce.

$$H_o = \frac{24 * 3600 G_{sc}}{\pi}[1 + 0.033 * cos(\frac{360d}{365})]*$$
$$[cos(\delta)cos(\phi)sin(\omega_s) + \frac{\pi * \omega_s}{180}sin(\phi)sin(\delta)]$$

Where $G_{sc} = 1367 W/m^2$ is solar conatant.

2. Temperature-based models($\Rightarrow$ Hargreaves and Samani)

This model is given as:

$$\frac{H}{H_o} = a(\sqrt{\Delta T})$$

Where $\Delta T = T_{max} - T_{min}$
Where T_{max} and T_{min} are maximum and miniumum temperature respectively.

1. PHOTOVOLTAIC ENERGY

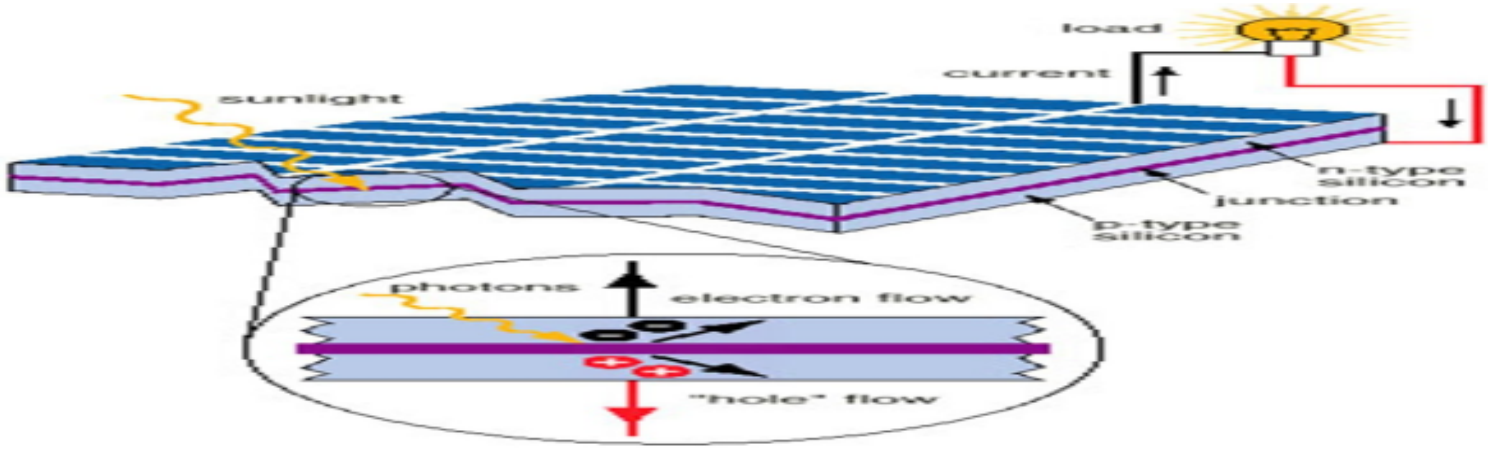
- PV is the direct conversion of radiation into electricity.
- The solar cell is the elementary building block of the pv technology.
- Solar cells are made of semiconductor materials, such as silicon.
- Semiconductors are most useful since their conductivity may easily be modified by introducing impurities into their crystal lattice.
- PV will play an important role in the field of renewable energies.
- PV modules are solid-state devices that convert sunlight(the most abundant) energy source on the planet.
- PV technology is modular (i.e., existing systems are expandable), has a long lifetime (manufactures give guarantees of up to 25 years), is silent and emissions-free during use.

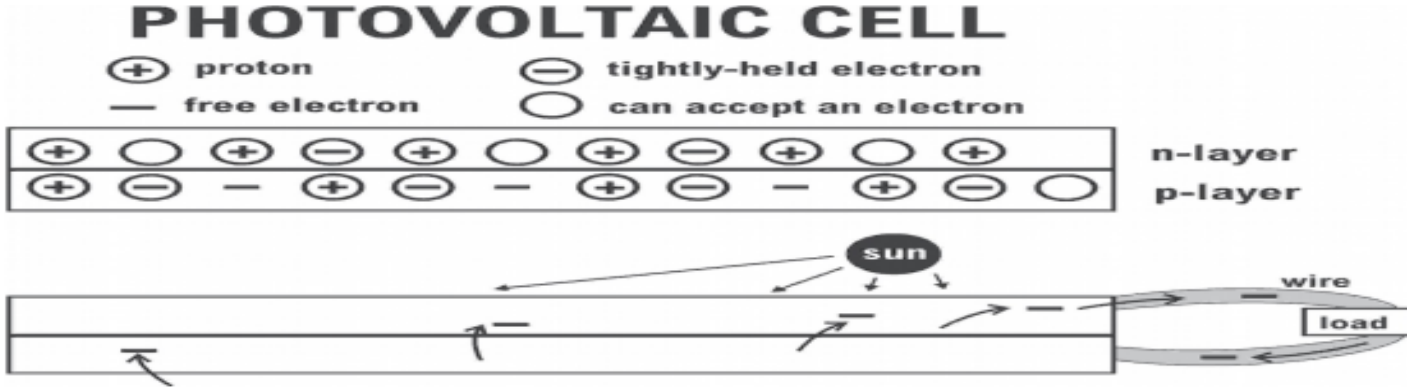
▶ A PV generator is mainly an assembly of solar cells, connections, protective parts, and supports.
▶ Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide.

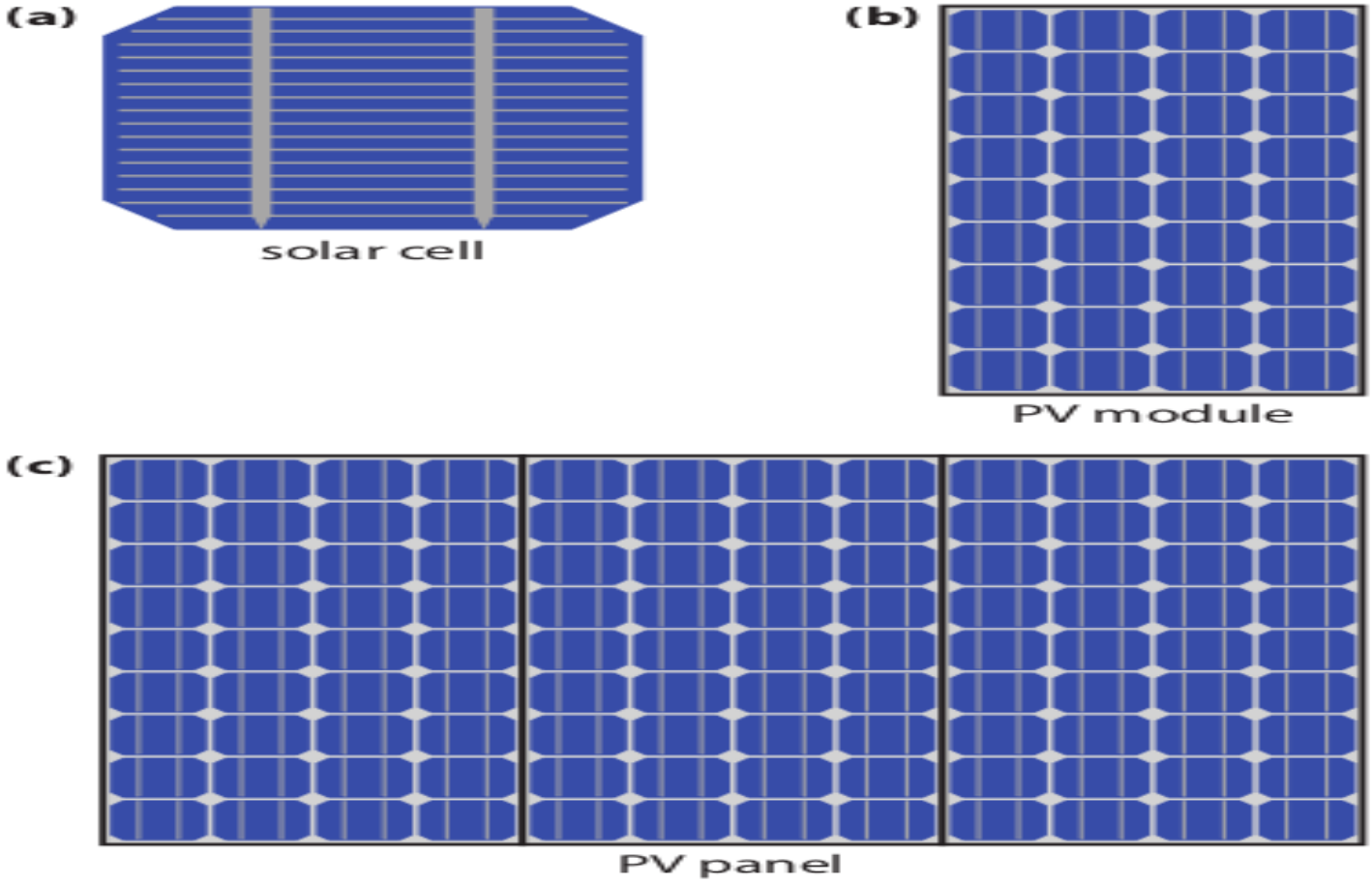
How Does it Work?

▶ Sunlight is composed of photons, or bundles of radiant energy.
▶ When photons strike a PV cell, they may be reflected or absorbed (transmitted through the cell).
▶ Only the absorbed photons generate electricity.
▶ When the photons are absorbed(negative side), the energy of the photons is transferred to electrons in the atoms of the solar cell.
▶▶ creating electron-hole pairs.
▶ The solar cell is fabricated by having an n and p layer, which is a junction.

▶ The junction acts as a battery, creating an electric field at the surface where they meet.
▶ The field causes the electrons to move from the semiconductor toward the surface and make them available for the electrical circuit.
▶ At the same time, the holes move in the opposite direction, toward the positive surface.
▶ So, when photons are absorbed by the PV cell, they create more electrons and holes, which become available for a current for an external load.
▶ The electrons are captured in the form of electric current, called photocurrent , I_{ph}.
▶ During darkness the solar cell is not active and works as a diode, i.e., a p-n junction that does not produce any current or voltage.
▶ If it is connected to an external, large voltage supply, it generates a current, called the diode or dark current , I_D.


load
current
sunlight
n-type silicon
junction
p-type silicon
photons
electron flow
"hole" flow


PHOTOVOLTAIC CELL
proton
tightly-held electron
free electron
can accept an electron
n-layer
p-layer
sun
wire
load


(a)
solar cell
(b)
PV module
(c)
PV panel

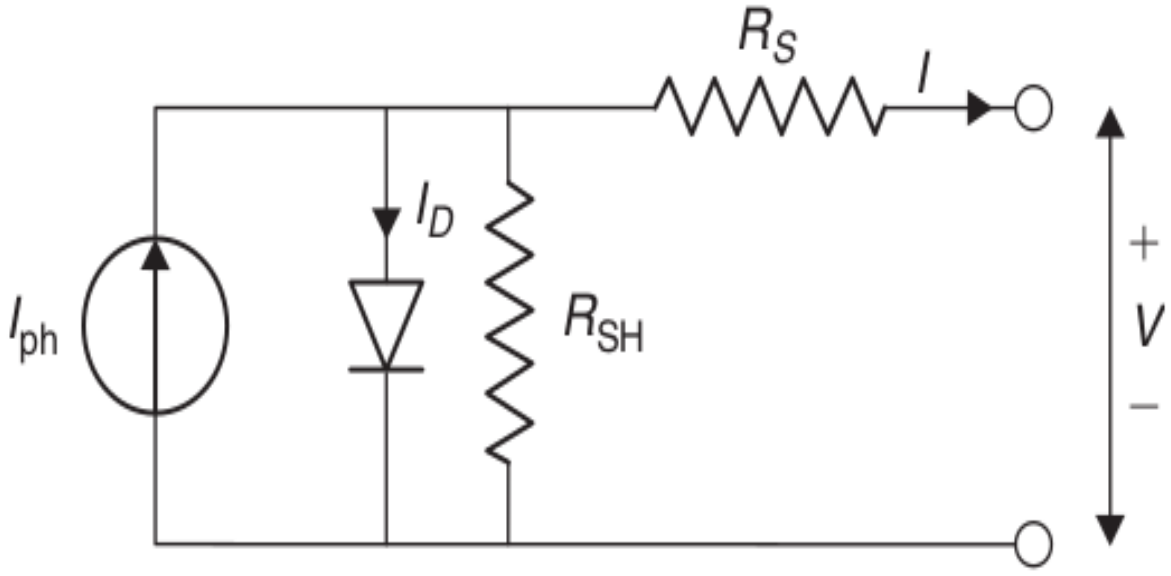


Figure: Single solar cell model

▶ This circuit can be used for an individual cell, a module or an array consisting of several modules.

▶ The model contains a current source, I_{ph} , one diode, and a series resistance R_S , which represents the resistance inside each cell.

▶ The diode has also an internal shunt resistance.

▶ The net current is the difference between the photocurrent, I_{ph} , and the normal diode current, I_D , given by;

$$I = I_{ph} - I_D = I_{ph} - I_o[exp[\frac{e(V + IR_S)}{KT_c}] - 1] - \frac{V + IR_S}{R_{SH}} - - - - - - - - 1$$

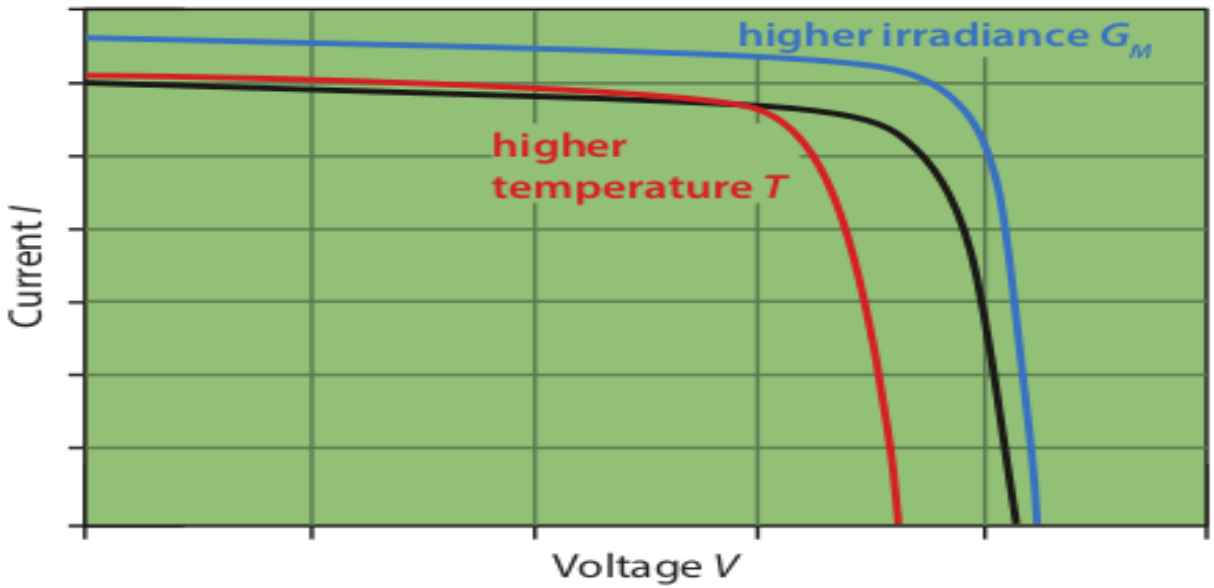
▶ Shunt resistance $>>$ load resistance and the above equation become;

$$I = I_{ph} - I_D = I_{ph} - I_o[exp[\frac{eV}{KT_c}] - 1] - - - - - - - - - - - - - - - - - - 2$$

Where
$K = 1.38 * 10^{-23}$ Boltmann's gas constant
T_c= absolute temperature of the cell (K).
$e = 1.602 * 10^{-19}$ electronic charge
V=voltage imposed across the cell (V)
I_o = dark saturation current which depends strongly on temperature (A)

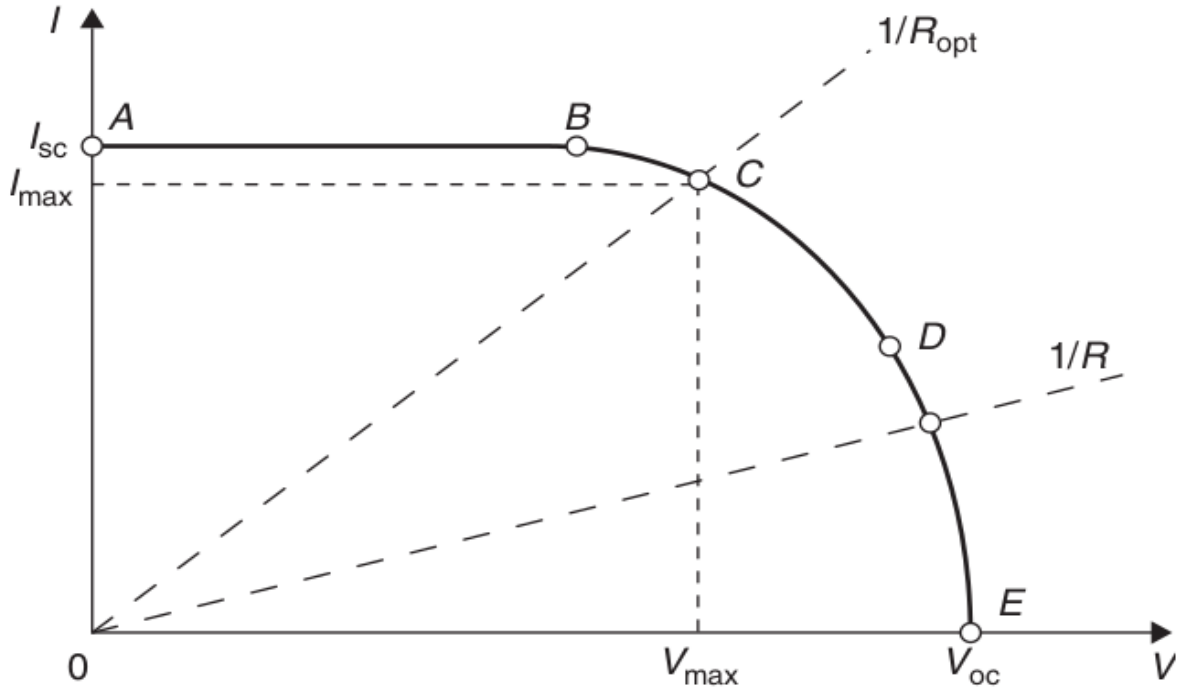
Maximum power point tracking

- It is very unique to the field of PV Systems and brings a very special application of power electronics to the field of PV.
- Solar cell can be characterised by an I-V curve.
- Interconnecting several solar cells in series or in parallel merely increases the overall voltage and/or current, but does not change the shape of the I-V curve.



▶ The current from a PV cell depends on the external voltage applied and the amount of sunlight on the cell.
▶ When the cell is short-circuited, the current is at maximum (short-circuit current, I_{sc}), and the voltage across the cell is 0.
▶ When the PV cell circuit is open, the voltage is at its maximum (open-circuit voltage, V_{oc}), and the current is 0.
▶ In either case, at open circuit or short circuit, the power (current times voltage) is 0.
▶ Between open circuit and short circuit, the power output is greater than 0.
▶ The curve presents the range of combinations of current and voltage.
▶ If the cell's terminals are connected to a variable resistance, R , the operating point is determined by the intersection of the I-V characteristic of the solar cell with the load I-V characteristics.

▶ For a resistive load, the load characteristic is a straight line with a slope $\frac{1}{V} = \frac{1}{R}$.



▶ If load is small;

▶▶the cell operates in the region AB,

▶▶the cell behaves as a constant current source, almost equal to the short-circuit current.

▶ If the load resistance is large;
▶▶ the cell operates on the region DE
▶ ▶ the cell behaves more as a constant voltage source, almost equal to the open circuit voltage.
▶ The maximum power passes from a maximum power point (point C), at which point the load resistance is optimum, R_{opt}, and the power dissipated in the resistive load is maximum and given by;

$$P_{max} = I_{max} V_{max} - - - - - - - - - - - - - - - - - - 3$$

▶ At which the output power is maximized.
▶ Given P_{max} , an additional parameter, called the fill factor , FF, can be calculated such that;

$$FF = \frac{P_{max}}{I_{sc} V_{oc}} = \frac{I_{max} V_{max}}{I_{sc} V_{oc}} - - - - - - - - - - - - - - - 4$$

▶ The fill factor is a measure of the real I-V characteristic.
▶ For good cells, its value is greater than 0.7.
▶ The fill factor decreases as the cell temperature increases.

▶ From figure I_{sc} has high value under short circuit conditions($V = 0$) and is equal to I_{ph}.

▶The open circuit voltage corresponds to the voltage drop across the diode when it is traversed by the photocurrent, I_{ph} , which is equal to I_D, when the generated current is $I = 0$.

▶ This is the voltage of the cell during night time and can be obtained from equation(2);

▶ During night time ($I_{ph} = 0$) and $I = I_{sc}$;

$$I_{sc} = I_o(exp[\frac{eV_{oc}}{KT_c}] - 1)$$

$$exp[\frac{eV_{oc}}{KT_c}] = \frac{I_{sc}}{I_o} + 1$$

▶ Taking natural logarithms;

$$V_{oc} = V_t \ln[\frac{I_{sc}}{I_D} + 1] - - - - - - - - - - - - - 5$$

Where
$V_t = K\frac{T_c}{e}$ is thermal voltage.

- The output power, P , from a photovoltaic cell is given by;

$$P = IV - 6$$

- The output power depends also on the load resistance, R ;

$$P = IR^2$$

- Using equation(2) into (6);

$$P = (I_{sc} - I_o[exp(\frac{eV}{KT_c}) - 1])V - - - - - - - - 7$$

- Differebtiating equation (7) wrt V the external voltage, V_{max} , that gives the maximum cell output power can be obtained:

$$exp[\frac{eV_{max}}{KT_c}][1 + e\frac{V_{max}}{KT_c}] = 1 + \frac{I_{sc}}{I_o} - - - - - - - - - - - 8$$

▶ This is an explicit equation of the voltage V_{max} , which maximizes the power in terms of the short-circuit current ($I_{sc} = I_{ph}$), the dark saturation current (I_o), and the absolute cell temperature, T_C .

▶ If the values of these three parameters are known, then V_{max} can be obtained from Eq. (8) by trial and error.

▶ The load current, I_{max} , which maximizes the output power, can be found by substituting Eq. (8) into Eq. (2):

$$I_{max} = I_{sc} - I_o[exp(\frac{eV}{KT_c}) - 1] = I_{sc} - I_o[\frac{1 + \frac{I_{sc}}{I_o}}{1 + \frac{V_{max}}{KT_c}} - 1]$$

Which gives;

$$I_{max} = \frac{eV_{max}}{KT_c + eV_{max}}(I_{sc} + I_o)$$

▶ By using equation(3) and we have;

$$P_{max} = \frac{eV_{max}{}^2}{KT_c + eV_{max}}(I_{sc} + I_o)$$

▶ Efficiency is commonly reported for a PV cell temperature of 25^0C and incident light at an irradiance of 1000 W/m^2 with a spectrum close to that of sunlight at solar noon.

▶ Maximum efficiency, which is the ratio between the maximum power and the incident light power, given by;

$$\eta_{max} = \frac{P_{max}}{P_{in}} = \frac{I_{max} V_{max}}{A G_i}$$

Where;

A= cell area (m^2)

G_i is irradiance.

Example:

If the dark saturation current of a solar cell is $1.7 * 10^{-8} A/m^2$, the cell temperature is $27^0 C$, and the short circuit current density is 250 A/m^2 , calculate the open circuit voltage, V_{oc} ; voltage at maximum power, V_{max} ; current density at maximum power, I_{max} ; maximum power, P_{max} ; and maximum efficiency, η_{max} .

What cell area is required to get an output of 20 W when the available solar radiation is $820 W/m^2$?

Solution

First the value of $\frac{e}{KT_c}$ is evaluated, which is used in many relations:

$$\frac{e}{KT_c} = \frac{1.602 * 10^{-19}}{1.381 * 10^{-23} * 300} = 38.67 V^{-1}$$

$$V_{oc} = KT_c \ln[\frac{I_{sc}}{I_o} + 1]$$

$$V_{oc} = \frac{1}{38.67} \ln[\frac{250}{1.7 * 10^{-8}} + 1] = 0.605 V$$

Voltage at maximum power can be found from Eq. (8) by trial and error:

$$exp[\frac{eV_{max}}{KT_c}][1 + \frac{eV_{max}}{KT_c}] = 1 + \frac{I_{sc}}{I_o}$$

$$exp(38.67 V_{max})(1 + 38.67 V_{max}) = 1 + \frac{250}{1.7 * 10^{-8}}$$

which gives $V_{max} = 0.47 V$

The current density at maximum power point can be estimated from

$$I_{max} = \frac{eV_{max}}{KT_c + eV_{max}}(I_{sc} + I_o)$$

$I_{max} = \frac{(1.602*10^{-19})(0.47)}{(1.38*10^{-23})(300)+(1.602*10^{-19})(0.47)}[250 + 1.7 * 10^{-8}]$
$I_{max} = 237A/m^2$
Maximum power;

$$P_{max} = I_{max}V_{max}$$

$P_{max} = (237)(0.47) = 111.4W/m^2$
Maximum efficiency;

$$\eta_{max} = \frac{P_{max}}{P_{in}}$$

$\eta_{max} = \frac{111.4}{820} = 13.58percent$
Finally, the cell area required to get an output of 20 W is;

$$A = \frac{P_{req}}{P_{max}} = \frac{20}{111.4} = 0.18m^2$$

2. Solar Thermal Energy Systems

- Solar thermal systems convert sunlight to heat.
- Systems can be passive or active.
- Passive solar heating refers to architectural design techniques.
- The building structure absorbs much solar energy during daylight hours in the winter months.
- Then this "stored" energy replace the heat that provided by a fossil fuel-fired furnace, or by electric heating.

E.g: Building materials that absorb and slowly release the heat of the sun are used in the flooring and walls.

- Such building materials include rocks, stone, or concrete, which can collect the solar energy as heat.

- Active solar heating uses "solar collectors", usually mounted on roof tops for residential buildings, to heat water, or another fluid which is then circulated to other parts of the building.
- Solar water heater is a combination of a solar collector array, an energy transfer system and a storage tank.
- Its main part is the collector array, which absorbs solar radiation and converts it into heat.
- This heat is absorbed by a heat transfer fluid that passes through the collector.
- The heat can be stored or used directly.
- The amount of the hot water produced depends on;
  - type and size of the solar collector array
  - the size of the water storage,
  - the amount of sunshine available at the site and
  - the seasonal hot water demand pattern.

- There are several ways to classify solar water heating systems.
  - When the fluid used in the application is the same that is heated in the collector it is called a direct or open loop.
  - When the fluid heated in the collector goes to a heat exchanger to heat up the utility fluid, it is called an indirect or closed loop.

Solar Thermal Collectors

- The working fluid is heated by the solar radiation.
- The collector determines how efficiently the incident light is used.
- Consists of a black surface, called the absorber, and a transparent cover.
- The absorber is able to absorb most of the incident energy from the sun and rises its temperature and transferring that heat to a working fluid.
- The efficiency of the collector depends mainly on two factors:
  - the extent to which the sunlight is converted into heat by the absorber and
  - the heat losses to the surroundings.
  - Usually, collectors are classified in three categories: **uncovered, covered and vacuum**.

Uncovered collectors do not have a transparent cover, so the sun strikes directly the absorber surface, hence the reflection losses are minimized.

- It is only used for swimming pools.

Covered collectors are covered by a transparent material, providing extra insulation but also increasing the reflection losses.

- Used for absorber temperatures of up to 100^{O}C.

vacuum collectors the absorber is encapsulated in vacuum tubes.

- Little heat is lost to the surroundings.
- It is more complicated and expensive.
- It can be used for high temperature applications since the convection losses to the surroundings are much lower than for the other types.

▶ Collectors also can be classified by their shape as: flat-plate collectors and concentrating collectors.

Flat-plate collectors consist of flat absorbers that are oriented towards the sun.

▶ They can deliver moderate temperatures, up to around $100^{O}C$.

▶ They use both direct and diffuse solar radiation.

▶ No tracking systems are required.

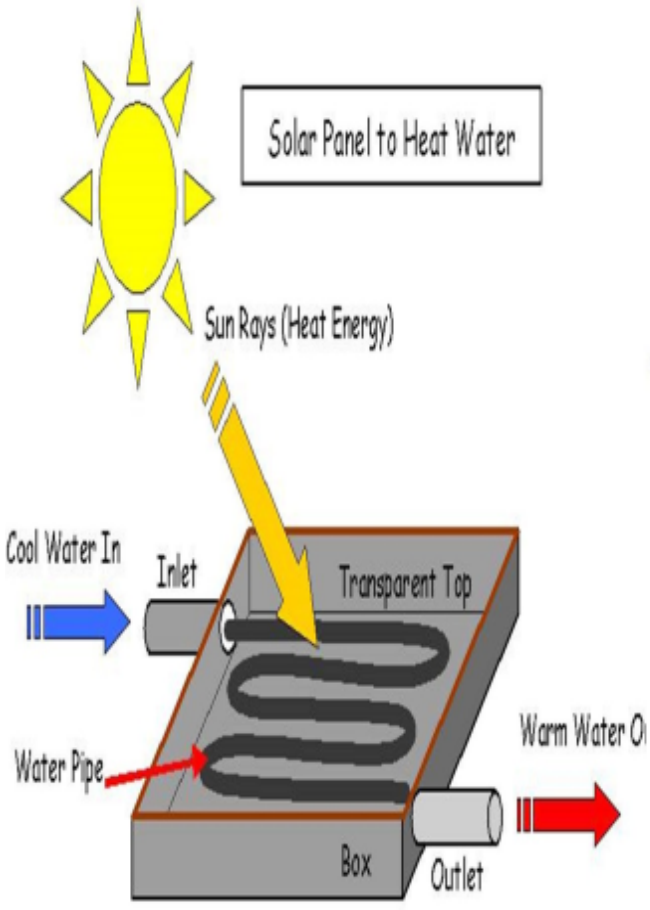
▶It can be used for solar water heating, heating of building, air conditioning and industrial processes heat.

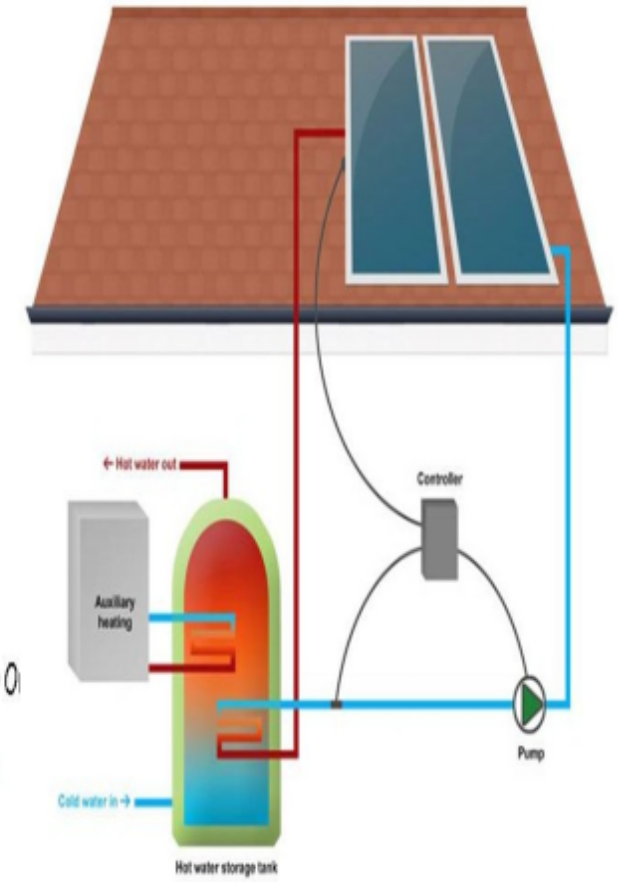
Concentrating collectors

▶ For systems that require a higher temperature than achievable with flat collectors.

▶ The performance can be optimized by decreasing the area of heat loss.

▶ This is done by placing an optical device in between the source of radiation and the energy absorbing surface.


Solar Panel to Heat Water
Sun Rays (Heat Energy)
Cool Water In
Inlet
Transparent Top
Water Pipe
Warm Water O
Box
Outlet


Hot water out
Controller
Auxiliary heating
Pump
Cold water in
Hot water storage tank

▶ Concentrating solar collector(CSC) is an active solar thermal energy installation usually used to generate electricity on a fairly large scale.

▶ These systems use one or more reflecting mirrors to concentrate a beam of solar energy onto a focal point in order to provide a source of high temperature heat.

▶ Installation systems using an array of mirrors (CSC) built primarily using two different approaches; either a "solar power tower" concept or a "trough" concept.

Solar Power Tower Thermal Plant:

▶ Uses a large number of mirrors, or "heliostats" which are able to automatically track the sun and focus the reflected rays onto a "receiver" on top of the central tower.

▶ The steam which is ultimately produced is then used to drive a steam turbine-powered generator.
▶ The receiver is heated to a very high temperature by highly concentrated solar radiation.
▶ This is used to heat water to produce steam directly.

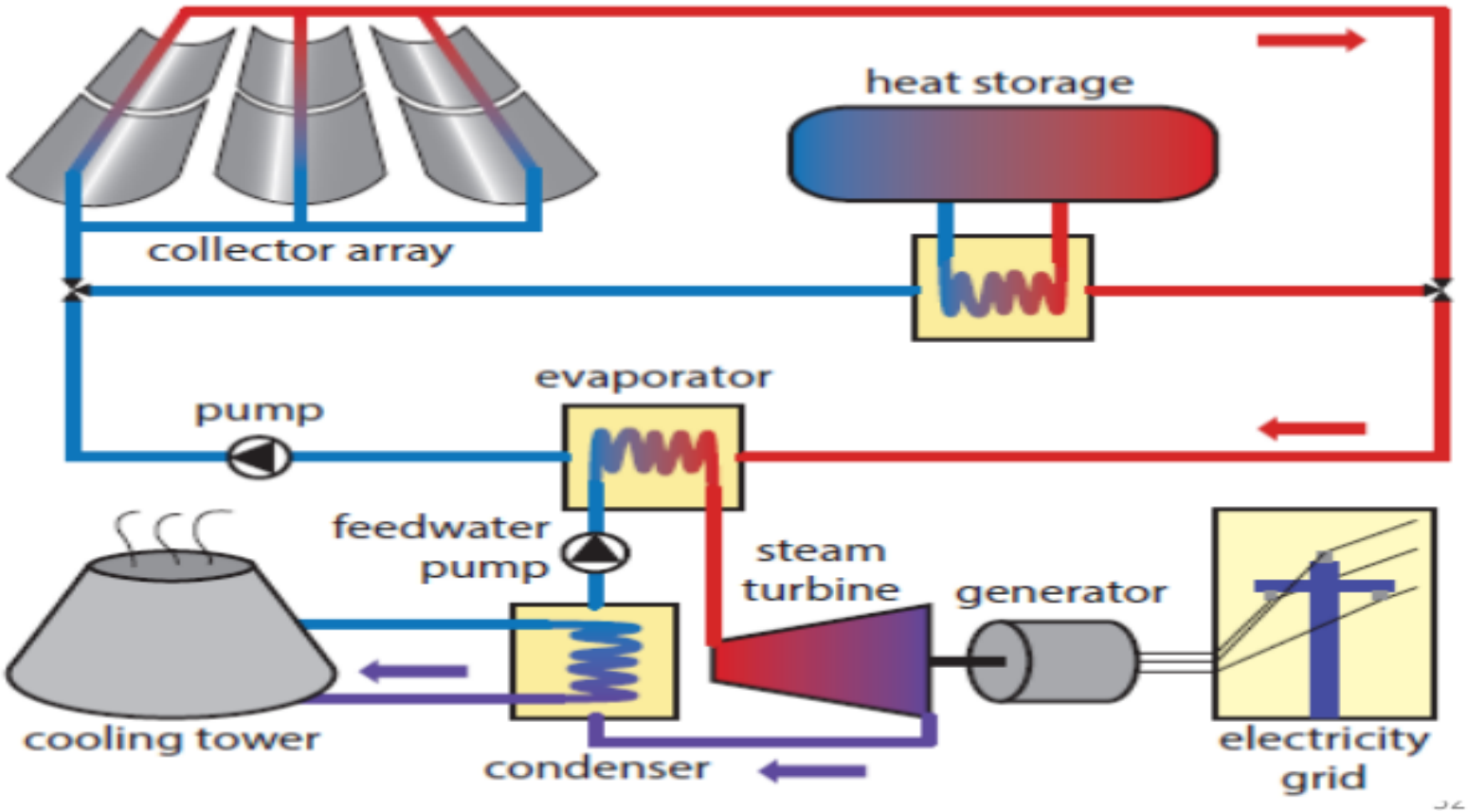
Solar Trough

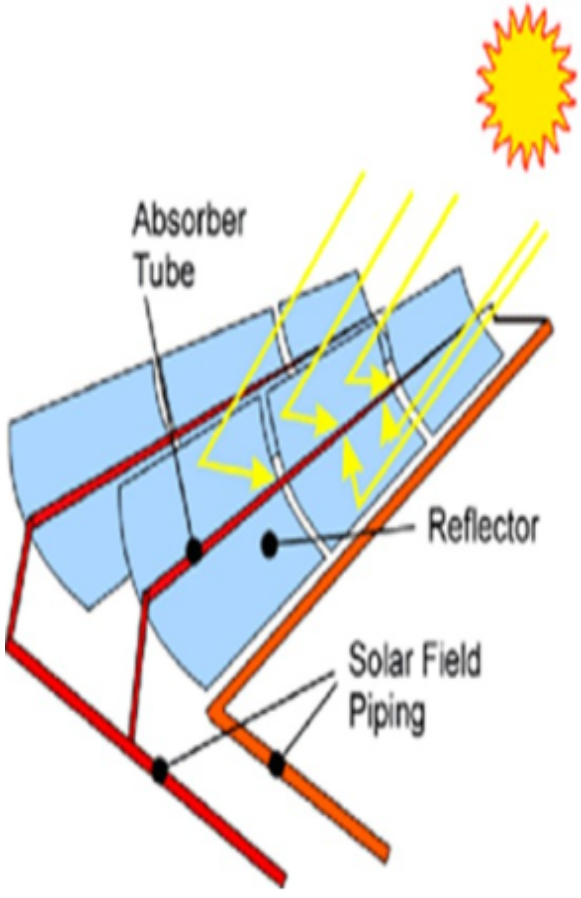
▶ It is a newer technology now being demonstrated in the USA, uses an array of parabolic mirrors which focus the sun‘s rays on a receiver pipe.
▶ This concept does not require a tower, since the heat is collected continuously by the hot oil heat transfer fluid piped around the complete linear mirror array.
▶ A heat exchanger is used to transfer heat from the hot oil to boil water with the resulting steam used to generate electricity.

▶ Parabolic trough consists of a linear parabolic reflector that concentrates the light onto an absorber tube located in the middle, in which the working fluid is located.

▶ The fluid is heated to 150 to $350^0 C$, and then used in a heat engine as shown figure below.

Solar thermal electric power system




Absorber
Tube
Reflector
Solar Field
Piping



Benefit and Drawback of solar energy

Benefit

- Stand-alone systems can eliminate the need to build expensive new power lines to remote locations.
- For rural and remote applications, solar electricity can cost less than any other means of producing electricity.
- Solar systems are flexible as solar electric modules can stand on the ground or be mounted on roof tops.
- Solar power systems require minimal maintenance.
- Solar power systems run quietly and efficiently without polluting.
- Solar power systems are easy to combine with other types of electric generators such as wind, hydro, or natural gas turbines.
- Solar electric power systems are good for the environment.
- Solar power systems can charge batteries to make solar electricity continuously available.

▶ For utilities, large-scale solar electric power plant can meet the demand for new power generations, especially in distributed applications.
▶ Solar electric plants are easier to site and are quicker to build than conventional power plants.
▶ Solar electric plants are easy to expand incrementally by adding more modules as power demand increases.

Draw back of solar Energy

▶ Solar PV cells and solar collectors are still very expensive.
▶ It is very expensive to build solar power towers and furnaces.
▶ Solar energy is not available on demand in every location on Earth.
▶▶ large areas of land are needed.
▶▶Big dish systems, trough systems, and power towers take up land that animals live on and affect their habitats.

WIND ENERGY



OUT LINE

- Sources of wind energy
- Types of wind turbine
- Generation of energy
- Types of wind turbine
- Parts of wind turbine

Wind Energy

▶ All renewable energy (except tidal and geothermal power), ultimately comes from the sun.
▶ Wind power is the conversion of wind energy into use form energy using;
▶ wind turbines to make electricity
▶ windmills for mechanical power
▶ Wind pumps for water pumping
▶ Estimated total solar power received by the earth is approximately $1.8 * 10^{11}$ MW.
▶ Of this solar input, only 2 percent (i.e. $3.6 * 10^{9}$ MW) is converted into wind energy and about 35 percent of wind energy is dissipated within 1000 m of the earth's surface.
▶ Therefore, the available wind power that can be converted into other forms of energy is $\approx 1.26 * 10^{9}$ MW.
▶ This value represents 20 times the rate of the present global energy consumption, wind energy in principle could meet entire energy needs of the world.

▶ Although oceans and land masses absorbs a great deal of this energy, much is absorbed by the atmosphere (the whole mass of air surrounding Earth).
▶ Energy from the sun does not strike the Earth evenly (equally).
▶ Air around equator absorbs more energy than the air above the poles.
▶ This difference causes air, a fluid much like water, to move in currents.
▶ Air like any substance expands when it is warmed and contracted when it is cooled.
▶ As warm air rises, colder, heavier air flows into to replace it, causing current of air is called wind.
▶ Air moving parallel to the ground is called wind.
▶ Air moving up or down is called a current.

- OR (Differential heating of the earth's surface and atmosphere induces vertical and horizontal air currents that are affected by the earth's rotation and contours of the land is called WIND).

e.g.: Land Sea Breeze Cycle

- Hence, Earth rotation's also plays a role in wind production.
- For various reasons, including the revolutions of the Earth and features of its terrain, some part of the Earth have more wind than others.

Calculation of wind energy and power

- Calculating wind energy available in the wind relies on knowledge of basic geometry and the physics behind kinetic energy of an object (or collection of object) with total mass M and velocity v is given by the expression:

$$k = \frac{1}{2}Mv^2 ------------------1$$

▶ Kinetic energy of moving air molecules (i.e wind), with the geometry of a collection of air molecules passing through the plane of a wind turbine's blades (which sweep out a cross sectional area A), with thickness (D) passing through the plane over a given time.
▶ The volume (V) of this parcel is determined by the parcel's area multiplied by its thickness
i.e $V = A.D$
▶ Let ρ represent the density of the air in this parcel.
▶ It is mass of air flow per volume and is expressed as:
$\rho = \frac{M}{V_{ol}}$.....2
▶ If a time T is required for this parcel (thickness D) to move through the plane of the wind turbine blades, then the parcel's velocity can be expressed as;
$v = \frac{D}{T}$
i.e $D = v.T$

- Using $M = \rho V_{ol}$ into equation (1)

$$K = \frac{1}{2}\rho V_{ol} v^2$$

and volume can be replaced by $V_{ol} = AD$ (also D=vT)

-

$$K = \frac{1}{2}\rho v^3 AT$$

- The power available from air parcel can be expressed

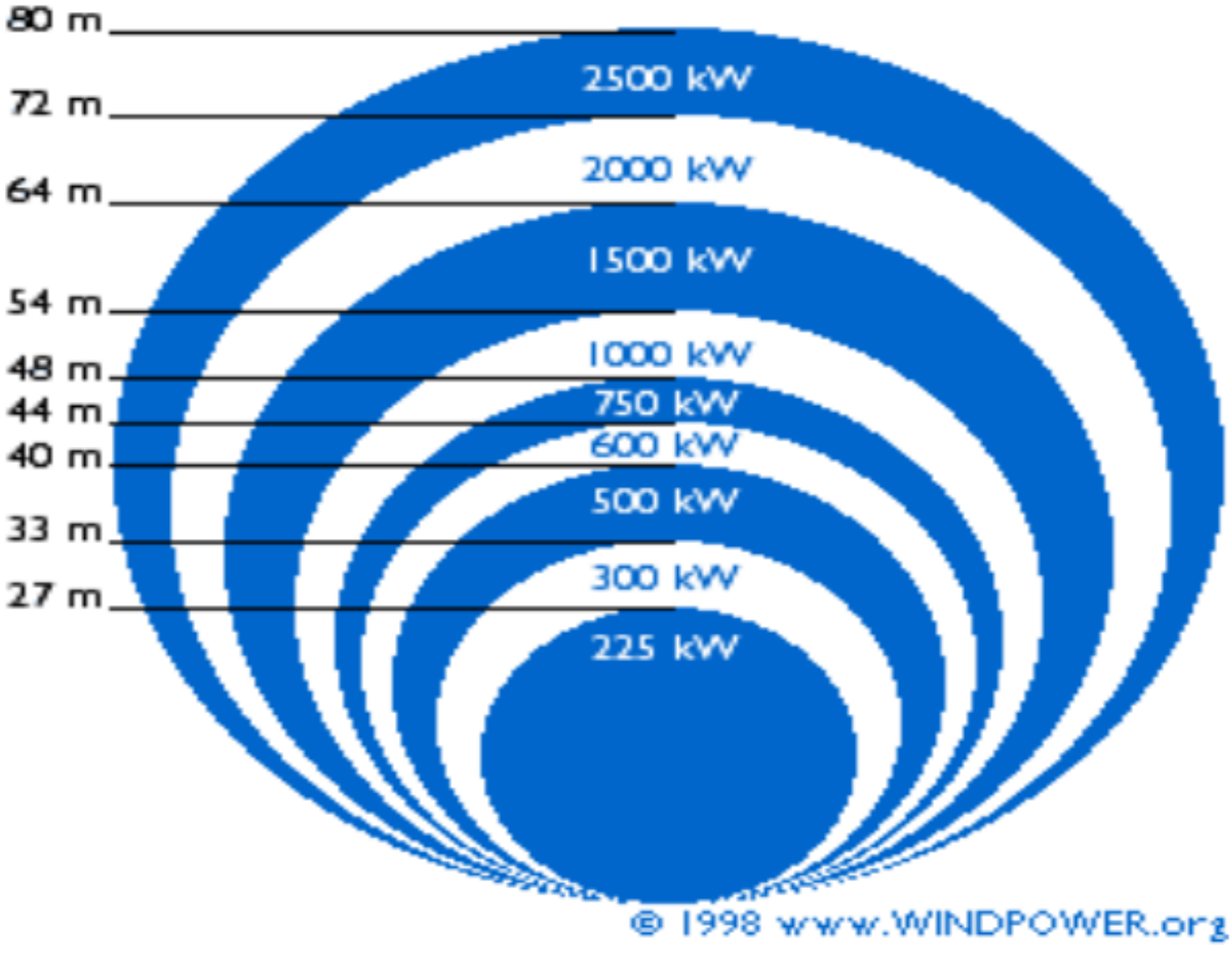
$$P = \frac{K}{T} = \frac{1}{2}\rho v^3 A$$

Wind Power density is

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

- Wind power is a measure of the energy available in the wind.
- It is a function of the cube (third power) of the wind speed.
- If the wind speed is doubled, power in the wind increases by a factor of eight.
- This relationship means that small differences in wind speed lead to large differences in power.
- 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.

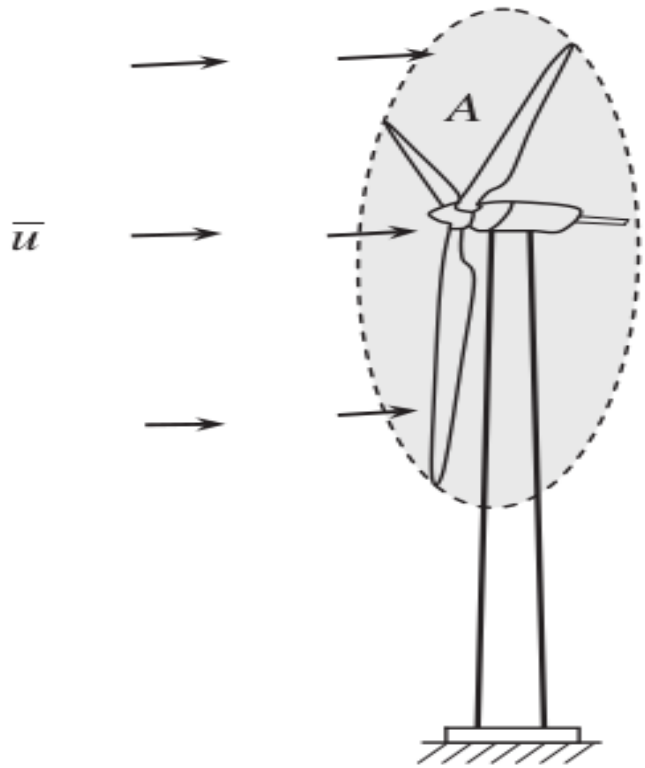
▶ The kinetic energy of a moving body is proportional to its mass (or weight).
▶ The kinetic energy in the wind thus depends on the density of the air, i.e. its mass per unit of volume.
In other words, the "heavier" the air, the more energy is received by the turbine.
▶ At 15^0C air density about $1.225kg/m^3$, but the density decreases slightly with increasing humidity.
▶ A typical 600 kW wind turbine has a rotor diameter of 43-44 meters, i.e. a rotor area of some $1,500m^2$.
▶ The rotor area determines how much energy a wind turbine is able to harvest from the wind.
▶ Since the rotor area increases with the square of the rotor diameter, a turbine which is twice as large will receive $2^2=$ four times as much as energy.


80 m
72 m
64 m
54 m
48 m
44 m
40 m
33 m
27 m
2500 kW
2000 kW
1500 kW
1000 kW
750 kW
600 kW
500 kW
300 kW
225 kW
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Blade swept area

- The blade swept area can be calculated from the formula:

$$A = \pi[(\ell + r)^2 - r^2] = \pi\ell(\ell + 2r)$$



▶ The variation in wind speed at a particular site can be best described using the Weibull distribution function.
▶ It illustrates the probability of different mean wind speeds occurring at the site during a period of time.
▶ The probability density function of a Weibull random variable $\bar{u}$ is;

$$f(\bar{u}, k, \lambda) = \frac{k}{\lambda}(\frac{k}{\lambda})^{k-1} exp(-[\frac{\bar{u}}{\lambda}]^k)$$

for $\bar{u} \geq 0$
and

$$f(\bar{u}, k, \lambda) = 0$$

for $\bar{u} < 0$
where λ is the scale factor which is closely related to the mean wind speed and k is the shape factor which is a measurement of the width of the distribution.
▶ These two parameters can be determined from the statistical analysis of measured wind speed data at the site.

Wind shear

- It 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;

$$u(z) = (\frac{z}{z_o})^a$$

- Where z is the height above the earth's surface, z_0 is the reference height for which wind speed u (z_0) is known, and a is the wind shear coeffi cient.
- In practice, a depends on a number of factors, including the roughness of the surrounding landscape, height, time of day, season, and locations.
- a is lower in daytime and higher at night.

Wind power parameters

Power coefficient

- The conversion of wind energy to electrical energy involves:
- kinetic energy in wind is converted into mechanical energy to drive the shaft of a wind generator.
- The critical converting devices are wind blades.
- For maximizing the capture of wind energy, wind blades need to be carefully designed.
- The power coeffi cient C_p defined as the ratio of the actually captured mechanical power by blades to the available power in wind:

$$C_p = \frac{P_{mec,out}}{P_w} = \frac{P_{mec,out}}{\frac{1}{2}\rho \bar{u}^3}$$

- Because there are various aerodynamic losses in wind turbine systems, for instance, blade-tip, blade-root, profi le, and wake rotation losses, etc., the real C_p is much lower than its theoretical limit, usually ranging from 30 to 45 percent.

Total power conversion coefficient and effective power output

- ME captured by wind blades is converted into electrical energy via wind generators.
- Converting efficiency is determined by several parameters:

$\surd$ Gearbox efficiency(η_{gear})
$\surd$ Generator efficiency(η_{gen})
$\surd$ Electric efficiency(η_{ele})

- Total power conversion efficiency from wind to electricity η_t is the production of these parameters,

$$\eta_t = C_p \eta_{gear} \eta_{gen} \eta_{ele}$$

- The effective power output from a wind turbine to feed into a grid becomes;

$$P_{eff} = C_p \eta_{gear} \eta_{gen} \eta_{ele} P_w$$

Power curve

- P_{eff} is directly proportional to the available wind power P_w and the total effective wind turbine efficiency η_t.
- The power curve of 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.
- Power curves are usually determined from the field measurements.
- Wind turbine starts to produce usable power at a low wind speed, defi ned as the cut-in speed.
- The power output increases continuously with the increase of the wind speed until reaching a saturated point, to which the power output reaches its maximum value, defined as the rated power output.
- Correspondingly, the speed at this point is defi ned as the rated speed.

▶ At the rated speed, more increase in the wind speed will not increase the power output due to the activation of the power control.

▶ When the wind speed becomes too large to potentially

$\surd$ damage the wind turbine

$\surd$ the wind turbine needs to shut down immediately to avoid damaging the wind turbine.

▶ This wind speed is defi ned as the cut-out speed.

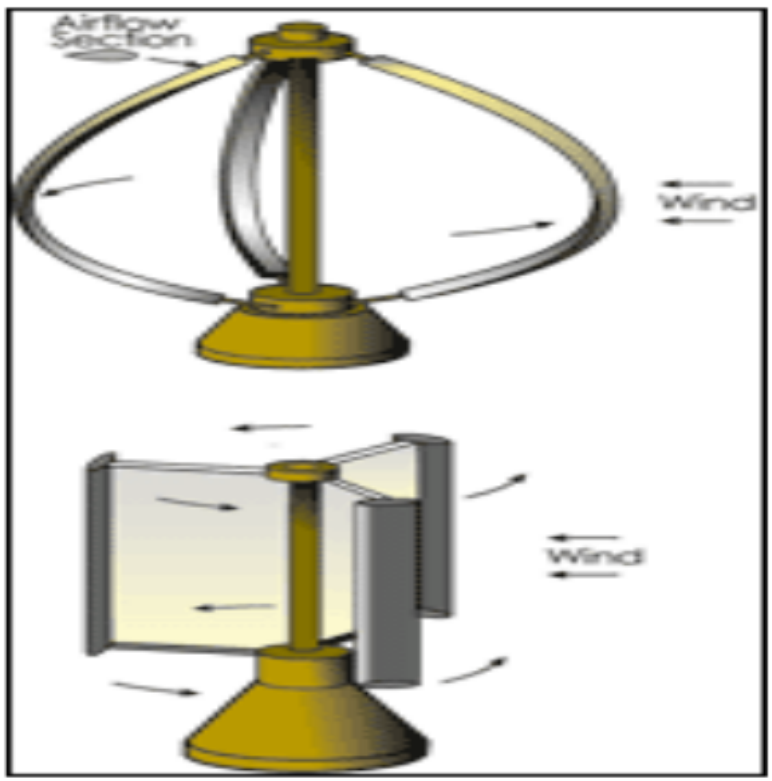
▶ Thus, the cut-in and cut-out speeds have defi ned the operating limits of the wind turbine.

Types of Wind Turbine

Vertical Wind Turbine

▶ Existed for centuries and are not as common as their horizontal counterparts.

▶ Do not take advantage of the higher wind speeds at higher elevations above the ground as horizontal axis turbines.

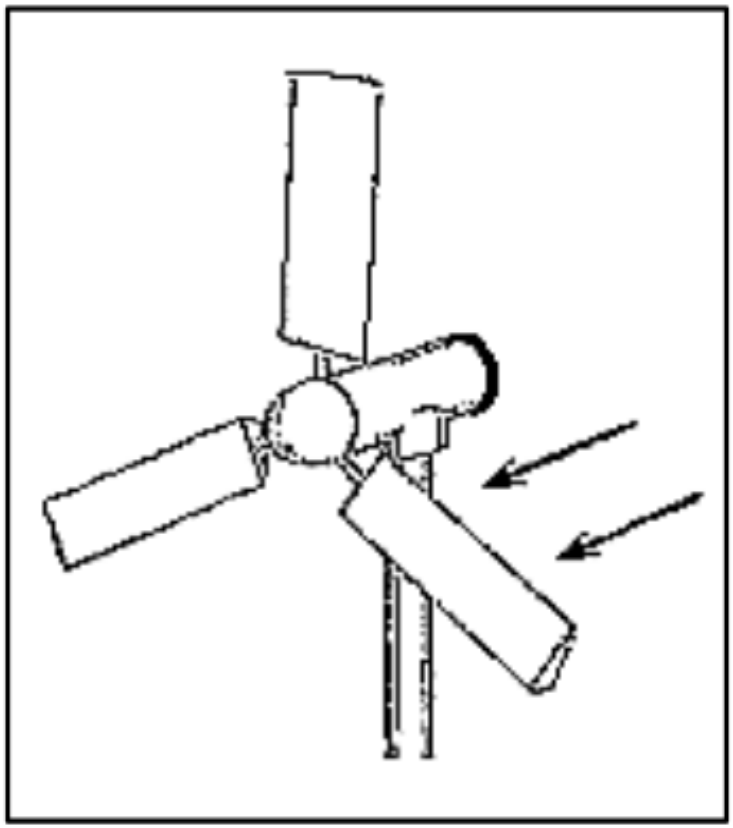


Horizontal Wind turbine

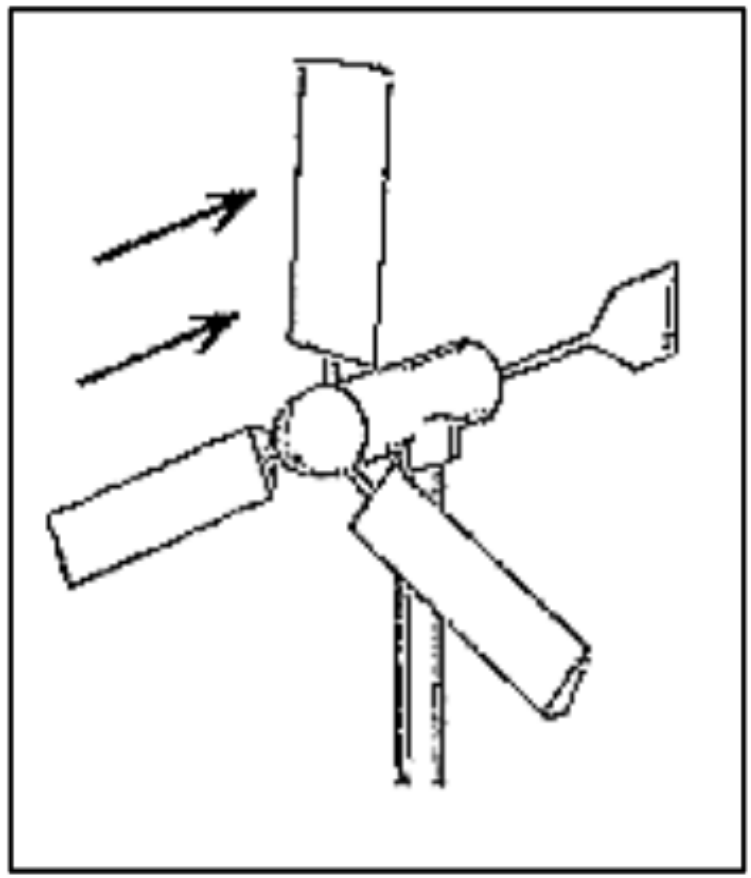
- Most common wind turbine design.
- The axis of blade rotation is parallel to the wind flow.
- Some machines are designed to operate in an upwind mode, with the blades upwind of the tower.
- Other designs operate in a downwind mode so that the wind passes the tower before striking the blades.
- A tail vane is usually used to keep the blades facing into the wind.



DOWNWIND TURBINE



UPWIND TURBINE



Parts of Wind Turbine

1. Rotor- The hub and the blades together are referred to as the rotor.

▶ Wind turns the blades which turn drives shaft.

2. Shaft- Two different shafts turn the generator.

▶ One is used for low speeds while another is used in high speeds.

3. Gear Box- Gears connect the high and low speed shafts and increase the rotational speeds from about 10-60 rotations per minute to about 1200-1800 rpm, the rotational speed required by most generators to produce power.

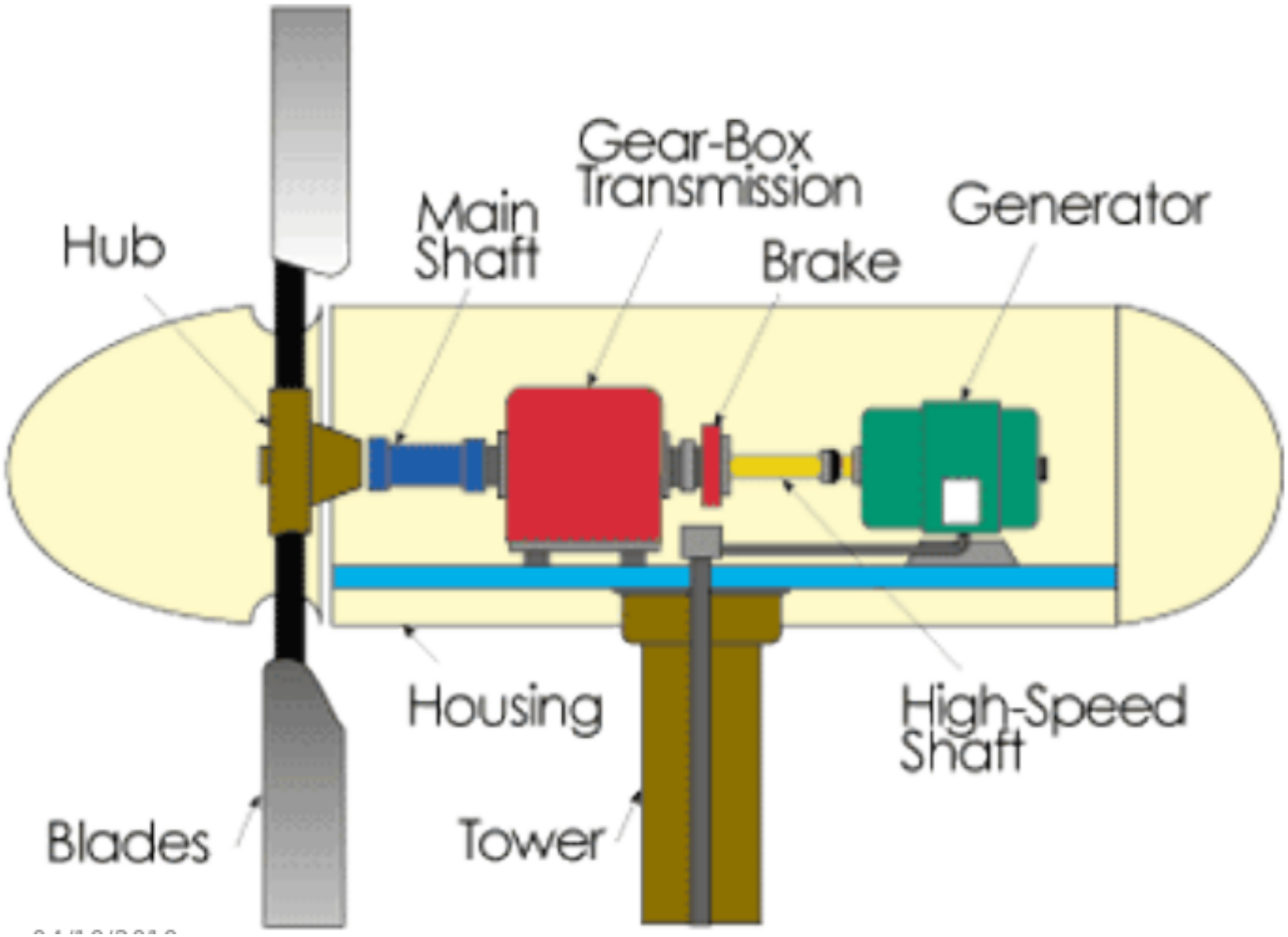
4.Generator- converts the turning motion of a wind turbine's blades into electricity.

▶ Inside it, coils of wire are rotated in a magnetic field to produce electricity.

▶ Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings.

▶ The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades.
▶ 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.
5. Controller- Turns the blades on at 8-16 mph and shuts them down around 65 to prevent any high wind damage.
6. Tower- Tall tubular metal shaft. The taller the tower, the more power produced.

Parts of Wind turbine



Advantage and disadvantage of both turbines

Vertical Axis Advantages

$\surd$ Can place generator on ground

$\surd$ You don't need a yaw mechanism for wind angle

Vertical axis Disadvantages

$\surd$ Lower wind speeds at ground level

$\surd$ Less efficiency

$\surd$ Requires a "push"

Horizontal axis Advantages

$\surd$ Higher wind speeds

$\surd$ Great efficiency

Horizontal axis Disadvantages

$\surd$ Angle of turbine is relevant

$\surd$ Difficult access to generator for repairs

Advantages of Wind Power

Clean, zero emissions

– NO_x , SO_2 , CO, CO_2

– Air quality, water quality

– Climate change

Reduce fossil fuel dependence

– Energy independence

– Domestic energy—national security

Renewable

– No fuel-price volatility

Limitations of Wind Power

Power density is very low.

Needs a very large number of wind mills to produce modest amounts of power

$\surd$ Cost

$\surd$ material and maintenance costs.

$\surd$ Noise, birds and appearance, caused TV/radio interference in areas near the turbine

$\surd$ Cannot meet large scale and transportation energy needs